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Precise Worlds for Certain Minds: An Ecological Perspective on the Relational Self in Autism

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Abstract
Autism Spectrum Condition (ASC) presents a challenge to social and relational accounts of the self, precisely because it is broadly seen as a disorder impacting social relationships. Many influential theories argue that social deficits and impairments of the self are the core problems in ASC. Predictive processing approaches address these based on general purpose neurocognitive mechanisms that are expressed atypically. Here we use the High, Inflexible Precision of Prediction Errors in Autism approach in the context of cultural niche construction to explain atypicalities of the relational self, specifically its minimal, extended, and intersubjective aspects. We contend that the social self in ASC should not be seen as impaired, but rather as an outcome of atypical niche construction. We unpack the scientific, ethical, and practical consequences of this view, and discuss implications for how the challenges that autistic persons face should be approached.

Keywords Autism spectrum condition · Relational self · Minimal self · Extended self · Intersubjective self · Predictive processing · Niche construction · Ecological approach to psychopathologies

Inevitably we construct ourselves. Let me explain. I enter this house and immediately I become what I have to become, what I can become: I construct myself. That is, I present myself to you in a form suitable to the relationship I wish to achieve with you. And, of course, you do the same with me.
— Luigi Pirandello.

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1 Introduction

Autism Spectrum Condition (ASC) is a cluster of early-onset cognitive and neurodevelopmental atypicalities that relate to social-communicative deficits, and restricted, repetitive, or stereotyped behavior and interests (American Psychiatric Association 2013). Relational and social accounts of the self posit that the sense of self depends on the entanglement of the individual with a significant, or *generalized* other understood respectively as the representation of an individual of profound significance in one's life (Andersen and Chen 2002), and as the individually internalized 'attitude of a whole community' (Mead 1934). On that view, the self would heavily rest on the individual's ability to coordinate a diversified repertoire of selves (cf. Zahavi 2010) accumulated over time through interpersonal relationships (Andersen and Chen 2002). We interpret these selves as aspects of selfhood (Neisser 1991), and focus on the extended, intersubjective, and minimal bodily aspects in ASC (see Gallagher 2013 for a review of the aspects of the self).

ASC offers an interesting challenge for the relational views of the self precisely because it is broadly recognized as a disorder primarily impacting social relationships (American Psychiatric Association 2013), yet for which it is unclear whether the diagnosed individual truly experiences an impoverished sense of self (McGeer 2004; Schriber et al. 2014). In effect, while they do not claim that autistic people completely lack a sense of self, many influential theories tend to suggest that the requirements for a sense of relational self are reduced or otherwise impaired. For instance, "early deficits in self-development including impaired relations with others [would] result in a fragmented and atypical sense of self in ASD" (Lyons and Fitzgerald 2013, p. 758). Also, autistic people tend "not to have the powerful pull towards, nor fully organized experience of, relations that have the other-person-centred qualities [, and their] ability to apprehend, be moved by, and have feelings configured by, other-person-centred attitudes is compromised" (Hobson 2011, p. 572). And when it comes to identifying with the attitudes of others, and when it comes to understanding the nature of subjective perspectives and therefore of people's minds, children with autism—like chimpanzees—have serious limitations. (Hobson 2004, p. 274). They would be compromised in their ability to engage social interactions because of deficits of normal neurocognitive mechanisms involved in social interaction (e.g., deficit in theory of mind module, Baron-Cohen et al. 1985; cf. Frith and Frith 2003; difficulties in attributing mental states to others spontaneously; Senju et al. 2009). More generally, their limitations in social engagement would impair their ability to occupy the implicit 'form of life' held in common by others (Hobson 2009).

Yet, autobiographical and phenomenological accounts seem to suggest that many autistic individuals, although they experience difficulties in social interactions, often have an acute awareness of these difficulties, and a desire to overcome them. For example, a recent phenomenological study with adults diagnosed with ASC later in life suggests that, at least for this subset of individuals, the desire to stand one's ground in social relations is often accompanied by deep reflection on one's own self in relation to others—e.g., reflection on the relevance of showing one's authentic self in social situations (Hens and Langenberg 2017). This suggests that the assumption of a more general impoverished relational self is not generalizable to the entire autistic community. More generally the abundance of autobiographical reports (Van Goidsenhoven and Masschelein 2016) by autistic people across the spectrum suggests that a desire for self-identification and recognition is particularly pronounced in people with ASC. At any rate, ASC begs the intriguing question of how the various aspects of the relational self are experienced by people presented with clear challenges in social interaction.

In recent years, much attention has been given to a novel paradigm, the predictive processing (PP) paradigm, in explaining core behavioral traits of ASC (e.g., Lawson et al. 2014; Palmer et al. 2015a, b; Pellicano and Burr 2012; Van de Cruys et al. 2014). PP approaches challenge the claims about the presence of specific neurocognitive dysfunctions in autistic cognition, as it traces back the symptoms of ASC to normal, though differently 'tuned', domain general neurocognitive mechanisms (cf. Bolis and Schilbach 2017).

In this paper, we use the PP paradigm to attempt an ecological explanation of atypicalities of the relational self in ASC, specifically, those relating to its minimal, extended, and intersubjective aspects, though without positing major incapacities in social functioning. We are interested in how these aspects become organized in patterns of sensory and social interactions with the body (e.g., interoception), the world (e.g., exteroception and material environment), and other agents (e.g., social interactions). For convenience, we present the minimal, extended, and interpersonal aspects separately, though we aim at showing how they develop and become entangled over the lifespan of the individual.

In comparison to other PP approaches to the self (Limanowski and Blankenburg 2013; e.g.; Palmer et al. 2015b; Quattrocki and Friston 2014; Seth et al. 2011), our approach integrates novel PP theoretical approaches to niche construction theory and learning (e.g., Constant et al. 2018; Bruineberg 2018; Flynn et al. 2013). Crucially, because PP approaches address the symptoms of ASC with atypically expressed, general purpose neurocognitive mechanisms, they can support our main claim, namely that the atypical development of aspects of the relational self in ASC, and the limitations they entail for everyday functioning, do not preclude a rich social self for autistic people, *albeit* differently articulated.

We focus on a recent PP account of ASC called "HIPPEA", the High, Inflexible Precision of Prediction Errors in Autism account (Van de Cruys et al. 2014). PP accounts of ASC emphasize different aspects of PP, even though they generally include a treatment of all basic mechanisms. We focus on HIPPEA because of its interpretation of the mechanism of meta-learning. According to PP, meta-learning enables to detect learnable sensory cues, relevant for predicting future events with a certain level of reliability. It is a mechanism crucial to distinguish random sensory variability from the variability reporting causal regularities (e.g., recurrent causes of inputs). HIPPEA further insists on the role of actions in meta-learning (e.g., how actions themselves can constrain variability, Clark 2013a). This enables us to leverage the ecological and embodied implications of PP to discuss aspects of the relational self in ASC. Crucially, HIPPEA's interpretation of meta-learning provides a direct link to the approaches to niche construction theory mentioned above, defining the activity of niche construction as a meta-learning process. The ecological implications of PP for understanding ASC are far-reaching (e.g., Bolis and Schilbach 2017; von der Lühe et al. 2016), but have so far not been exhaustively treated in the literature.

The remainder of this paper comprises four sections. In Sect. 1, we give a general presentation of the PP paradigm. In Sect. 2, using HIPPEA, we discuss the most basic type of self, the so-called *minimal self*. In Sect. 3 we connect the PP approach to niche construction to discuss the *extended self*, and how it may differ in ASC. Section 4 is about the *intersubjective self* constructed through activities like turn-taking and joint attention (two processes assumed to be compromised in ASC). We conclude by providing ethical considerations and suggestions for future research, based on our ecological approach.

2 Predictive Processing

The tendency of organisms to model, or infer sensory causes is a fact of their very existence, enduring over time (Friston and Stephan 2007). Living systems are open systems, which means that the entropy of their states should increase exponentially over time, as they engage in energy exchanges with their environment (see fluctuation theorem, Evans and Searles 2002). Yet, organisms manage to resist disintegration (i.e., they exist over time). Therefore, one must assume that they limit the entropy of their states by revisiting a restricted repertoire of physiological, and sensory interoceptive and exteroceptive "expected states" consistent with continued existence (Friston 2013; Limanowski and Blankenburg 2013; Seth et al. 2011). This homeostatic repertoire is "discovered" by evolution and gets embodied in a phenotype simply because an organism that would not model its environment with its expected states would not be able to continue to exist (cf. the good regulator theorem, Conant and Ashby 1970). Because expected internal states can usually only be fulfilled by the actions of the organism in the environment (e.g., foraging food to fulfill the expected glucose levels), the organism's own actions and the states it can attain by applying them is an intrinsic part of its models. To be a living system then *means* dynamically modeling oneself in relation to one's body, and one's environment: living organisms are fundamentally in the business of self-evidencing (Hohwy 2014), bringing evidence for a model of one's own existence (Friston 2011).

Much of this modeling in biology is implicit, embodied, inflexible, and pragmatic. The models will be minimal (cf. Baltieri and Buckley 2017) in the sense that hidden causes of change in the environment are only modelled insofar they are relevant to attain the expected set of viable states. However, more complex organisms will build and update more flexible, hierarchical "embrained" models, that can track a complex, changing interplay of environmental causes, how they can be manipulated (e.g., affordance structure), and what their effects are on (the wellbeing of) the organism.

Inspired by recent advances in computational neurobiology (e.g. free-energy principle, Friston et al. 2006), PP has become the umbrella term for the scientific and philosophical efforts of spelling out how those models are updated and applied to support fluent, self-organizing interaction with the environment (Hohwy 2013). According to PP, models are used to predict incoming sensory inputs. Discrepancies between expected and current inputs are called sensory prediction errors. Given that models are hierarchical, with abstract expectations unpacked into increasingly finer predictions on the specific perceptual features throughout the cortical hierarchy, predictions and inputs are compared at every level. In the PP literature, this process is known as perceptual inference (Clark 2013b; Hohwy 2013; Seth 2015), and is often the one referred to when thinking about 'predictive processing'. The central objective of perceptual inference is the minimization of prediction errors. This, however, can be done only in so far as the organism engages simultaneously another form of inference, known as active inference (Friston et al. 2009). While perceptual inference updates the internal model, which enables inferring the causes of sensory inputs, active inference, via physical action changes sensory inputs in accordance to the expected sensory causes. This amounts to the inference of bodily movements which will best shape the sensory array, so as to comply to the sensory predictions embodied by the internal model (Buckley et al. 2017; Friston and Stephan 2007). Within the formalism of the variational free-energy principle, it is more often stressed that active and perceptual inferences are the two necessary, and concurrent ways to bring models and world closer to each other. One adjusts the internal model to the current flow of inputs (corresponding to perception and learning), and the other selects actions most likely to sample expected inputs conforming to the internal model (corresponding to active behavior). These two directions in model fitting work together to encode in the brain a hierarchically structured reiteration of the causal regularities generating sensory inputs, and spanning various spatio-temporal scales, or depths (Kiebel et al. 2008; cf. Timmermans et al. 2012).

Despite the PP system's best efforts to match the stream of incoming inputs, prediction errors will be abundant, because no two natural events are exactly the same. The source of those prediction errors might be in mere physiological noise or external incidental variation in the inputs, *or* in actual, important changes in the environment that should be incorporated into the models. So prediction errors should not be taken at face value. Because there is no a priori way for the agent to know whether a given prediction error reports a deviation that warrants updating the model (i.e., signal), or a mere irregularity unlikely to recur (i.e., noise)

(Feldman 2013), the agent must learn the expected variability across similar experiences in the same context.

Consider for instance a bus that you know arrives everyday at 8 pm at your bus stop. This is your prediction of the arrival time. Your past experiences have also taught you there is significant variation in arrival times at this stop. This is often called the expected "precision". Now, when at any given day you notice your bus is late, i.e. it deviates from your expectation, you will not immediately search alternative transport (act) or conclude that suddenly the bus schedule has been changed (update your model), as long as this "prediction error" is within the expected variation. In short, you weigh new prediction errors by expected precisions to determine what impact they need to have on learning and behavior. This holds for all prediction errors in the perceptual hierarchy: their gain is regulated on the basis of expected precisions or estimates about uncertainties in the input and in our predictions (Yu and Dayan 2005). Precision can also be thought of as a kind of meta-learning: learning what can be learned. It requires learning (across experiences) of the expected uncertainty for a given regularity (e.g., the variance of arrival times), and an estimate of how volatile the regularity itself is (e.g., how frequently bus schedules change), to optimally weigh newly incoming evidence. It is the continuous, fallible and model-dependent process of disentangling signal and noise, to separate relevant changes from inconsequential variability and to make perception and action robust *and* flexible (Van de Cruys et al. 2017a, b).

3 Predictive Processing in ASC and the Minimal Self: Modelling Myself

3.1 Predictive Processing in ASC

Appropriate precision-tuning explains many aspects of cognition and behavior. For example, it is an attentional mechanism in the sense that it allows selectively weighing particular inputs at the expense of others. This again shows precision-estimation should be flexible and context-dependent. For example, when trying to predict the emotion of a social partner from her face, different parts of the input should be taken into account than when just trying to recognize her identity. Different facial regions will be diagnostic for different task sets, so weights should be flexibly assigned. Precision can also regulate whether perception is more top-down or more bottom-up driven.

For example, if we want to get the gist of a text, we read by relying heavily on our expectations to jump from word to word, without processing every letter, let alone its low-level features. The precision of those low-level features is lowered, to focus more on higher-level semantic predictions, but this also means we will often miss typos and will sometimes "read" things that we expected but were not there.

Problems in estimating precision have been at the center of several recent accounts of ASC (e.g., Pellicano and Burr 2012; Van de Cruys et al. 2014). HIPPEA argues that autistic agents assign atypically high precision to bottom-up prediction errors irrespective of context uncertainties, and thereby struggle to adapt to environmental uncertainties, explaining a local focus in perception and behavioral traits like insistence on sameness and stereotyped behavior, which would be strategies to increase the predictability of the sensory environment in hope of coping with overwhelming prediction error signals. If prediction errors are assigned high precision across the board, even incidental variability (i.e., noise) will induce learning, which will lead to overfitted models that will not readily generalize to new inputs (because they differ in their details). Importantly, on that view, difficulties in modelling regularities are mostly manifest in complex sensory environments.

It is of note, however, that evidence is still lacking to support PP approaches as applied to ASC, and contradicting evidence has yet to be accounted for in the literature. The expectations or priors that the internal model embodies are structural, or contextual (Seriès and Seitz 2013). Structural priors are either inherited, or learnt probabilistically, but are generally fairly robust (e.g., they are the kind that play out in illusions), where contextual priors are also learnt probabilistically, but are context dependent, as they respond to spatio-temporally isolated situations, and are easy to manipulate via instructions, or cuing (e.g., cuing in Posner paradigm Posner 1980). Recent studies suggest that structural and contextual priors may be intact in ASC (Croydon et al. 2017; Manning et al. 2015, 2017; Spanò et al. 2015; Van de Cruys et al. 2017b), which contrasts with theoretical assumptions made by one particular PP approach to ASC (e.g., Hypopriors hypothesis Pellicano and Burr 2012). For instance, Van de Cruys et al. (2017b) found no consistent differences between typically developing and ASC individuals participants in mooney image recognition tasks, which were designed to measure the influence of top-down priors in perceptual inference. In turn, Manning et al. (2017) found that ASC children and adults perform similarly in probabilistic learning tasks in volatile reward probability environment, and adjust their learning rate (precision) in a way similar to typically developing participants (Manning et al. 2017).

Those findings challenge the strong claim of PP approaches according to which individuals with ASC would have, either, weak priors across the board, or that precision would be continually aberrantly high in ASC. Nonetheless, the different PP approaches for ASC agree that some form of altered precision regulation lies at the core of the condition, which would be particularly apparent in social inferences, which we will see in the following sections, requires modelling deeper causes, in complex environment (e.g., other people intentions during social interactions). Difficulties in predictive processing could become manifest in the learning of social priors (Balsters et al. 2017), which requires heavy management of uncertainty (Lawson et al. 2014; Van de Cruys et al. 2017a), as there is no one-to-one mapping between causes and sensory inputs (Manning et al. 2017).

3.2 Predictive Processing and the Minimal Self in ASC

The most fundamental aspect of the self is the prereflective, *minimal* self. As indicated before, an agent necessarily models itself in the environment as far as it has the capacity to elicit change in that environment and so accomplish expected states (Seth 2013; Seth et al. 2011). The minimal self emerges implicitly from the modeling of oneself as the center of one's dealings with the world (Limanowski and Blankenburg 2013). Just as the agent builds models of how exogenous inputs are generated, it also infers the hidden causes for interoceptive and exteroceptive self-generated inputs. The self here is just another hidden cause: the best explanation for the continuous regularities in the self-generated multisensory stream of inputs (e.g., the link between exercise and heart rate). It is the construct of the most reliable and persistent cause of changes in inputs (the "most likely me"). How explicitly this self will be represented will depend on how deep (abstract) the models of the agent are. The minimal self becomes an explicit sense of body ownership and agency (Gallagher 2000; Tsakiris et al. 2006) through the active, successful explaining away of bottom-up interoceptive prediction errors (Seth et al. 2011), or from bringing about reliable, expected changes in exteroceptive inputs through action, supporting your models about the causes underlying them (cf. Tsakiris 2010; Tsakiris and Haggard 2005).

This view of the constructed "statistical self" receives support from body ownership illusions, like the rubber hand illusion (Apps and Tsakiris 2014). Put another way, things that are reliably predictable will be experienced as congruent with one's sense of minimal self, and conversely, things that generate persistent, precise prediction errors will not be readily and seamlessly integrated with the minimal self. Despite their altered predictive processing, nothing prevents autistic people to form a sense of minimal self. This is likely due to the fact that self-generated inputs are generally more reliably predictable, so precision estimation is less challenging. Nonetheless, if the problems in estimating precision generalize to interoceptive prediction errors, as some argue (Quattrocki and Friston 2014), differences in the sense of self might already start at the level of the embodied, minimal self.

There is some evidence that autistic people can more easily sustain attention to their body (Schauder et al. 2015). If things you become aware of are indeed the type of things that are not reliably predictable (i.e., generate much prediction errors), attaining a typical sense of minimal, bodily interoceptive self might be more challenging for autistic individuals. If interoceptive signals are assigned higher precision, more attention will go to the body, and the body (or part of it) will be experienced as relatively more foreign, or at least not as integrated as other parts of the self. Evidently, a core, implicit self remains present, but the minimal, embodied self already demands some effort to be kept together in ASC. The more inward looking propensity sometimes noted in ASC may then be interpreted as active construction and maintenance of the self (true to the etymology of the word 'autism'). It makes for a more precarious self but also to one that is more tightly knit to its niche, as we will see next. Indeed, since PP does away with the strict division between external and internal milieu (both are modeled in the service of sustaining existence), the construction of the self coincides with construction of a niche.

4 Niche Construction, and the Extended Self in ASC: Modelling My World

An agent not only learns a model of its environment, but also changes the environment to fit its models. As a result, it tends to construct an environment that mirrors its predictions, and, in a sense, makes the world its own. James (1890) suggests that the self includes objects that we possess, and to which we come to identify, what Gallagher (2013) defines as the extended aspect of the self. We propose to view the extended self as a process that takes hold through niche construction, such as conceived within the PP paradigm.

4.1 Predictive Processing and Niche Construction in ASC

Constant et al. (2018) offer a complementary view of precision estimation within the context of cultural niche construction (cf. Laland and O'Brien 2011). Cultural niche construction generally refers to the process by which humans modify their developmental environment via, for instance, cultural practices, thereby implicitly steering their evolutionary trajectory (e.g., the spread of lactose tolerant alleles over generations in populations practicing and relying on dairy farming, Odling-Smee et al. 2003). The PP perspective on niche construction defines niche construction as the outsourcing of information that is socially relevant to the ingroup in the form of *conventionalized action possibilities*, or cultural affordances (Ramstead et al. 2016). Such affordances are specified by socially shared expectations and patterned cultural practices, as well as by the materiality of the perceptual environment (Rietveld and Kiverstein 2014). Crucially, on that view, the prior expectations that enable agents to interact with cultural affordances become encoded in the material layout of the environment through routined, recurrent physical actions (cf. Christopoulos and Tobler 2016). The niche then can function as a meta-learning mechanism, by which socially relevant cues in the environment come to guide the agent's acquisition of adaptive cultural knowledge and skills (Flynn et al. 2013).

For instance, people might opt to use a shortcut through a grassy field rather than use a paved path during their commutes, and over time a dirt trail might form, which in turn will steer future interactions between the users and their urban niche. This means that the agent-niche fit is optimized both by the learning of the statistics of the environment, and by changes to the niche, which will come to fit the statistics of the agents. The optimal niche-animal fit corresponds to prediction error minima, that is, to stable configurations of the agent-animal coupled system. The ability to reach such stable points in turn depends on the capacity to learn, or the malleability, of both the animal and the environment (Bruineberg 2018). For instance, if the environment is rigid, and the agent malleable, the ensuing attunement dynamic will be that of the learning by the agent of the statistics of the environment (e.g., the learning of the laws of circulation in urban environment by kindergarteners on a trip to the playground). In the opposite scenario, the resulting attunement dynamics will be that of niche construction, that is, the changing of the statistics of the environment to fit the animals demands (e.g., kids cutting through the grass to reach the playground).

Since physical actions leave lasting changes in the sensory landscape and fulfill sensory expectations (e.g. action policies, Friston 2011), they will tend to modify the sensory landscape in a way that is consistent with the agent's sensory expectations (i.e., fit sensory causes to the agent's expectations). This means that by actively engaging with its environment, the agent tends to construct a sensory landscape that she expects to encounter. A consequence of this is that cultural affordances can function as *support for estimating the precision of incoming sensory inputs* (cf. Kirchhoff 2018). For instance, consider the conventionalized 'stopability' afforded by traffic lights leveraged by pedestrians to assess the precision of the flow of sensory prediction error at an intersection. The pedestrian can rely on the red or the yellow light to evaluate whether her visual input of, say, the stationary car indeed reports a car waiting, or one about to accelerate. The reliability of the information in turn depends on conventionalized practices held in common, and which are supported by the material layout of the niche.

Coupled with standard embrained mechanisms for precision estimation, cultural affordances—which are scaffolded by priors embodied in cultural artefacts and shared practices—ease the tracking of fluctuations at long time scales (e.g., intergenerational) as they structure the sensory space afforded by the environment. Intuitive examples of this are artifactually supported rituals (e.g., religious ceremonies) which uniformize behaviors and expectations (e.g., 'spiritual' visual patterns, monotonous rhythmic music, etc.). These have a prominent place in social organization, especially in times of environmental uncertainty, presumably because they increase predictability, e.g., increase of ritual and artful behavior at time of resource stress in prehistoric populations (Dissanayake 2009).

Some of the reports of people diagnosed with ASC suggest that autistic atypicalities in estimating precision using internal neuromodulation (e.g., HIPPEA) might equally have an 'ecological' counterpart, something akin to cultural rituals reining in uncertainty at the individual scale, based on conventionalized behavior and personal routines. Consider for instance this anecdotal report of a woman diagnosed with ASC:

> In the garden I had chicks, white till yellow–brown. There are also many sparrows here that eat the grains. One day, I saw from our terrace a small light colored bird outside of the chicken henhouse, and I thought: hey, a white sparrow!? At the end I concluded that I had made a mistake, there is no such thing as a white sparrow. It was a chick that had escaped from the henhouse. Someone else would have recognized a chick much faster (Hens and Langenberg 2017).

The ecological counterpart of high inflexible precision estimation in the above scenario corresponds to the *over-reliance* on the precision afforded by the physical structure of the backyard and the henhouse to limit the uncertainty of sensory information. The henhouse in that scenario is used to assess hypotheses about bird kinds—"Inside the henhouse there are chicks, outside the henhouse there are sparrows, therefore, if I see a bird outside of the henhouse, it *must* be a sparrow". Due to limitations in internal (precision) modeling (cf. HIPPEA), people with ASC might resort to actions aiming to reduce uncertainty and variability in sensory input. In practice, this means avoiding natural sensory niches, with their inherent complexity, and favoring the construction of one's own simplified, more predictable niche. As such, the lack of precision modelling in ASC entails an over-reliance on one's own sensory environment to limit uncertainty.

In sum, then, if an individual is not able to leverage cues about contextual variability, she will need to further rely on her environment to ensure the presence of reliable (reducible) prediction errors. By relying on routinized behavior, supported by social partners and a structured niche, one can be sufficiently certain that the remaining variability corresponds to information likely to recur, and thereby worth learning (i.e., is signal, and not noise). Autistic niche construction is a direct corollary of HIPPEA. As people with ASC are forced to fall back on actions to reduce uncertainty and input variability, they implicitly construct rigid and inflexible attentional loci, on the basis of which they are able to assess the reliability of sensory fluctuations. This is apparent from the fact that stereotyped behavior in ASC decreases during the developmental phase, in contrast to insistence on sameness which tends to persist, and even increase in development (Richler et al. 2010). This could be explained by the construction, throughout development, of an incrementally robust, adapted sensory niche along with habits, rituals and routines constraining the sensory space, and thereby affording enough certainty for the relief of stereotyped behavior. However, the relief would come at the cost of an increased insistence on the sensory niche warranting certainty.

4.2 Niche Construction and the Extended Self in ASC

Things to which we identify tend to be reliably predictable, and only then can they become part of our self, for instance, the fact that I identify to my body, and experience it as belonging to me (e.g., interoceptive, minimal self), or on days of fluent work, my computer as well, and similarly, my significant, or generalized others (e.g., I share reliable generative models of the typical other's behavior). The point here is that selfhood extends to one's body, people and objects of significance that constitute me—the sum total of what I can call own'(James 1890), where the significance in question refers to the extent to potential for uncertainty reduction. Hence, for instance, the feeling of being robbed from 'pieces of one's life', or lessening of the self when deprived from personal possession (Belk 1988), e.g., as is sometimes observed in psychiatric hospitals, aged care homes, prisons, concentration camps, military training camps, etc. (Goffman 1961). Take for instance this report from clinical work with Aspergers:

> AB was a 34 year-old lady who was diagnosed with Asperger syndrome in 1999. Since the age of 16 years, AB had been collecting, categorizing and storing a wide range of items in her two-bedroom apartment. [AB described] the difficulty that she had with discarding any of her belongings, as each item had a particular salience for her and prompted particular memories of where she received the item, when she had received it and what she was doing at the time. When asked what it would be like if someone were to remove the items, AB explained If you took all of them away, I wouldn't know who I was any more. AB went on to describe her collection as being akin to a photograph album or personal diary—each item (or 'entry') had a specific meaning and provided particular prompts to the life that she had lead. The collection appeared to provide a means of maintaining links with the past, and without it, AB was seemingly unable to experience a continuous sense of self [...] (Skirrow et al. 2015, p. 280).

We argue that what cannot be reliably predicted cannot be experienced as part of the extended self. Hence we can expect most of the social environment to be persistently experienced as foreign to autistic people. This, however, does not rule out the possibility to experience their self as extended to their self-constructed, reliable niche. In fact, if anything, as AB's case indicates, because of their need to further rely on the environment to assess precision, we can expect autistic individuals to experience a stronger, *albeit* less seamlessly integrated sense of extended self in familiar environments.

AB's belonging provides her with "hard copies" of episodic memories, which function as external scaffolding, or extensions for her sense of self (Skirrow et al. 2015). Difficulties in taking 'on board' those memories bear witness of known difficulties for autistic individual to integrate episodic components (see McDonnell et al. 2017 for a review). From a PP perspective, this suggests a loss in internal models' independence. We now turn to this latter point.

5 Deep Models and the Intersubjective Self in ASC: Modelling Others' Modelling

5.1 The Formation of Deep Generative Models in ASC

At the highest levels of the hierarchical generative models sit narratives, or self-models (Hohwy and Michael 2017; cf. Letheby and Gerrans 2017; Pezzulo 2017) that link events on a longer time scale. Though they unpack into expected (dynamics in) perceptual objects and actions, they also gain some independence from their sensorimotor implementation as they can be used to explain (away) one's own behavior as well as that of social partners. Because of this abstraction of the concrete details of inputs (one-to-many relationship), one can think of narratives as models which generalize very well to a variety of social contexts (Hirsh et al. 2013).

Because of the difficulties in lowering the weight of prediction errors, autistics will struggle to gain the abstraction and flexibility by which narratives are generalized. They will generally reduce prediction errors by intervention in the environment, or by increasing the level of detail in their models (Kwisthout et al. 2017). The former, as we've seen, is the niche construction by which autistics and their caregivers enforce an environment with reliable cue-effect relations (e.g., this word always means that concept). Such an environment affords learning with 'collapsed models':

models that are less contextualized by higher-level expectations (Giovanni Pezzulo et al. 2015).

There is little need to estimate precisions in reliable environments and overfitted predictions apply, given that cues are also repeated exactly. This is generally not the case in social (or more naturalistic) settings, which require estimating uncertainty, as cue-effect relations are more probabilistic and context-dependent (e.g., there is no deterministic mapping from intentions/emotions to behavioral expression). For example, "trust" partly involves estimating reliability of your partner's cues and actions. If one can estimate uncertainty, one can start partitioning it, attributing some variability to contextual elements, and others to other agents' mental states (higher level constructs), and as a result, build 'deeper' models of utterances to base adequate action on (e.g., reciprocate using this model rather than always with blunt honesty, as sometimes noted in ASC). Such deeper models of the social domain will more efficiently and reliably explain away (render predictable) perceived behaviors.

To the extent possible, autistic people will try to compensate by increasing the level of (low-level) detail in their models to (inefficiently) explain away the variability at the sensory level. The resulting models will use a more fine-grained hypothesis space, but will be less integrated across levels. Behaviorally, this is supported by problems in seeing "how things hang together" (e.g., the narrative), often denoted as "weak central coherence" (Happé and Frith 2006). For example, autistic people tend to need concrete cues to report (part of) a self-narrative (e.g., prompting for autobiographical memory retrieval, Losh and Capps 2003). Neurophysiologically, this view may find support in the evidence on reduced long-range connectivity and associated lower frequencies on the one hand, and increased short-range and higher frequency connectivity on the other (O'Reilly et al. 2017). Less integrated models can in principle include deeper levels, but their application will be more limited. Hence, the key difficulty will lie in recognizing and leveraging cues to flexibly switch to more contextually appropriate models when engaging in social interactions with others.

Narratives are acquired and shared through communication and socialization (Nelson and Fivush 2004), which implies the alignment of generative models among different individuals. It requires the internalization of how I expect that you expect me to behave given some cues/context (e.g., how I expect fellow pedestrians to expect me to behave at a red light). This is what we called shared expectations in the previous section, which allows the perception of cultural affordances.

According to Hohwy and Michael (2017), the self, or self-model transcribes statistical regularities of sensory events generated by bodily interoceptive and world involving exteroceptive causes spanning various depths, mental states of others being the deepest. Crucially, via positive feedback loops among those causes (Hohwy and Michael 2017), the self-model scaffolds into a persisting, and unified 'object' that binds bodily interoceptive, sensory exteroceptive saliences (i.e., signal), and autobiographical experiences (Letheby and Gerrans 2017). In development, for instance, those feedback loops would enable children to model culturally specific patterns of behavior performed by adult members, and consequently allow them to become increasingly in tune with those adults members in their community (Hohwy and Michael 2017). Hence, if based on dominant cultural conventions, a narrative can be described as a generalized generative model (as in the "generalized other"), referring to its wide applicability in predicting behavior of social (cultural) partners.

Generative models come to be aligned through two related processes, both based on precision modulation and hence both compromised in ASC, namely communication or turn-taking (see Friston and Frith 2015) and joint attention. Turn taking involves a fluent alternation between listening to (or watching) social partners to infer their models, which requires raising precision of exteroceptive inputs, and expressing (or reproducing) your own models for verification or persuasion, which requires increasing the precision of the proprioceptive consequences of your own actions (speech) while lowering exteroceptive precision (we often even look away while talking). Indeed, one cannot talk and listen at the same time (Donnarumma et al. 2017). Difficulties in regulating the precision in this alternating fashion may explain echolalia and more generally communication problems in ASC (Dawson and Adams 1984).

Similarly, joint attention implies temporarily turning down the precision of your own sensorimotor implementation to make room for exteroceptive cues that will help accomplish your goals in more efficient or more socially desirable ways. It is the key way by which parents can limit variability early on in development, guiding the baby to reliable information that can reduce uncertainty relative to her goals. However, this requires that the child monitors her own uncertainty (metacognition) to be able to realize that the gaze or pointing finger of the parent can reduce this uncertainty. The proposed inadequate monitoring of uncertainty in ASC in this way connects to their joint attention problems, e.g., gaze following (Mundy and Crowson 1997).

5.2 The Intersubjective Self and Causal Inference in ASC

Joint attention enables the acquisition of an adequate 'regime of attention', that is, the set of shared expectations about precision or salience that are learned through patterns of coordinated attention in ontogeny (Veissière 2016). These enable to perform complex causal inference, like inferring others' mental states in social context. They allow an agent to infer what the other attempts to infer about you; expecting what one expects you to expect (Ramstead et al. 2016); to share intentions with others (Tomasello and Carpenter 2007; Tomasello et al. 2005); or to be aware, and model how others interpret your own mental states (Baker et al. 2011; Palmer et al. 2015b). Ultimately, they involve modelling the other's modelling activity of your own modelling (cf. the concept of meta-mentalising, Hohwy and Palmer 2014). when performed smoothly and automatically during social interaction, this would enable a typical sense of intersubjective self, defined as the experience of immediate, and unreflective engagement in social interaction, and the attunement to intersubjective existence (Neisser 1988).

Crucially, joint attention is the necessary step toward collective attention (Tomasello 2014). While joint attention is the dyadic coordinated attentional activity just discussed (e.g., two persons attending to the same object), the collective attention concerns third-person coordination, i.e. attending to that which a generalized other would attend to in a given situation. The leap from joint to collective intentionality allows for the grounding of social interactions beyond the concreteness of particular intersubjective exchanges, and for that reason is central to the intersubjective self. In turn, the intersubjective self can be seen as entangled with the extended self because the leap to collective attention depends on the ability to anchor models on material artefacts, and motor interactions with other individuals (Bolis et al. 2017; Bolis and Schilbach 2017; von der Lühe et al. 2016).

This can be viewed as collective niche construction, understood as the coordinated narrowing down of the variance of sensory samples to expected sensations via joint sensorimotor patterns of attention leaving durable, informative modifications in the physical environment (cf. Tomasello 1999), e.g., materially mediated turn taking. It leads to the acquisition of sensory expectations congruent with those of other agents because it implies the gathering of evidence about the other's relation to the shared object of attention. A paradigmatic instance of this is the sort of play that children engage in throughout development (Currie and Ravenscroft 2002). Over time, collective niche construction allows the infant to concretely access the other agent's mind, and integrate a shared regime of expectations about how the other expects you to make sense of the world and behave. In this sense, it is "only when each child perceives the [affordance] of things for other as well as for herself [that] she begins to be socialized"(Gibson 1979, p. 141).

Social symptoms of ASC, and the ensuing atypicalities of the intersubjective self thus would pertain to struggles in engaging immediately, and unreflectively social interactions with typically developing individuals, which can be viewed as struggles in attuning to intersubjective existence (Neisser 1988). These may be better understood by looking at the dissimilarity between the sensorimotor attentional patterns used by individuals to update their beliefs in the course of social interaction, and their ensuing effects on the modifications of the local environment (cf. materially mediated turn-taking), rather than by considering a mere disruption of neurocognitive functions *per se* (Bolis and Schilbach 2017). Autistic individuals are not neurophysiologically 'blind' to the information typically available in social interaction, and consequently, nor is it an impossibility for them to integrate a generalized other and thereby engage in unreflective social interaction, or even share a form of life in common with other individuals. What we can say is that "the other" will tend to be less generalized, which will result in highly formalized, conventional social responses to familiar environmental cues, and difficulties to on-the-fly switch social narrative, or model, for cues in a new context.

The view that we sketch here is continuous with, and complement the intersubjective approach to ASC (Bolis and Schilbach 2017). The intersubjective approach seeks to explain aspects of the autistic phenotype in terms of atypicalities in processing sensory information within the context of the recognition of social cues. For instance, the Dialectical Misattunement Hypothesis (DMH) (Bolis et al. 2017) argues that ASC is better understood as a disorder resting on the misattunements of interpersonal dynamics, expressed at different levels of description (e.g., from biological to socio-cultural), unfolding at various spatiotemporal scales. The notion of misattunement refers to the imbalance, or lack of synchrony among those levels collectively experienced by typically and atypically developing individuals. The cumulative misattunement between autistic and typically developing individuals would lead to divergent developmental trajectories in terms of the learning of expectations (e.g., internal, brain model), and 'interaction styles', or sensorimotor patterns of interactions (e.g., active inference) (Bolis et al. 2017). Bolis et al. (2017) suggest that dialectical misattunement in ASC would result in "impoverished opportunities for acquiring socioculturally mediated knowledge and skills" (Bolis et al. 2017, p. 366).

Our ecological approach can be framed as an extension of DMH's levels of descriptions to the level of the material environment, and niche construction. Interestingly, Constant et al. (2018) argue that niche construction—as a meta-learning mechanism—enables agents to synchronize their behavior with events unfolding at multiple spatio-temporal scales: i.e., implicitly infer causes hidden at various depths. Future research on the intersubjective approach to psychopathologies would benefit from an integration of the PP approach to niche construction.

6 Concluding Remark: Why Go Ecological?

The ecological mechanism explored in this paper under the auspices of the PP approach to cultural niche construction was the *environmentally mediated* reciprocal modelling of oneself, one's world and the others, the "becoming the one[s] I listen to"(Merleau-Ponty 1969) if you will. In ASC the tuning of that mechanism is such that modelling becomes a hurdle to overcome, and for that reason renders precarious the stability of structures like that of the relational self. We have proposed that to compensate, such structures are stabilized by the construction of, and over reliance on, the environment. Like the intersubjective approach to psychopathology (e.g., DMH), the ecological perspective sketched here offers scientific, and practical-ethical alternatives to understand the atypical experience of autistic individuals.

Scientifically, as noted by Bolis et al. (2017), more ecologically valid approaches shift the comprehension of "healthy individuals" versus "patients" towards considerations of social interactions *per se*, taking hold among differently tuned individuals. These look at psychopathologies like ASC as the outcome of an interaction between nature (e.g., the neuromodulatory handling of precision) and nurture (e.g., the scaffolding of aspects of the self via cultural niche construction) (cf. Adams et al. 2016). It fits more dynamic and interactive approaches stressing the constitutive, causal role of communication, embodiment, and environments in autistic cognition (McGuire and Michalko 2011), whilst providing a connection—via PP— with a neurodevelopmental substrate for a description of ASC as a, nevertheless, possibly adaptive neurodevelopmental pathway (Johnson 2017).

Ethically, and practically, the ecological perspective does justice to the many stories autistics tell about themselves and their social functioning (Van Goidsenhoven and Masschelein 2016), which in themselves are a clear sign that a relational self in ASC is possible. It allows embracing the diversity of autistic life stories (Hens and Langenberg 2017) as an authentic spectrum whilst retaining coherence based on the common atypical way of 'tuning to others' (Bolis et al. 2017), and as we have argued 'tuning to the material world'. As such, the ecological perspective entails that issues in building a social self could generally be overcome in ways other issues related to different embodiments are overcome (e.g., blindness, or deafness), that is, by mutual adaptation on both sides of the intersubjectivity equation (Glackin 2010).

That being said, we need to acknowledge a limitation of our approach. ASC ranges from individuals barely able to communicate to individuals only diagnosed later in life, and that if combined with other disadvantages, the challenges that some autistics face may prove insurmountable even *with* socio-environmental supports. Fortunately, in many cases, the challenges are hurdles that can be overcome to let talents come to fruition. Taking seriously the ecological perspective, and in order to help to avoid social exclusion (Bolis et al. 2017), allowances should be made in society for helping autistic people without stereotyping them as a different 'breed of people' that need to be socialized in a specific and typical one-size-fits-all ways (Mole 2017). Although this does not exclude medication and therapy, the help cannot primarily consist in pharmacologically ensuring that precision will be handled in a typical way, but in ensuring that the best social and environmental conditions are available to each individual.

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