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Why ritualized behavior? Precaution Systems and action parsing in developmental, pathological and cultural rituals

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Abstract: Ritualized behavior, intuitively recognizable by its stereotypy, rigidity, repetition, and apparent lack of rational motivation, is found in a variety of life conditions, customs, and everyday practices: in cultural rituals, whether religious or non-religious; in many children's complicated routines; in the pathology of obsessive-compulsive disorders (OCD); in normal adults around certain stages of the life-cycle, birthing in particular. Combining evidence from evolutionary anthropology, neuropsychology and neuroimaging, we propose an explanation of ritualized behavior in terms of an evolved Precaution System geared to the detection of and reaction to *inferred* threats to fitness. This system, distinct from fear-systems geared to respond to *manifest* danger, includes a repertoire of clues for potential danger as well as a repertoire of species-typical precautions. In OCD pathology, this system does not supply a negative feedback to the appraisal of potential threats, resulting in doubts about the proper performance of precautions, and repetition of action. Also, anxiety levels focus the attention on low-level gestural units of behavior rather than on the goal-related higher-level units normally used in parsing the action-flow. Normally automatized actions are submitted to cognitive control. This "swamps" working memory, an effect of which is a temporary relief from intrusions but also their long-term strengthening. Normal activation of this Precaution System explains intrusions and ritual behaviors in normal adults. Gradual calibration of the system occurs through childhood rituals. Cultural mimicry of this system's normal input makes cultural rituals attention-grabbing and compelling. A number of empirical predictions follow from this synthetic model.

Keywords: childhood ritual; compulsion; event boundaries; evolutionary psychology; obsessive-compulsive disorder; ritual; thought intrusion

1. Ritualized behavior

In a variety of circumstances, humans[1] produce rituals, intuitively recognizable by their stereotypy, rigidity, repetition, and apparent lack of rational motivation. Behavior of this kind is found in cultural rituals, religious or non-religious; in the complicated routines of many children; in the pathology of obsessive-compulsive disorders; in normal adults around certain stages of the life-cycle, especially during birthing. The common features of these behaviors cry out for explanation.

We build on a variety of prior models to describe a core psychological process that we call *action ritualization* – which is only a part of individual or cultural rituals but a crucial part. The occurrence of ritualization depends on the conjunction of two specialized cognitive systems. One is a motivational system geared to the detection of and reaction to particular *potential* threats to fitness. This "Hazard-Precaution System" includes a repertoire of clues for potential danger as well as a repertoire of species-typical precautions. The other system might be called "Action Parsing." It is concerned with the division of the flow of behavior into meaningful units. In some circumstances, specific interaction between these systems creates ritualized actions. The circumstances are different for individual, pathological, and collective rituals, as we will see. But the core ritualization process explains some of their common properties.

There is no precise definition of "ritual" in any of the three fields that deal with its typical manifestations. Cultural anthropologists generally accept a very vague definition of the term as scripted, stereotypic forms of collective action (Gluckman 1975). Ethologists use criteria such as repetition and stereotypy (Payne 1998). Clinical psychologists' descriptions of OCD pathology, as in the DSM-IV, mention "ritualistic behaviors" without more precision (American Psychiatric Association 1995).

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Besides, models of the phenomenon are generally limited to one domain of ritual. There is a large clinical literature about children's OCD but little study of normal childhood ritualization, simply because the latter is not pathological, even though it may be difficult to understand one without the other (Evans et al. 1997). Models of OCD do not usually cover normal episodes of obsessiveness and ritualistic compulsion in the life-cycle although these are probably continuous with the pathology (Mataix-Cols et al. 2005). Very few anthropologists have considered the striking similarities between cultural ritualized behavior and individual pathology (Rappaport 1999). A notable exception is Alan Fiske (Dulaney & Fiske 1994; Fiske & Haslam 1997), who re-opened an issue famously framed by Freud a long time ago (Freud 1928).

Following up on Fiske's pioneering work, discussed in section 8.1, as well as neuro-physiological (Szechtman & Woody 2004) and evolutionary (Abed & de Pauw 1998) models, we aim to provide a model of the different domains of occurrence of ritualized behavior. We certainly do not mean to underestimate the obvious differences, but we do think that the common features of ritualized actions require an explanation. We aim to provide an *integrated* model that includes not only a cognitive specification of the behavioral patterns and their elicitation conditions, but also the neural correlates of the behaviors and of their pathological distortion, the developmental patterns involved, and the evolutionary background.

It might seem imprudent to make any general statements about a disparate set that includes pathological and normal manifestations, and individual as well as collective rituals. Note, however, that our aim here is not to account for all these behaviors. Our aim is to account for the psychological salience of a particular feature they share, namely the performance of what we call here "Ritualized Behavior," a precisely defined way of organizing a limited range of actions. In the following sections we outline the diverse domains of ritualized behavior before putting forward an integrated neural-developmental-evolutionary model of ritualization.

2. Diverse domains of ritualization

2.1. Obsessive-compulsive disorder (OCD)

The main features of the pathology of OCD are familiar: intrusive, bothersome thoughts about potential danger, as well as a strong compulsion to engage in stereotyped and repetitive activities with no rational justification. Standard criteria in the DSM-IV include (a) intrusive thoughts that (b) cause distress and (c) are often accompanied by ritualistic behaviors that (d) disturb normal activity and (e) are recognized as irrational by the patient (American Psychiatric Association 1995).

Typical obsessions include contamination and contagion (i.e., fear of catching other people's germs, of ingesting contaminated substances, of passing on diseases to others), possible harm to others (e.g., handling kitchen utensils and wounding people), as well as social ostracism following shameful or aggressive acts (thoughts about assaulting others, shouting obscenities, exhibitionism, etc.). This is often combined with "thought-action fusion" – the assumption that having forebodings of possible misfortunes is tantamount to bringing them about – and an exaggerated feeling of responsibility for others (Salkovskis et al. 2000).

Obsessions are typically accompanied by rituals. Some patients engage in endlessly repeated sequences of washing hands, cleaning tools or utensils (Hodgson & Rachman 1972). Others repeatedly verify that they properly locked their door, rolled up the car window, or turned off the gas stove (Hodgson & Rachman 1977). Still others are engaged in constant counting activities or need to group objects in sets of particular numbers, with specific alignments (Radomsky et al. 2001). Although a categorical division between "checkers," "washers," and "hoarders" has become popular in descriptions of OCD and as a descriptive clinical tool, there seems to be a large overlap in these categories (Khanna et al. 1990). A more accurate description would construe "contamination," "insecurity and doubt," and "excessive precautions" as *dimensions* of the syndrome (Mataix-Cols et al. 2005), with each patient presenting a cluster of symptoms distributed along these dimensions (Calamari et al. 2004). Most patients are aware that their obsessions are unreasonable and their rituals pointless (patients' insight used to be a criterion in the DSM) but they also report that neither is easily controlled (Eisen et al. 1999).

2.2. Children's rituals

Most young children engage in ritualistic behaviors in a limited range of situations and at a particular stage of development, starting at age 2 and peaking in middle childhood. This developmental phase is characterized by perfectionism, preoccupation with just-right ordering of objects, attachment to a favorite object (imbued with a special value), concerns about dirt and cleanliness, preferred household routines, action repeated over and over or a specific number of times, rituals for eating, awareness of minute details of one's home, hoarding, and bedtime rituals. (Obviously, most children in most situations also create disorder, at least relative to what adults expect; insistence on "just so" performance is limited to highly specific contexts.) The themes and the age-range are similar among American and other cultural groups (Zohar & Felz 2001). In many children, rituals are connected to anxiety states with specific targets. Among them is the fear of strangers, as well as the possibility of inflicting harm to self or others, possible contamination, attack by strangers or animals. The tendency to engage

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in rituals is correlated with anxiety or fearful traits (Zohar & Felz 2001). Both fears and rituals typically evolve with development, from "just so" insistence to elaborate rituals (Leonard et al. 1990). Younger children's ritualistic behaviors are related to prepotent fears such as stranger and separation anxieties, whereas the ritualistic behaviors of older ones are related to more specific and contextual fears such as contamination and social hazard (Evans et al. 1999). Some children connect their rituals to supposed effects by magical beliefs in ritual efficacy (Evans et al. 2002), but this is by no means necessary or even general.

Although the facts of childhood ritualization are familiar and impressive, there is no definitive account of the functional basis of such behaviors in young children. This is mostly because OCD pathology is seen as discontinuous with the "normal" routines of childhood, given both the obvious differences in frequency and emotional intensity and the fact that only very few young ritualists become clinically obsessive (Leonard et al. 1990). However, it seems difficult to understand the pathology in the absence of a proper causal model for this highly recurrent, culturally stable part of the normal developmental process (Evans et al. 1997).

2.3. Life-stage-relevant intrusive thoughts

Specific disturbing thoughts occur in many people at particular phases in the lifetime, notably pregnancy, motherhood, and fatherhood. Senseless, intrusive, unacceptable ideas, thoughts, urges, and images about infants are common among healthy parents of newborns, both fathers and mothers (Abramowitz et al. 2003). The content of intrusions is related to specific stages of the life-cycle. While new fathers and post-partum mothers report fears about harming the infant, pregnant women report heightened fears about contamination (Abramowitz et al. 2003). They also develop rituals of washing and cleaning related to these intrusions. A common underlying theme is uncertainty and doubt concerning possible harm to the infant. Three-quarters of the new parents surveyed by Abramowitz et al. reported persistent thoughts about accidents, suffocation, and other possible ways of intentionally harming the infant (Abramowitz et al. 2003). The individuals feel responsible for these intrusive thoughts. Development of specific perinatal anxieties may be part of a "primary parental preoccupation" complex that includes nesting behaviors, repeated checking, thoughts about the infant's perfection, and fantasies about possible threats to its security (Leckman et al. 2004). Rodent models suggest oxytocin as a major modulator of such maternal behaviors (Leckman et al. 2004).

The connection between these non-clinical context-relevant intrusions and OCD is not just a matter of similarity. The onset of OCD in women occurs during pregnancy more than at other life-stages (Maina et al. 2000; Neziroglu et al. 1992). Note that the development of intrusions and early rituals into OCD is quite distinct from the evolution of post-partum depression (Williams & Koran 1997). The former triggers very specific, highly consistent obsessive thoughts as opposed to unfocused or frequently shifting depressive ruminations. OCD onset also results in an urge to act (perform specific rituals) very different from the withdrawal from action observed in post-partum depression (Hagen 2002). Among OCD patients, pregnancy and postpartum result in more severe symptoms (Labad et al. 2005). Activation of the fronto-striatal networks as a result of infant cries is different in new mothers and controls (Lorberbaum et al. 2002), suggesting functional calibration of the circuitry involved in OCD (see section 3.1.).

2.4. Cultural rituals

A great variety of social occasions are identified as "rituals" in the anthropological literature. They range from private ceremonies with few participants, or indeed just one person, to large gatherings, and from single acts to long sequences spread over months or years. The general themes range from worship to protection to aggression. The occasions for ritualized behaviors also vary, either contingencies such as illness or misfortune, life-stages like birth, initiation, and death, or recurrent occasions such as seasonal changes. Finally, the connections between rituals and religious concepts are crucial in some cases (e.g., ancestor worship, Islamic prayer), or only peripheral (e.g., anti-witchcraft divination), or just absent (as in "secular" rituals).

How do we recognize such actions? As Roy Rappaport argued, it seems that we (anthropologists but also lay folk) use a conjunction of specific criteria that a model of ritual should explain (Rappaport 1979). Here is a slightly modified list of features he emphasized:

1. First, actions are divorced from their usual goals. In cultural rituals, one typically washes instruments or body parts that are already clean, one enters rooms to exit them straightaway, one talks to interlocutors that are manifestly absent. Also, many rituals include actions for which there could not possibly be any clear empirical goal, such as passing a chicken from hand to hand in a circle, going round a temple seven times, and so forth.

2. Second, cultural rituals are often presented as compulsory, given a particular situation. People are told that a particular ceremony must be performed. More often than not, there is no explanation of why that ritual should be performed given the circumstances. True, a ritual often has a specific overall purpose (e.g., healing a particular person, keeping witches at bay); but the set of sequences that compose the ritual are not connected to this goal in the same way as sub-actions connect to subgoals in ordinary behavior (Boyer 1994).

3. Third, in many cultural rituals people create an orderly environment that is quite different from the one of everyday interaction. People line up instead of walking, they dance instead of moving, they wear similar clothes or make-up, they build alignments of rocks or logs, they create elaborate color and shape combinations, and so on. Related to this is the recurrent concern with delimiting a particular space (a sacred circle, a *taboo* territory) often visually distinct from the other, unmarked space.

It is important to distinguish "rituals" from ritualization. There may be lots of different reasons why particular kinds of ceremonies are found in human cultures, why they persist, and why they are relatively stable. We discuss these issues elsewhere (Lienard & Boyer, forthcoming). For instance, one may propose plausible evolutionary scenarios for the existence of birth celebrations and of death rituals in most cultural environments. But these

scenarios do not explain why these social occasions all include *ritualized* behavior in the precise sense intended here.

2.5. General features of rituals

Behavior in these different domains displays obvious similarities:

1. *Compulsion.* Given certain circumstances, people feel that it would be dangerous or unsafe or improper not to perform ritualized actions. There is an emotional drive to perform the action, often associated with some anxiety at the thought of not performing it (especially in patients and children) and some relief after performance. Naturally, this varies between domains. Anxiety precedes ritual actions or behavior in many personal and pathological rituals but not always in cultural rituals. Common to all domains, though, is the important fact that compulsion does not require any explanation. People feel that they must perform the ritual, otherwise... [something might happen], but they require no specific representation of what would happen otherwise.

2. *Rigidity, adherence to script.* People feel that they should perform a ritual in the precise way it was performed before. They strive to achieve a performance that matches their representation of past performances and attach negative emotion to any deviation from that remembered pattern. This is familiar in childhood rituals and OCD but also in the "traditionalistic" flavor of most cultural rituals (Bloch 1974). Deviation from the established pattern is intuitively construed as dangerous, although in most cases the participants have or require no explanation of why that is the case.

3. *Goal-demotion.* Rituals generally include action-sequences selected from ordinary goal-directed behavior. But the context in which they are performed, or the manner of performance, results in "goal-demotion," in performance divorced from observable goals. For instance, people tie shoe-laces that were tied already; they touch a specific piece of furniture without trying to move it or use it as support; they wash hands many more times than hygiene would require; and so on.

4. *Internal repetition and redundancy.* Repeated enactments of the same action or gesture, as well as reiterations of the same utterances, are typical of many rituals. A given sequence is executed three or five or ten times. What matters is the exact number. This makes many ritual sequences clearly distinct from everyday action, in which there is either no repetition of identical sequences (e.g., in assembling a musical instrument, one performs a series of unique actions), or each repeated act has a specific outcome (e.g., in weaving), or repetition is cumulative (the egg-whites rise only after a long period of whipping).

5. *A restricted range of themes.* Many rituals seem to focus around such themes as: pollution and purification, danger and protection, the possible danger of intrusion from other people, the use of particular colors or specific numbers, the construction of an ordered environment (Dulaney & Fiske 1994). A ritual space or instruments are described as "pure" or "safe" (or, on the contrary, as the locus of concentrated "pollution") or the point of the ritual is to "purify" people or objects, to "cleanse" mind or body, and so on. In collective rituals, this concern with pollution and cleansing is so prevalent that it has been considered a foundation of religious ritual (Douglas 1982).

Is there a common explanation for these different features of ritualized behavior? Here we will start from pathology and summarize what can be safely concluded from the clinical and neuropsychological evidence. This supports a particular model of *action ritualization* which we will also extend to developmental rituals in children and adults, before proceeding to the distinct case of cultural rituals.

3. Interpretations of compulsive ritualization

3.1. Neuropsychological modeling

OCD has been interpreted as a specific dysfunction of the basal ganglia (Rapoport 1990, 1991). To understand how this would result in the specific symptoms, the impairment should be described in terms of the specific functions of a cortical-striato-pallidal-thalamic circuit (CSPT). This network includes projections from many cortical areas (including medial and orbital frontal cortex) into the striatum (caudate and putamen) and back to the cortex via the substantia nigra and thalamus (Rauch et al. 2001; Saxena et al. 1998). This has been confirmed by neuroimaging studies, as OCD is associated with increased activity of the orbitofrontal cortex (OFC) as well as in the striatum, thalamus, and anterior cingulate cortex (ACC) (Saxena et al. 1998; Saxena et al. 2004). Also, the anatomy of the caudate, putamen, and globus pallidus seems to differ between patients and controls (see, e.g., Giedd et al. 2000). One generally distinguishes between a "direct" and an "indirect" pathway in the CSPT networks (see Fig. 1). The direct pathway links (1) frontal cortices to (2) the striatum, to (3) the globus pallidus (pars interna) and substantia nigra (pars reticulata) to (4) thalamus and (5) cortex. The indirect pathway connects (1) cortex to (2) striatum to (3a) globus pallidus (pars externa) and subthalamic nucleus to (3b) globus pallidus (pars interna) and substantia nigra (pars reticulata) to (4) thalamus to (5) cortex.

The basal ganglia are involved in the formation of habits, motor habits in particular (Rauch et al. 1997). The pattern of projections from the cortex to the striatum suggests that the latter may store summaries or "chunks" of motor behavior. This is confirmed by involvement of the striatum in the learning and production of habitual responses (Graybiel 1998). Striatal networks may act as coordinators of cortical input and orchestrators of motor habits.

What specific dysfunction would result in OCD symptoms? In animal models, modifying dopamine uptake in the striatum results in stereotypic and repetitive behavior (Canales & Graybiel 2000; Szechtman et al. 1998). So an imbalance between various parts of the basal ganglia system or a modification in the dynamics of cortico-striatal pathways are probably involved in the condition. Saxena and colleagues identify the "indirect" pathway as the locus of impairment. In their model, the association of globus pallidus (external) and subthalamic nucleus can be construed as a "basal ganglia control system" that modulates the projections to the thalamus and cortices (Saxena et al. 1998). The indirect pathway consists of inhibitory (GABAergic) projections from the striatum to

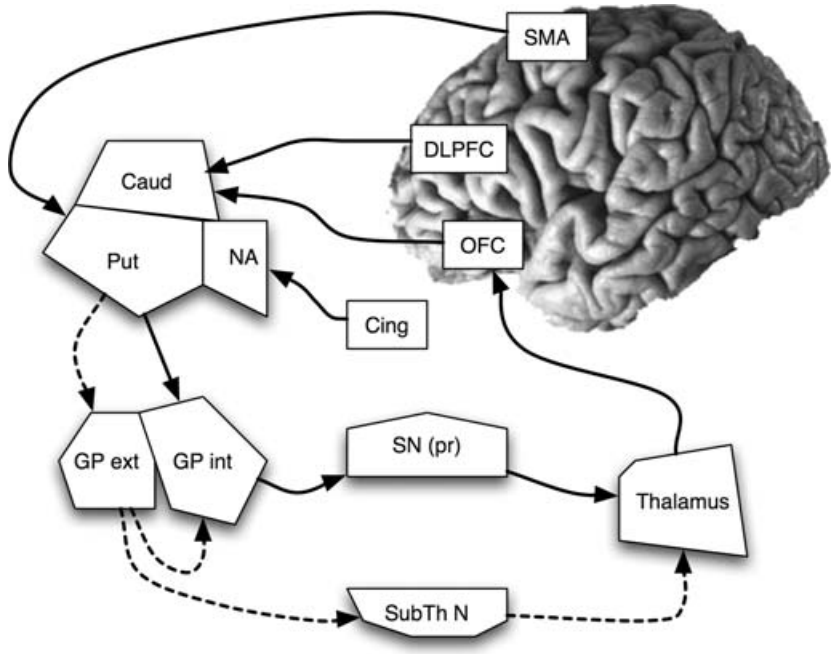

Figure 1 (Boyer & Liénard). A summary of some cortico-striatal pathways relevant to OCD. Continuous line for the "direct" pathway and dotted line for "indirect" pathways (both highly simplified). SMA: Supplementary Motor Area, DLPFC: dorso-lateral prefrontal cortex, OFC: orbito-frontal cortex, Caud: caudate nucleus, Put: Putamen, Cing.: Cingulate Cortex, NA: Nucleus Accumbens, GP: globus pallidus (external and internal), SN(pr): substantia nigra pars reticulata, SubTh Nuc: Subthalamic nuclei.

the thalamus. To the extent that this pathway becomes less tonic, it would fail to inhibit habitual motor responses and result in unmotivated, stereotypic routines (Saxena et al. 1998).

Also important is the regulatory role played by the orbitofrontal cortex (OFC) and the anterior cingulate cortex (ACC). Early neuroimaging studies showed differential activation of these regions in OCD patients in situations of symptom provocation (Adler et al. 2000; Rauch et al. 1994). OFC activation makes sense given its role in the selection, control, and inhibition of behavior as demonstrated both by neuroimaging and by lesions of this area (Happaney et al. 2004; Ogai et al. 2005; Schnider et al. 2005). Anterior cingulate activity is also revealing. Ablation of the area has been used in refractory OCD cases (Kim et al. 2003). ACC hyperactivity is not limited to situations of symptom provocation (Ursu et al. 2003). In an event-related study of error-processing, Fitzgerald and colleagues found increased ACC activity with error-detection in both patients and controls, with significantly higher increases in patients. The amount of ACC activity also correlated with the severity of the patients' compulsive symptoms (Fitzgerald et al. 2005). The anterior cingulate can be described as an error-detection network that activates top-down responses to situations of conflicting information, for example, between expectation and perception in errors, or between discrepant stimuli (Van Veen & Carter 2002).

All this converges to suggest that OCD may stem from a dysfunction of a neural system involved in the production and inhibition of a particular set of habitual or routinized behaviors. The etiology of the dysfunction includes probable genetic factors (Campbell et al. 1999; Zohar et al. 2004) as well as infectious conditions (Giedd et al. 2000; Henry et al. 1999), although evidence for either cause is tentative. The compulsive nature of the actions seems to result from a failure to inhibit strongly motivated routines initiated in the striatum, either because striatal networks over-respond to cortical inputs, or because their inhibitory effect on thalamic networks is diminished, or both, leading to ritualization. This picture is consistent with the clinical and pharmacological evidence (Kaplan & Hollander 2003; Zohar et al. 2004).

3.2. Cognitive models: General or specific?

Cognitive models provide a bridge from neuropsychological findings to the phenomenology of OCD symptoms. A classical cognitive model describes the condition as a disorder of threat-appraisal and cognitive control (Rachman & Shafran 1998; Salkovskis 1985). Patients produce a misguided appraisal of intrusive thoughts, exaggerate the threats present in the environment as well as the extent of their own responsibility for what befalls others, and finally fail to appreciate the measure of safety introduced by normal precautions. In this model, OCD differs from other anxiety conditions (general anxiety disorder, panic) only in that the eliciting stimuli are very specific – a series of intrusive thoughts with recurrent themes (Clark 1999).

Obsessions and compulsions might then result from a general failure to appreciate levels of danger, to evaluate one's responsibility in external events, and to form an appropriate picture of one's situation. For instance, ritualized repetition may stem from the patient's failure to realize that he or she has actually accomplished the action (Pitman 1987). There is indeed evidence (though not conclusive) for general memory problems. OCD patients have the right intuitions in both memory for actions and source monitoring (i.e., whether they

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performed as opposed to imagined performing an action) but they report less confidence in their own intuition (Hermans et al. 2003).

However, there is also definite evidence for domain-specific aspects of OCD. For instance, OCD patients are similar to controls in their recall of neutral objects but are markedly better at recalling dangerous items (Tolin et al. 2001). OCD "checkers" are impaired in their recall of own actions but less so in recall of other information (Ecker & Engelkamp 1995). In terms of attention, modified Stroop tasks show that OCD "washers" are more attentive to contamination words than are controls, and OCD patients in general show more interference than controls do from danger-related words (Foa et al. 1993).

3.3. Security-motivation

Most cognitive models of OCD are phrased in domain-general terms. An exception is Abed and de Pauw's evolutionary hypothesis about OCD as a disruption of a specific "psychological immune system" (Abed & de Pauw 1998). The hypothesis starts from the observation that the prevalence of OCD would suggest the tail of a phenotypic distribution rather than harmful mutations. According to Abed and de Pauw, obsessional phenomena are an exaggerated version of thought processes selected because they lead to risk-avoidance behavior (in particular through fear or disgust). Central to the hypothesis is the fact that intrusive thoughts, in patients and normal individuals, consist of detailed scenarios of possible danger, an "Involuntary Risk Scenario Generating System" (Abed & de Pauw 1998).

A similar evolutionary background motivates Szechtman and Woody's interpretation of the condition in terms of a "security-motivation" system (Szechtman & Woody 2004). The model is an attempt to integrate the diverse components of the relevant behaviors (emotion, perception of specific information, typical actions, inhibition or disinhibition of automatic routines) in a *motivational* system functionally specialized in potential danger.

In contrast to general cognitive impairment models, both Abed and de Pauw's and Szechtman and Woody's models provide a parsimonious account for the specificity of OCD intrusions.

The security system is present in all normal human beings and monitors external signals of particular kinds of *potential* danger. The neural circuitry involved in both normal and pathological safety motivation can be broken down in three major functional components with excitatory and inhibitory links. An appraisal system handles information that matches input conditions for environmental cues of potential danger. A security motivation system handles the evaluation of these cues. A set of various evolved security-related programs is engaged, depending on the outcome of this motivation assessment, with specific motor and visceral output (see Fig. 2).

As a result of engaging security-related motor-programs (this may consist in visual inspection of one's environment, cleaning, ordering, etc.), the security motivation system produces a specific experience of things being "just right" which feeds back into the danger appraisal system.

Szechtman and Woody's identification of the neural correlates of these systems extends beyond the cortico-striatal pathways. The appraisal of potential danger involves perceptual and memory information and feeds into both orbital cortex and the cortical-striatal pathways. From there, Szechtman and Woody identify two distinct informational loops. One of them, the affect loop, includes most of the "indirect pathway" structures, producing a specific anxiety. In parallel, a "security-related programs" loop, connects striatum to the globus pallidus (internal) and ventral thalamus to elicit the performance of stored motor routines. Finally, the normal inhibition of these two loops is provided by brainstem structures after performance of the elicited motor routines. The model states that OCD is the result of a *dysfunction in a satiety signal*, plausibly generated in brainstem structures, that connects the performance of security related behaviors as inhibitory feedback to a subsystem that generates and sustains security motivation.

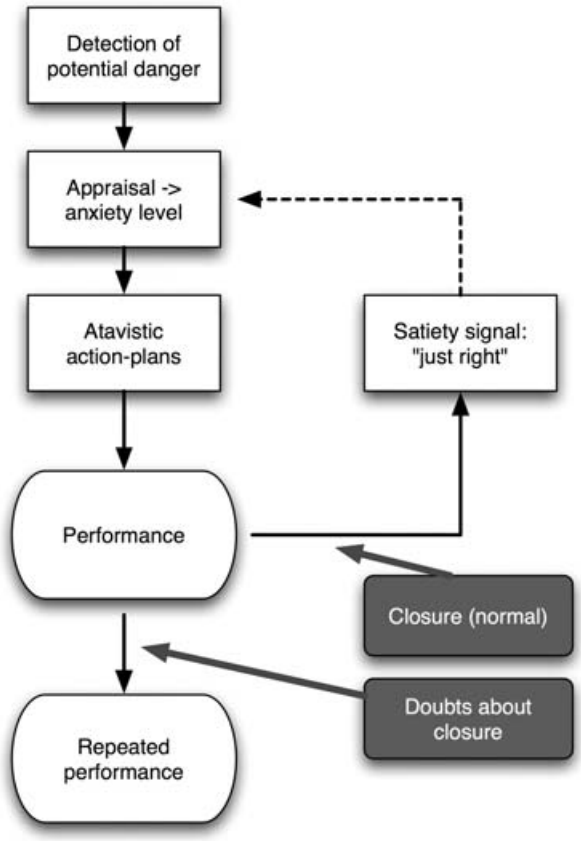

Figure 2 (Boyer & Liénard). An interpretation of Szechtman and Woody's (2004) model. Rectangles correspond to distinct systems activated, rounded boxes to behavioural results and call-outs to aspects of the processing. Danger clues are evaluated and action-plans selected, resulting in a "just right feeling" that sends negative feedback to danger appraisal. This loop is absent or impaired in patients, leading to doubts about performance, which themselves result in repetition and rigid action-plans.

3.4. Outstanding questions

In our view, while current models of compulsion have great descriptive and explanatory value, they still provide an incomplete account of various aspects of the obsessive and compulsive spectrum, especially if we include normal as well as pathological manifestations of ritual dispositions.

A more complete model should account for the following aspects of ritualized behavior:

1. *Why these specific themes?* The thoughts patients and others report are clearly not random conceptual associations. They center on a few threats that are particularly disturbing. Even this is much too broad a description. People have intrusive thoughts about causing accidents involving their kin, but not complete strangers; they fear contamination more than bone fracture or inflammation; they fear that they may have left the back door open or the oven on, not that their car will be stolen or the fridge will break down.

2. *Why these specific actions?* Compulsions seem to focus on a narrow set of possible actions. This is clear for contamination compulsions which result in repeated washing and cleaning. The same applies to checking behaviors, limited to visual cues. Not all actions seem likely to become compulsive.

3. *Why combine the actions in that way?* Many compulsive rituals organize action in a very specific way. For instance, there are many negative rules in compulsions (avoid treading on the lines on the pavement). Also, there are specific rules about the number of iterations (touch this chair three times) or about the order of actions (tie the right shoe before the left one).

4. *Why does ritual provide relief?* Most clinicians agree on a temporary lowering of anxiety levels after the performance of rituals. The question points to one possible explanation for the compulsive character of the behavior. Could it be that patients intuitively reproduce behaviors that reduce anxiety? But then, what is it about such organization of action that could reduce anxiety?

5. *Why does ritual eventually strengthen obsessions?* This too is a feature often noted by clinicians (see, e.g., Salkovskis 1985). Although rituals provide some relief, this is only temporary and the intrusive thoughts quickly come back. Indeed, it would seem that the more rituals one performs, the more focused and bothersome are the intrusive thoughts.

4. Ritualized action: The core process

What follows is a list of the different points of the model which will be explained in the following sections. In our view, ritualization in young children, in normal adults at particular life-stages, and in patients comprises a series of processes in which specific information is acquired or retrieved and specific behavioral plans are engaged:

1. Security-motivation systems are engaged. This may be because of potential danger cues in the environment (described below), information imparted by other people, self-generated thoughts, or intrusions. In any case, these thoughts focus on cues for *potential* hazards chosen in a small set that we call the Potential Hazard Repertoire.

2. Safety motivation triggers an arousal state in which non-action is intuitively considered dangerous (something *must* be done) although there need be no clear representation of why that is the case.

   2a. This state triggers a non-deliberate, non-controlled search for action-sequences that appear intuitively appropriate. Some cues make some actions seem apposite although the subject generally has no explanation for the intuition (or may only have *ex post facto* rationalizations). These actions are selected from what we call an Evolutionary Precaution Repertoire.

   2b. The arousal triggers a special attentional state that focuses on low-level properties of own actions. The action-flow is parsed in smaller units than is usually the case.

   2c. The arousal state may bias the appraisal system in such a way that "just right" or "closure" experience is delayed. This triggers doubts about actual or proper performance and reiteration of action-plans.

3. Performance of the actions with attention to low-level parsing [see 2b above] may impose a heavy load on working memory-systems, with two consequences:

   3a. The intrusive themes are temporarily pushed away from conscious access, resulting in a short-lived reduction in anxiety level.

   3b. The intrusive themes are monitored by automatic, not controlled processes, which should result in higher salience (and renewed intrusion) after performance.

These different steps are summarized in Figure 3. In what follows we explain the processes engaged in more detail and provide arguments for their presence in most domains of ritualization. An important point to emphasize is that we do not identify any particular component of the overall process as being exclusively pathological. In our view, most reactions to inferred threats engage all these processes. Whether or not a given action triggers doubt about proper performance, leading to rigid repetition, that is, *ritualization* of these reactions, may be a matter of degree.

5. Why these particular obsessions and compulsions?

5.1. Logic of our evolutionary approach

Intrusions and compulsions are bothersome and time-consuming. Not only do they confer no particular adaptive advantage, they seem to be clearly maladaptive in diverting attention and memory resources from valuable goals. However, note that OCD and other disorders of the frontostriatal circuitry (Tourette's syndrome, ADHD, and schizophrenia) all have some genetic basis, as may be suspected from their prevalence (Bradshaw & Sheppard 2000) and is tentatively confirmed by gene-loci studies (Arnold et al. 2004; Grados et al. 2003).

To the extent that a specific kind of motivation is involved in the pathology of ritualization (perhaps also in its normal occurrence), it makes sense to wonder why and how humans are endowed with this special focus on particular kinds of hazards. In particular, are such systems the outcome of the evolutionary history of the species? In this case *ultimate* explanations would help us make sense of the pathology (Nesse 1998), a strategy used in physiology (Nesse & Williams 1996), psychiatry (Baron-Cohen 1997; Cosmides & Tooby 1999; Stevens & Price 2000) and neuropsychology (Duchaine et al. 2001; Gazzaniga & Miller 2000), and, as mentioned earlier, already outlined in some studies of OCD (Abed & de Pauw 1998).

Providing an evolutionary model requires the following steps: (1) Identify the relevant fitness-related problem; (2) identify the knowledge base and computational rules that would be minimally required to solve that problem

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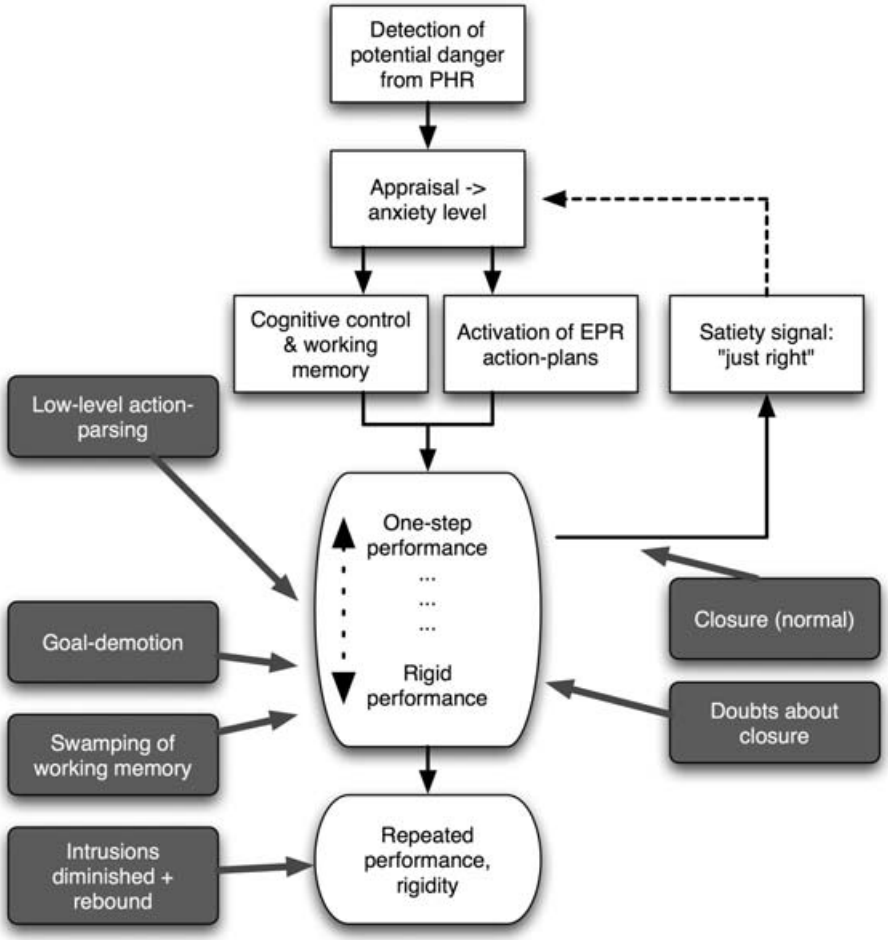

Figure 3 (Boyer & Liénard). Summary of our Potential Hazard and Precaution model. Boxes denote specific processes with corresponding neural systems. Rounded box describes performance. Dark call-outs describe some of their typical properties. Clues for danger must suggest hazards from the Potential Hazard Repertoire. Appraisal of the clues if modulated by anxiety, leading to activation of plans from Evolutionary Precaution Repertoire and action-monitoring systems. At the normal end of the spectrum, performance triggers satiety feelings with a negative feedback to danger appraisal systems. At the pathological end of the spectrum, doubts about proper performance lead to repetition and a positive feedback to danger appraisal.

in ancestral environments; and (3) provide experimental evidence for the actual operation of a mental system that meets this computational specification. Once this is accomplished, such a model may allow us to delineate possible pathogenic scenarios, causally deeper than the vague clusters identified in DSM-IV (Murphy & Stich 2000).

There are some indications that this approach may be appropriate for anxiety disorders and OCD in particular. First, negative emotions like anxiety or persistent low mood should not be considered as dysfunctional. They may consist in evolved warning systems whose negative rewards steer organisms away from fitness-reducing situations (Nesse 1998). Second, the specific thoughts and actions that compose the symptoms may be linked to evolutionary concerns (Leckman 2003; Mataix-Cols et al. 2005). Third, some of the conditions associated with fronto-striatal impairment may actually result in adaptive phenotypes (Bradshaw & Sheppard 2000).

5.2. Two types of fitness-threats

We know enough of early primate and early human living conditions to identify broad categories of highly salient danger in our evolutionary past: reproductive risk (e.g., for females, mating with un-nurturing or low-fitness males; for males, cuckoldry or choosing unhealthy females); predation (failing to detect or deter predators); contamination from pathogens (bacteria, viruses, toxins); resource scarcity (e.g., failing to anticipate seasonal changes); social harm (e.g., ostracism, but also reduced cooperation).

From an evolutionary standpoint, we should expect (1) that such recurrent hazards, not more recent ones, would be the target of specific emotions, and (2) that different kinds of hazard require different decision rules. On the first point, it is clear that specific emotions target hazards of great evolutionary ancestry rather than more recent ones, even though the latter may be much more dangerous. Our danger-avoidance systems do not seem to rely on an unprejudiced tabulation of which features of the environment effectively predict harm or misfortune. If this were the case, we would observe in modern conditions many cases of anxieties, fear, or even phobic aversions to electricity, cars, and cigarettes, which cause vastly more deaths than do spiders and rats. But we observe the opposite. Second, it seems that different kinds of fitness-threats do activate different inferential

rules. Specific principles inform the gender-specific perception of particular mates as more or less of a waste of reproductive potential (Buss 1989). Predator-prey interaction is governed by early-developed intuitions that do not apply to other interactions (Barrett 1999). Recurrent features of disgust reactions suggest a pathogen-minimizing system that adapts to local conditions (Fessler et al. 2003; Rozin et al. 1993) or to particular individual circumstances such as pregnancy (Fessler & Navarrete 2003a; Profet 1993). Problems of resource scarcity are handled by specific foraging strategies (Krebs & Inman 1994) which can override explicit reasoning (Rode et al. 1999). Finally, a host of "social intelligence" principles support the monitoring of social interaction, from the establishment of friendships and coalitions (Harcourt & de Waal 1992; Kurzban et al. 2001; Tooby & Cosmides 1996), to dominance (Sidanius & Pratto 1999) and punishment (Boyd & Richerson 1992; Kurzban & Leary 2001).

At this point we must introduce an important distinction between two types of fitness-threatening situations. First, there are cases of *manifest* threats, cases in which the organism receives signals about the presence of the source of danger: for example, a predator or enemy attack, or seeing one's infant in danger. Situations of this type are handled by specialized and context-specific fear-mechanisms in humans as in other primates (LeDoux 2003; Maren & Quirk 2004) and result in aggression, freezing, or flight routines (Blair 2001; Payne 1998). Second, there are *inferred* threats, when the potential danger is probable given certain clues in the environment. For instance, the strange taste of a particular dish may be evidence of rotting; tracks may betray the recent passage of a dangerous predator; a particular person's attitude may indicate that they will not cooperate. Such circumstances typically engage what Abed and de Pauw called an "Involuntary Risk Scenario Generation." Naturally, the distinction is a rough one (many situations involve threats for which there are direct and indirect clues). It is also, obviously, species-specific since some situations are a threat to some organisms but not others.

5.3. Potential danger as a specific domain

It may seem odd to hypothesize a domain-specific system whose activation is triggered by such disparate potential inputs as a footprint, a disgusting odor, or the fact that one's infant is out of sight for a moment. How specific is the system if it can encompass such physically different stimuli? But this objection assumes that domain-specific inference systems are tied to a physically specified range of stimuli, which is true for some perceptual systems (e.g., 3D vision) but certainly not for most higher-level functional systems. A human mind can parse linguistic input in just the same way on the basis of auditory, visual, or tactile information. Neuro-cognitive systems specialized in assessing the value of potential mates use information from conversations, from comparison of visual information to some ideal template, from observed interactions between the potential mate and other people, and so forth. Indeed, it would be surprising (and maladaptive) if a particular kind of physical input always triggered a unique inference-system. A man is a man is a man, but a father, a brother, an attacker, and a potential mate should activate different mental systems.

So the autonomy or specificity of a domain-specific system can be inferred, not from focus on a physically specific range of cues, but from specific processing principles, a specific kind of output, a specific learning logic, and – in some cases – a specific pattern of impairment. These are criteria that seem present in the case of the Hazard-Precaution system.

There is indeed some behavioral evidence that humans have specific inference rules for information relative to precautions. Fiddick and colleagues have demonstrated that when considering precautionary rules (e.g., "if you take oranges on board you will not get scurvy"), subjects pass logical tests for verification of rule-violation that they fail in other contexts (Fiddick et al. 2000). This is a replication, in another domain, of the performance on rule-verification in the Wason selection task observed when the rules allude to social contracts, however unfamiliar, as opposed to other deontic domains, however familiar (Cosmides 1989; Fiddick et al. 2000). Although these findings concern explicit judgment more than intuition, they suggest that potential hazard management might require cognitive processing that is quite different from other inferential tasks.

5.4. The limited range of obsessions and compulsions

To explain the recurrent features of both intrusions and compulsions, our model stipulates two kinds of databases, called Potential Hazard Repertoire and Precaution Repertoire respectively. Intrusions and compulsions have to do with a specific, narrow range of hazards, which, in our view, are best explained as recurrent threats to fitness in ancestral environments.

One reason for defending this hypothesis is that the actions combined in ritual sequences are generally (i) species-specific and (ii) precaution-related. Ritualists do not generally design entirely novel behavioral sequences from scratch. Rather, they combine familiar elements of actions (e.g., washing, cleansing, checking) into novel sequences. This is also manifest in animal models of the condition. The ritualistic behaviors triggered in rats treated with quinpirole (a dopamine agonist) are species-specific, consisting in checking with return to a home-base, similar to those of controls, but stylized, redundant, and time-consuming (Szechtman et al. 1998). Second, these actions are generally relevant ones as a protection against various kinds of fitness-threatening situations (Rapoport & Fiske 1998). A review of the different dimensions of OCD obsessions but also adult normal intrusions and children's anxieties should illustrate the point.

5.4.1. Contamination. Thoughts about contamination and contagion are too specific to be interpreted as the outcome of a general lowering of the anxiety threshold. They tend to center on invisible agents such as toxins, viruses, and microbes – of obvious evolutionary import. Besides, people's anxious thoughts about contamination focus on modes of contact (touching with the hand, kissing, licking, having sex, sharing food, breathing next to a particular source) that are actually used by pathogen vectors. In patients, the compulsions associated with these thoughts are not arbitrary either. They center on measures such as washing and cleansing, protecting oneself from intrusive material by staying at a distance,

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avoiding contact, suspending breathing. In ancestral environments, before the discovery of asepsis, these procedures would indeed constitute the only measures to reduce or control contamination.

There is behavioral and cross-cultural evidence that a concern with possible contamination triggers specialized inferential circuitry in humans. For instance, Fessler and colleagues have documented the disproportionate representation of meat among the foods that are "good to taboo" in many cultures. They connect this to the specific challenges of meat consumption caused by protozoa and other pathogens (Fessler & Navarrete 2003b). In the same way, meat seems to be the chief target of early-pregnancy aversions, a period of dangerous immunodepression (Fessler 2002). More generally, many sources of disgust are also sources of contamination: decaying corpses but also rotting substances, faeces, spit, and so on.

5.4.2. Symmetry and order in one's environment. Many children and adults are concerned with creating an orderly environment. Children align toys in a particular order, ritual participants need to create elaborately ordered displays, and the same is true of many OCD "checkers." These behaviors are often construed, especially in the domain of children's rituals, as the expression of a need for reassurance; as the urge to create a recognizable and therefore reassuring environment.

However, this "therefore" is question-begging. What is reassuring about a predictable environment? True, predictability implies a reduction in computational load, but that cannot be the reason, as children and ritualists in general devote great amounts of time and cognitive resources creating their orderly world. So there might be other aspects of order and symmetry that motivate cognitive investment. In our view, ordered environments combine two properties that may explain this motivation.

First, alignments and symmetry are such that they make other agents' intrusions clearly visible. Anecdotal (but massive) evidence suggests that children but also various sub-clinical obsessive personality-types get quite upset when "intruders" such as parents or cleaners disrupt their sequences and alignments. We speculate that the point of the ordering may be precisely to detect such disruptions. Or rather, that the behavior may be a stored action-plan that would have this function in other environments. This is indeed the one explanation of some animals' "tidying up" routines as an anti-predator strategy (Curio 1993). So the creation of a non-trivial order that is not immediately detectable by intruders may be a powerful motivation in such compulsions. Note that childhood rituals center on the *home* environment and in particular on children's own *personal* space (usually their bedroom).

Second, the specific use of symmetry and conceptual order (alternating colors, corresponding shapes) is diagnostic of uniquely human dispositions to alter the environment. Bowerbirds may be among the few exceptions – and seem to resort to similar ways of making a display salient: pure colors, symmetry, and so on. Indeed, people readily detect such specific alterations – which has been used for millennia as a way of advertising human presence. Cairns are improbable pilings of rocks that no species other than human beings would build. Broken twigs, straight paths, and color markings serve as landmarks for the same reason. What makes this possible is the combination of sophisticated symmetry and pattern-detection capacities in humans (Bornstein & Krinsky 1985; Bornstein & Stiles-Davis 1984; Fisher et al. 1981) and sophisticated tool-making capacities (Wynn 1993). This is particularly relevant to children's construction of ordered environments, which may consist of a period of systematic training in the construction of such signals of human presence.

These are bound to remain speculative as there is, to our knowledge, no systematic research on the cognitive and emotional processes involved in ordered displays, particularly in children's strong motivation to produce such environments.

5.4.3. Social offence. Some of the intrusive thoughts of obsessive people center on possible acts that would offend or harm other people, resulting in social exclusion. These fears also represent, in our view, a domain of evolutionary hazard. Given human dependence on conspecifics for all aspects of survival, it is not surprising to find that possible social strife is seen as extremely dangerous. Life in complex societies makes this dependence diffuse and impersonal. By contrast, in ancestral environments people depended on known members of the group. Conflict in such groups threatens each member's access to resources, cooperation, and information (Tooby & DeVore 1987). In this domain too, it seems that the precautionary measures taken by obsessives are in fact rather appropriate. For instance, one of the features of OCD patients (especially checkers) is a tendency to monitor actions, in particular the minutiae of one's own behavior, well beyond the "normal" limits. Another common feature is that people choose to avoid social contact lest they insult or assault others, which again is intuitively appropriate as a precautionary device.

5.4.4. Harm to offspring. Intrusive thoughts reported by adults often focus on possible harm to one's own offspring, accompanied by fears of handling tools and utensils in a dangerous way, smothering or dropping the infant, as well as forgetting about the baby and losing it (particularly in stores and other public places). Again, the danger is one of obvious evolutionary significance, as tools and weapons are part of our ancestral past. Also, shifting attention away from one's infant is risky but unavoidable in humans who need to attend to such tasks as foraging or processing food. Again, the compulsive precautions (hyper vigilance, neglect towards other people and social interactions, etc.) would seem appropriate given these hazards.

5.5. The Precaution System associates domain-specific repertoires

Specific reactions to inferred threats suggest a functional system that we called the Precaution System, whose specific input consists in inferences to non-manifest threat and whose output is selective activation of particular precautions. At both ends of its operation, the postulated system is highly specific. The Precaution System does not respond to all or most *actually significant* signals of potential danger, but to a limited repertoire of cues. As we said above, humans seem to infer fitness threats, with a specific anxiogenic response, from wounds or rotting carcasses, but not from tobacco smoke or electricity.

The range of action-plans activated is also restricted to a few possible precautions (washing, avoiding contact, etc.) that may or may not be most appropriate given changing circumstances. Note that this model does not account for some sub-varieties of OCD symptomatology. Hoarding, for instance, does not seem to result in ritualized behavior in the precise sense described here. This may be because the underlying processes are different from other OCD dimensions, as is suggested by neuroimaging studies (Calamari et al. 2004; Saxena et al. 2004). In our model, the specificity of cues and responses maps a set of highly recurrent threats in human evolutionary history.

6. Why the complicated action?

6.1. Ordinary action-parsing

The ritualization process imposes particular constraints on the performance and sequencing of action. This is why the features of ritual should be considered in the context of action representation in general. Human beings attend to each other's behavior and react to it, which means that they must "parse" other people's and their own behavior in meaningful units (Newtson 1973). The experimental study of such parsing mechanisms provides a background against which we can understand specific features of ritual.

People identify actions as belonging to particular categories (e.g., putting on one's socks) but also as part of larger sequences (putting on one's socks as part of getting dressed). This "partonomic" structure is general to action sequences in normal contexts. Small units are parts of larger units and the boundaries between large units tend to coincide with a boundary at a lower level. Zacks and colleagues distinguish between three levels of representation: that of simple *gestures* (sequences of a few seconds), that of *behavioral episodes* (an order of longer magnitude, actions like "getting dressed"), and that of a *script* (series that can span a much longer time, e.g., "eating out," "giving a talk") (Zacks & Tversky 2001; Zacks et al. 2001b).

In the absence of specific instructions to the contrary, people spontaneously describe and recall behavior in terms of middle-level behavioral units (Zacks & Tversky 2001; Zacks et al. 2001b), that could be called a "basic level" for event-taxonomies (Rifkin 1985). Indeed, people can generate far more categories of events at that middle-level than either super- or subordinates (Morris & Murphy 1990). Mid-level breakpoints also correspond to specific neural activity (Speer et al. 2003; Zacks et al. 2001a). It is certainly not a coincidence that this is also the level of description at which people typically ascribe *goals* to behavior. While gestures do not readily reveal intention, and scenes include many different intentions, behavioral episodes typically constitute the realization of a particular goal. Action-parsing develops early in infants and seems to focus on the intentional unit level from that early stage (Baldwin & Baird 1999; Baldwin et al. 2001).

6.2. Goal-demotion in ritualized action

These studies converge to suggest that spontaneous parsing focuses on middle-level action-units connected to specific goals. It is very difficult for normal humans *not* to parse action at that level. Indeed, an excessive focus on a low-level, gestural description of behavior, with the attendant imprecision about goals, is characteristic of frontal lobe or schizophrenic patients (Janata & Grafton 2003; Zalla et al. 2003).

Now this focus on low-level gesture analysis of the action-flow is precisely what happens in cultural and individual rituals. People's attention is typically drawn to the details of performance, the particular direction of a gesture, the specific number of times an action should be performed, and so on. Conversely, the description of ritual action in terms of goals is either not available or in any case irrelevant.

This is what we call "goal-demotion." Although there may be a goal for the overall ritual script, there are no obvious sub-goals for its components. In typical patients' rituals or in developmental rituals, there may be an explicit goal. For instance, producing a particular alignment of twigs in a particular order is supposed to ward off intruders; or a sequence of familiar actions, for example, tying one's shoes in a very specific way, will prevent accidents. But the contribution of each part of the script is *not* connected to particular sub-goals. For some ritual actions it is impossible for the actor to imagine what contribution they would make as they reverse the results achieved through previous actions (e.g., piling up objects and carefully putting them back in a line before piling them up again). More generally, the actions are considered an indispensable part of the script although the subject has no representation of why he or she should be included in it. This contrasts with the standard parsing of action-flow, where the units identified at all levels of partonomic division correspond to specific goals. Indeed, in a typical example of routinized efficient practice, that of blacksmithing techniques, the correspondance between action-units and goals serves to mobilize different units of knowledge as they become relevant to the sub-task at hand (Keller & Keller 1996). This is emphatically not the case in ritualized behavior, the performance of which seems to be a "tunnel" in which each action only points to the following one in the prescribed sequence (Bloch 1974).

6.3. Swamping of working memory

There is very little study of the attentional effects of the focus on low-level features of action, combined with high control and hypersensitivity to possible mistakes, during performance of personal rituals. Our model suggests a specific, temporary effect on working memory which would explain some effects of rituals. Working memory is a specific memory system that holds information for a short time and allows updates and transformations of that information (Baddeley 2000). In typical working memory tasks subjects are asked to repeat a sequence of letters in the right order, repeat in inverse order, repeat the sequence formed by letters while ignoring digits provided in between, or specify which was the third letter before last in a series that ends unexpectedly. In all such tasks, the subject must consider a certain set of information units or chunks at the same time in order to perform the required operations (Baddeley 2000).

In our view, one of the effects of prescribed, rigidly compulsory action-sequences is a momentary overloading or "swamping" of working memory, especially if the action

sequences are represented at the fine-grain parsing level. This is very much what happens to some patients whose spontaneous action-parsing remains at this same low level of description. As Zalla puts it in her description of frontal lobe patients, "the weakening of the causal connections between the component actions leads to the decomposition and the fragmentation of the action representation. [. . .] The increased amount of fragmented information rapidly overloads subjects' working memory capacity" (Zalla et al. 2004). A similar point can be made about fragmentation of action in OCD compulsions (Ursu et al. 2003).

Many ritual prescriptions resemble the tasks designed by cognitive psychologists in the study of working memory. They require focused attention on a set of different stimuli and their arrangement. For instance, a requirement to turn round a ritual pole three times clockwise without ever looking down imposes executive control of two tasks at the same time. Also, the frequent combination of a positive prescription ("do *x*. . .") and a negative one ("...while avoiding doing *y*") would seem to engage working memory and executive control in a way that is not usually present in everyday action flow.

6.4. Core ritualization is the opposite of routinization

In the model proposed here, ritualized acts are very different from other routines. However often an individual may perform a ritualized action, it does not seem to become automatic. On the contrary, it remains constrained by high-level cognitive control. Ritualized actions as described here require high cognitive control because the rules often apply to familiar actions (e.g., walking, talking, preparing food) and turn them into more difficult tasks (e.g., walking *without* treading on the line). This clashes with a commonsense notion that rituals only include actions that one performs "routinely" or "without thinking." Indeed, it is essential to our model that the component of rituals that we called Ritualized Behavior cannot be automatic.

7. Implications of the model: Individual ritual

7.1. Intrusions as context-sensitive adaptive algorithms

A surprising conclusion from the very few systematic studies of intrusions and mild compulsions in the normal population is that thoughts about potential dangers (contamination, social harm) and some compulsive reactions are not confined to the clinical population. Most normal people seem to experience the same kind of intrusive thoughts as patients do, and to some degree generate the same ritualized action-plans to avoid such dangers (Abramowitz et al. 2003; Rachman & de Silva 1978). The crucial difference, then, is not in the contents of the thoughts but in their appraisal (Salkovskis 1985).

The evidence available is insufficient to address the fundamental questions of the distribution, themes, intensity, and effects of intrusions in the normal population. Our model implies that intrusions are generally not dysfunctional. They are the outcome of systems geared to protecting the organism against potential dangers by over-interpreting specific inputs, which would suggest this prediction:

[P1] The position of an individual along fitness-related life-cycle dimensions (young vs. old, male vs. female, nulliparous vs. multiparous, high vs. low status) should predict the frequency, intensity and contents of intrusive thoughts.

So far, we only know that contagion and risk intrusions become highly salient during the perinatal period (Abramowitz et al. 2003; Leckman et al. 2004). This may also be true of other stages in the life-cycle, such as puberty, menarche, and the death of relatives. There is simply no general, population-sample study of thought-intrusions and their correlates. Sampling bias is particularly likely in this domain. Perinatal intrusions get noticed only because pregnancy is a period of higher medical monitoring.

7.2. Spontaneous optimization and relief

Why the strange rules and prescriptions in compulsive action? Also, why should such performances induce temporary relief? Many patients explicitly associate their rituals with specific obsessions, stating that performing the ritual is one way of inhibiting or repressing the unwanted thoughts (Salkovskis 1985). Clinicians' observations and patients' reports converge in suggesting that the relief from unbearable anxiety, though temporary, is palpable. But there is nothing in current cognitive models to explain the fact.

In our view these two questions are related, and the common answer lies in the effects of ritualization on cognitive control and working memory. We suggested earlier that the performance of rituals, accompanied by numerous, specific, attention-demanding prescriptions, has the effect of "swamping" working memory. We propose that such rituals constitute spontaneous and moderately efficient forms of *thought-suppression*. The difficulties of thought suppression in everyday life (trying not to recall unpleasant experiences or not to mull over possible future misfortunes) are familiar to everyone. Dan Wegner and colleagues have studied the phenomenon in controlled environments and demonstrated the complex control processes at work in such attempts (Wegner & Erskine 2003; Wegner & Schneider 2003). One interesting feature of these experimental studies is that only a few techniques are available to effectively "push away" unwanted thoughts. They include focusing on emotional information of greater intensity than the target thoughts, or focusing attention on intrinsically difficult tasks like mathematical problems. These are difficult precisely because they recruit working memory to a greater extent than most everyday tasks and cannot be accomplished automatically.

Obviously, compulsive rituals are in many ways different from the phenomena observed in such studies. First, Wegner's subjects generally have no intrinsic motivation to avoid the suppressed thoughts, other than compliance with the experimenter's instructions. By contrast, OCD patients are strongly motivated. Second, the intrusions in patients are far stronger (more difficult to push away from consciousness) than a simple neutral theme suggested by an experimenter. Third, patients have a history of thought-intrusion and thought-avoidance, whereas experimental subjects are genuine beginners in the domain.

Notwithstanding these differences, we think the studies on thought-suppression are important to suggest a possible mechanism for the elaboration and rigidity of ritual prescriptions. In our view, patients with complicated compulsions have spontaneously attained an optimal point in the kind of activity that is so demanding in cognitive control that intrusive thoughts can be, at least for a while, pushed away from consciousness.

This "trick" exploits certain features of the action-parsing systems reviewed (see sect. 6.1). Given that action-parsing processes are engaged when *any* behavior is witnessed or produced, there are not many tricks that could force attention to focus on the low-level description of action. Among these features is repetition, which results in goal-demotion. Another such gimmick, obviously, is to borrow a sequence from ordinary scripts and perform it in a context that makes goal-ascription impossible: for example, wash objects without using water, pretend to trace an imaginary line, and so on. What results from these "tricks" is what we called "goal-demotion" above. Actions are represented without attaching a goal to each behavioral unit, as would be the case in non-ritual contexts.

This has several implications for the organization of compulsive rituals:

[P2] Compulsive actions should be such that they mobilize working memory and require high degree of cognitive control.

We have suggested that this is precisely what complicated prescriptions achieve, in particular when they result in control of usually automatic actions, such as choosing which shoe to tie first, or whether to push the doorbell button with this or that finger.

[P3] Compulsive rituals may be the outcome of a trial-and-error process.

This means that patients more or less deliberately (usually not) try various behaviors with various prescriptive rules until they reach an optimum, that is, the maximal occupation of working memory that is compatible with the intrinsic limits of memory itself. This would carry another consequence:

[P4] The symptoms should become unstable if the actions become routinized.

Working memory is effectively swamped when usually automatic actions are submitted to cognitive control. But even demanding tasks (e.g., tying one's shoes in a particular order that changes with the time of the day) might become partly automatic with time. One would predict that this would result in diminished efficacy and the spontaneous search for different prescriptions, or for more complex sequences. Naturally, this dynamic model does not imply that patients are at any point aware of the effect of prescriptive rules on memory. They may simply come to associate slightly more controlled action to slightly diminished intrusion, which would be enough gradually to lead to the baroque complications of individual rituals. We do not have much comparative clinical evidence concerning the particular contents of obsessive-compulsive rituals, that is, the number of actions, their precise description, their prescribed order, and so on, as opposed to general descriptions such as "washing" or "checking." Nor do we have much in terms of longitudinal studies of ritual elaboration or progression; which is why these remain speculative predictions from the model.

7.3. Ironic outcomes

Studying normal subjects instructed *not* to think about a particular item, Wegner showed that thought suppression typically results in a "rebound" – in higher salience of the unwanted thoughts (Wegner & Schneider 2003). This, in Wegner's model, is caused by the combination of two distinct processes engaged in thought suppression. While an explicit process directs and monitors the suppression, implicit processes are engaged that detect material associated with the target item (Wegner & Erskine 2003). Here again, we do not wish to read too much in the parallel between an experimental paradigm and a long-lasting behavior pattern. However, an ironic outcome would seem to follow from the working-memory swamping scenario:

[P5] The precise intrusions that rituals can tone down should become more frequent or more difficult to resist as rituals are frequently practiced.

Although it has not been studied in precise quantitative terms, this ironic rebound does seem characteristic of compulsive rituals (Rachman & de Silva 1978). The patients who perform more rituals are typically more anxious, and also more bothered by their intrusive thoughts. In other words, the long-term effects of ritual performance are the opposite of its short-term results. Indeed, this may be why an effective cognitive and behavioral therapy for OCD, in particular exposure and reaction prevention (ERP), requires that the patient evoke the dangerous thoughts but restrain the compulsive response (Rachman et al. 1971).

7.4. Developmental calibration

Our model implies specific claims about the Hazard-Precaution system in children, suggesting that early childhood is a period of *calibration* of the system. Many cognitive systems require calibration, that is, a change in parameters as a function of specific information picked up in the child's environment (Bjorklund & Pellegrini 2002). A salient example is the development of food-preferences in young children, with a period of unlimited tolerance followed by "parameter-setting" when young children reject anything that does not taste familiar (Birch 1990). Another domain would be predator-prey relations, in which common assumptions are gradually refined in view of local circumstances (Barrett 2005).

We can make a similar point about the Potential Hazard Repertoire. As we said, the system should handle indirect clues and produce inferences about the potential presence of dangerous substances, predators, and conspecifics. But it immediately appears that the number of possible clues is multiplied by the fact that (a) any one of these dangerous situations could be detected using a large number of possible clues and (b) the situations themselves must have changed a great deal, and changed frequently, during human evolution. Indeed, modern humans have adapted to variable conditions of subsistence in primary forests, grasslands, and dry savannas. They also had to adapt to seasonal changes. Most important, cultural evolution led to rapid cultural change, or "life in the fast lane" (Boyd & Richerson 1995). Ecological and cultural change means that old predators are gone but new ones are present; that noxious substances are not found in

the same plants or animals; and that social interaction is handled in significantly different ways.

In this way the security system is a *learning system*, that appears in infants as a disposition to pick up particular kinds of locally relevant information from the natural and social environment, and changes its parameters as a function of that information. This would explain not just why children perform ritualistic behaviors, but also why the phenomenon appears and subsides at particular stages of development and why its typical manifestations evolve from prepotent fears for which there is clear preparedness, to more complex inferred threats like social harm. The system is designed to address a specific question: How to create a secure environment and to provide a series of contextually relevant solutions like washing, cleaning, checking, or modifying one's interaction with other agents? This implies particular directions for development in the kinds of thoughts and compulsions found in childhood. If the system is in calibration during that period, we should observe the following:

[P6] Anxiogenic thoughts should become gradually more specific with development.

[P7] Compulsive reaction should become more specific with development.

In terms of anxiety, a fear of vaguely defined predators animals should become a fear of particular animals, a fear of strangers should become a fear of particular strangers, and so forth, as the system picks up information from the environment. This applies to compulsions, too. At an early stage, all recipes should be equiprobable. At a later stage, children should acquire locally relevant associations between a particular potential danger and a particular recipe. This also predicts differences in the rituals of older children from different groups. To the extent that different cultural groups live in different conditions, different kinds of dangers would be relevant and different clues significant:

[P8] Fears and compulsions should become more culturally specific as children get older.

We already have some fragmentary evidence that developmental trends in children's fears support these predictions. Fantasies and intrusive thoughts change with development, as mentioned earlier (Evans et al. 1999; Leonard et al. 1990).

7.5. Cultural similarities and differences in pathological ritual

Our model assumes that there is a Precaution system focused on certain kinds of potential danger. We also suggested that this system undergoes calibration during childhood, given that clues about potential danger change with changing environments. This would imply specific predictions about cross-cultural variations in the condition:

[P9] Anxieties and fears that result in compulsion belong to the narrow range of ancestral potential dangers: contamination, intrusion, social offence, and resource-depletion.

[P10] We should observe important cultural differences in the relative prevalence of symptom clusters (or "subtypes").

There is very scant comparative anthropological evidence for anxieties or fears, although it seems to suggest something of this kind. In industrialized countries, the notion of electricity and cars as massive killers is virtually absent from the repertoire of phobic and obsessive patients. Also, the few studies of OCD patients in non-Western environments report the familiar obsessive themes of social offence, contagion, and potential danger (Abdel-Khalek & Lester 1998; Arrindell et al. 2002; Barker-Collo 2003; Bertschy & Ahyi 1991; Sasson et al. 1997) and the prevalence of OCD *as a general category* is the same in different places (Weissman et al. 1994).

Cultural differences too are suggestive, although there are to date very few (reliable) comparative studies of the condition and most of them only bear on clinical populations (so we have no evidence of what intrusive thoughts are common or exceptional in the population at large). For instance, a study from Bali documents a culture-specific tweaking of the general OCD themes. The patient needs to identify all passers-by in terms of genealogy and status, and reports obsessions about spirits and witches (Lemelson 2003). Both are culturally specific variants of the social harm and social exposure obsessions, as hierarchy and status are fundamental to social interaction in Balinese society and social strife is expressed through witchcraft accusations (Barth, 1993). In Muslim countries, by contrast, many patients report concerns about pollution and contamination strongly influenced by religious prescriptions on hygiene and purity of thought (Al-Issa 2000; Mahgoub & Abdel-Hafeiz 1991; Okasha et al. 1994). A sample of Bahrain patients showed that the fear of blasphemy was prevalent (about 40% of cases), which may be a local expression of the fear of social harm and potential exclusion (Shooka et al. 1998).

This would suggest that an important calibrating factor is the range of cultural messages emphasizing potential danger. In particular, further epidemiological studies of the various dimensions of OCD (contagion, social offence, checking) may be correlated to the intensity of precautionary messages available in the environment of development. While Islam includes many descriptions of possibly impure actions or thoughts, Western children are bombarded with insistent warnings about invisible germs. Whether this results in significantly different normal and pathological intrusions is simply not documented yet.

8. Implications of the model: Cultural ritual as derivative

So far, we have not mentioned one of the most salient and socially important manifestations of ritualized behaviors, namely, collective, culturally sanctioned rituals. We consider that the model presented so far can help us understand why rituals are widespread the world over and why they are compelling – an argument summarized here and presented elsewhere in more ethnographic detail (Liénard & Boyer 2006).

8.1. A capacity for ritual?

We start from the work of Fiske and colleagues. Comparing hundreds of ritual sequences with clinical descriptions of OCD cases, they showed that the same themes recur over and over again in both domains (Dulaney & Fiske 1994; Fiske & Haslam 1997). OCD-typical features that also enter into rituals include specific (lucky or unlucky)

numbers, use of special colors, repetition of actions, measures to prevent harm, ordering and symmetry, stylized verbal expressions, washing, concern with contagion, and so forth (Fiske & Haslam 1997).

Fiske and colleagues speculate that there may be a human capacity to perform cultural rituals, that is distorted or hyperactive in pathological individual ritual (Fiske & Haslam 1997). In Fiske's model, rituals are used to channel individual anxiogenic thoughts and make them bearable by providing a broader cultural context in which they can be shared and make better sense. Fiske and Haslam did not pursue the psychological and cultural implications of this hypothesis. It would provide a simple and elegant way of explaining the similarities in themes and actions between pathological and cultural ritual. Moreover, it would do so by connecting both to evolved, species-specific anxiogenic situations.

However, we consider that cultural rituals may be better explained in a different way, as partly parasitic on the Hazard-detection and Precaution systems described above. Our main reason for preferring this account is that it is more parsimonious. There is no empirical evidence that humans do have a *specific* capacity for ritual. There are no evolutionary grounds to consider that such a specific capacity would be adaptive (see our discussion of rituals as possible adaptation in section 9.1.) So this is a costly hypothesis. By contrast, we have seen that there is solid evidence for systems specialized in responses to potential hazard. So if the disposition to perform cultural rituals is a by-product of these systems, we do not need to posit additional mechanisms.

8.2. The cultural selection background

The first assumption in our treatment is that cultural rituals, like other forms of cultural behaviors, should be treated as the outcome of cultural selection (Boyd & Richerson 1985; Durham 1991; Sperber 1994). Representations that we call "cultural" occur with roughly the same content in other minds among people of a particular group. Indefinitely many factors (local or universal, psychological as well as physical) can in principle contribute to the spread of a particular mental representation. One type of factor of great interest to us is the set of general human dispositions that make certain representations, once they are expressed or conveyed by some people, particularly attention-grabbing or memorable or compelling, leading to their cultural transmission (Sperber 1985).

We observe that people seem compelled to perform particular ceremonies at particular junctures, and also that they seem compelled to perform them in (what they judge to be) the prescribed way. This is what we need to explain. Now, one way to explain this would be to posit that there must be a particular *urge* to perform such ceremonies, or that they may fulfill particular needs of the human mind or of human groups. However, there may be another kind of explanation, based on the fact that people who receive information about particular performances already have sets of mental systems designed to respond to particular classes of stimuli. The question becomes: What mental systems would be activated, such that performing *this* ceremony in *these* circumstances would seem compelling?

8.3. Cultural information, mimicry, and cognitive capture

Cognitive systems can be functionally described in terms of their particular *input format*, their *operating principles*, and their *output*. The input formats of cognitive systems are, in some cases, well known. For instance, the auditory stream provides information about pitch and location, which is then routed to different systems (Kaas et al. 1999; Romanski et al. 1999). The pitch information is divided into linguistic input and non-linguistic input, transmitted to different parts of the auditory cortex (Liegeois-Chauvel et al. 1999). At each step, the transfer from one system to the other depends on the signals' format. This extends to higher cognitive systems.

The range of stimuli or internally generated information that meets the input format of a system is its *domain*. Now it is important to distinguish between an *evolutionary* or *proper* domain of stimuli and an *actual* domain (Sperber 1996). The proper domain includes those objects or situations that played a causal role in giving the particular system a selective advantage. The actual domain includes all objects or situations that trigger activation of the system. In most evolved cognitive systems, the actual domain is larger than the proper domain, giving rise to false alarms. The frog snaps at any small objects whizzing by in its visual field, not just to actual edible insects.

Any system of this kind is vulnerable to *capture* and *mimicry*. The terms describe situations in which the system reacts to an input that matches its input format, is part of its actual domain, yet is not among the classes of stimuli that the system was designed to process, its proper domain. We reserve the term "mimicry" for the situations in which a particular behavior or physical trait in an organism gains adaptive value by entering the actual domain of another organism's cognitive system. This is what happens in familiar cases, like that of Viceroy butterflies adopting the genuine poison-warning garb of Monarchs without having to manufacture the poison.

A different situation is what we call "cognitive capture." Consider a familiar example. Most visual art in humans (from tattooing to painting to architecture) seems strongly biased towards vertically symmetrical displays, while other symmetries are less salient. Vertical symmetry detection capacity appears in infancy (Bornstein & Krinsky 1985; Fisher et al. 1981), influences pattern recognition in childhood (Bornstein & Stiles-Davis 1984; Mendelson & Lee 1981), and has evolved for purposes other than the appreciation of aesthetic displays, most probably for detecting facing predators and healthy mates (Thornhill 1998). Music too is a good example, as it "hijacks" certain parts of the auditory cortex and provides auditory super-stimuli (Jerison 2000). Narratives about imagined persons can be, as we say, "captivating" because they capture our capacities for mind-reading and the explanation of behavior.

This is not mimicry since in the cases mentioned here the organism's Type I error does not benefit another organism. The important point about cognitive capture is that a great deal of human culture is acquired and transmitted because of this inevitable propensity of cognitive systems to "fire" beyond their proper functional range. Most items of "culture" in the sense of group-specific sets of norms and concepts depend for their transmission on cognitive capture of this kind (Sperber 1996).

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8.4. Core ritualization in cultural rituals

To understand the cognitive effects of collective rituals, we must describe the kinds of information available to the participants. At first sight, it would seem that most people who participate in most rituals do not have much information at all. People do not generally hold a "theory" of their own rituals – this is what makes ethnography indispensable and difficult.

However, this is not to say that people participate in a ritual on the basis of mere imitation, peering at their cultural elders and simply performing similar gestures. This would be implausible, given that very little human cultural transmission actually involves such mindless imitation (Sperber 2000). In this particular case, some behavior activates some mental templates in the mind of observers, and triggers non-random inferences about what is accomplished by the behavior. This, we contend, may be sufficient to explain the cultural success of Ritualized Behavior.

To make comparisons simpler, we follow in our description the outline of action ritualization processes described earlier. The individual reaction to a particular cultural ritual can be functionally described as consisting in the following elements:

1. People receive specific information about the ritual:
   a. They are told that a ritual should be performed and are led to infer that non-performance is a dangerous option. For instance, one is told that because of a particular event (someone's illness, a death or a birth, the change of seasons, a war with another group, possible damnation), it is necessary to go through a particular ritual sequence.
   b. People also receive information and produce inferences about the kind of danger against which the ritual is supposed to protect the group, for example, "pollution" by invisible substances, attacks by invisible predators like witches or spirits, threat of disease, possible famine, social strife, and so on. These themes substantially overlap with the Potential Hazard Repertoire.
2. This triggers a (dampened) activation of Hazard-Precaution system.
3. People are instructed to participate in the ritual in particular ways. That is, people are generally not allowed to just add to their ritual whatever action they think fit. They are enjoined, more or less explicitly, to follow a particular script. Information about the script has the following properties:
   a. Action descriptions include themes that mimic some of the typical outputs of the Hazard-Precaution system: actions such as cleansing, washing, checking.
   b. Descriptions of prior conditions, particular taboos, substances to avoid, et cetera, reinforce activation of security motivation system.
   c. There is great emphasis on the details of each action, inducing low-level parsing of the action flow during performance, especially because of negative prescriptions.
   d. Description induces goal-demotion, by insisting on repetition, redundancy, apparently pointless acts, and so forth.
4. Performance enacted in these conditions temporarily swamps working memory because of the attentional demands of the tasks.
5. Performance ironically strengthens the salience of particular themes associated with gestures or situations to avoid during ritual.

These various elements and their putative causal relations are outlined in Figure 4. In the next sections we present some evidence for these various claims and for the psychological and cultural effects of the processes.

8.5. Cognitive capture in cultural rituals

Our model suggests that ritualized actions are culturally successful to the extent that they activate information-processing and motivation systems made manifest in other domains of ritualization. In this sense, cultural rituals result in *cognitive capture* of the systems described so far, and this is why they can seem attention-demanding and compelling to participants.

Many features of collective rituals activate the Hazard-Precaution system by including cues for potential dangers of the Evolutionary Potential Hazard Repertoire. First, occasions for ritual often allude to clues of possible danger that overlap with the Potential Hazard Repertoire: for example, threats to fitness such as famine or illness, invisible germs or miasma, dangerous invisible pollution present in newborn infants, dead bodies and menstruating women (Bloch & Parry 1982; Metcalf & Huntington 1991). Second, details of prescribed performance also include many security-related motifs. As we said previously, many collective rituals include such operations as washing and cleaning, checking and re-checking that a particular state of affairs really obtains, as well as creating a symmetrical or otherwise orderly environment (Dulaney & Fiske 1994; Fiske & Haslam 1997), so we will not comment on this any further.

In our model, precaution systems are activated to the extent that particular themes (e.g., "this village must be purified") and prescribed actions (e.g., "wash hands three times in this particular river") trigger activation of evolved Precaution systems. This, however, does not entail that the ritual as a whole should be explicitly and exclusively about these themes. Indeed, there are many ceremonies in which prescribed behavior is only weakly related to these themes, while other themes (e.g., procreation, social exchange, hierarchy) are at the forefront of people's attention. Our claim is only that the *ritualization* itself is derived from the operation of Precaution and action-parsing systems.

8.6. Ceremonies, ritualized action, and routinization

This model, in our view, provides at least elements towards an explanation of why ceremonies that include ritualized actions are found in most human groups and are generally stable within traditions. The model also has some implications that make it diverge from received anthropological usage and common intuitions about ritual.

Ritualized actions are not "rituals." Ritualized actions as described here are only a subset of what people actually do in what are called "rituals." For instance, a ceremony may include a typical example of what we described earlier, such as, a prescription to turn around a cow three times clockwise while avoiding to stare above the horizon and making sure to touch the cow with one's thumb only.

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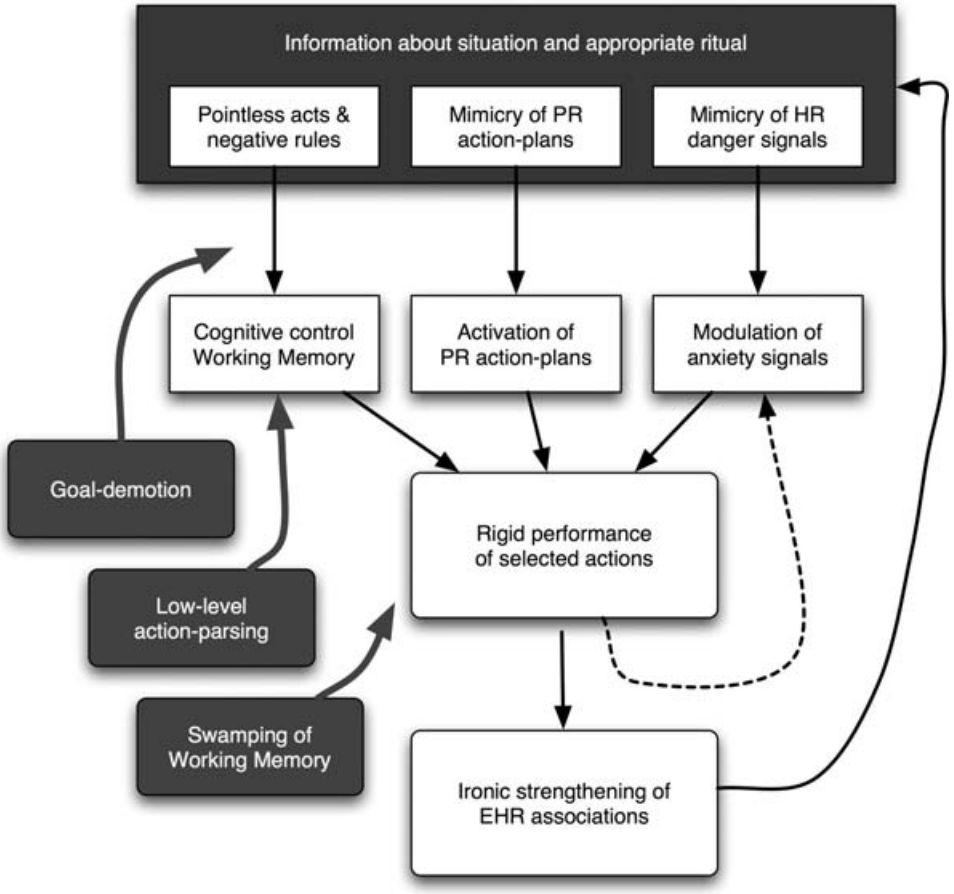

Figure 4 (Boyer & Liénard). A simplified model of action ritualization in cultural rituals. Boxes identity different functional systems in the same way as in Figure 3. Participants in rituals are provided with two kinds of information, (a) statements about potential danger and (b) scripted recipes for ritual action, that activate the security-motivation systems. Rules for ritual performance result in both goal-demotion and low-level action-parsing with the resulting swamping of working memory. These processes result in highly attention-demanding and compelling performance of rigidly scripted actions. This in turn makes the associations more salient, which should make subsequent messages about ritual more intuitively compelling.

But the circumambulation of the cow may be an element of a larger ceremony that also includes singing, dancing, feasting, and all sorts of other behaviors that are not precisely scripted in the sense described here. In other words, ritualized behaviors are certainly not the whole of "rituals."

Ritualization is not routinization. The model has the slightly counter-intuitive implication, that ritualized action is described as quite different from routinized behavior, indeed as its opposite. In most ceremonies we expect to find an alternation between phases of ritualized action (high control, attentional focus, explicit emphasis on proper performance) and routinized action (possible automaticity, low attentional demands, lesser emphasis on proper performance).

Cultural ritual is not individual ritual writ large. We said that cultural ritualized actions are "derivative" and it is important to stress that they are a by-product of the Precaution systems and the action-parsing systems, *not* of individual ritualized behavior. Given the similarities between individual and cultural forms of ritual, it is of course tempting to take one as a scaled version of the other, as Freud suggested (Freud 1928). But this is clearly misguided. First, to maintain the parallel, cultural rituals would need to be behaviors that social groups initiate because they perceive certain potential dangers. But groups as a whole do not literally behave or perceive, only their members do. Also, cultural rituals differ from individual ones in the way the information about compelling action is acquired – from other agents and from personal intuition, respectively. Most importantly, what compels performance is entirely different in the two situations. While individual ritualists (especially patients) may feel great anxiety at the prospect of not going through the ritual sequence, participants in a cultural ritual are likely to participate (among other reasons) to the extent that the particular sequence meets a minimal threshold of relevance. The idea of "scaling" would also predict all sorts of interesting phenomena that are simply not observed; for example, that people who become more religious would tend to become more obsessive, or that OCD patients would tend to be more religious than controls, that children during early childhood should be more interested in religious ritual than at other stages of development, and so on. Although there are connections between certain forms of religious practice and obsessionality (Fallon et al. 1990; Hermesh et al. 2003), they fail to support these general conjectures.

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9. Conclusions

9.1. Ritualization and cognitive adaptations

Our models of individual and cultural ritualization take as a starting point a specific connection between obsessive pathology and security motivation (Mataix-Cols et al. 2005; Szechtman & Woody 2004) but also a more general set of assumptions about the adaptive character of specialized neuro-cognitive function (Cosmides & Tooby 1999; Duchaine et al. 2001). We have assumed that the Hazard-Precaution system was the outcome of selective pressure for gradually finer-grained inferential detection of and appropriate response to recurrent hazards in ancestral environments. This naturally leads to the question, whether action-ritualization might constitute a cognitive adaptation, in the same way as other domain-specific capacities do (Cosmides & Tooby 1994). The question should be more specific and bear on either individual or cultural rituals, since the cognitive processes involved are so different.

Let us consider cultural rituals first. In the anthropological literature, there are various hypothetical models of the ways in which participation in collective ceremonial may have conferred adaptive advantage to individuals (Burkert 1996; Knight et al. 1998; Rappaport 1999; Sosis 2000; Watanabe & Smuts 1999). This stems from a long anthropological tradition of construing ritual as crucial to social organization and cohesion (Durkheim 1947; Hocart & Needham 1970; Smith 1889). We discuss the various hypotheses in more detail elsewhere (Liénard & Boyer 2006). Suffice it to say that these different models may well explain a disposition to participate in coordinated social action, but not why these common endeavors should include scripted, goal-demoted, redundant scripting of familiar actions.

The question of individual ritualization is more complex. In our model, the activation of the Precaution system normally results in performance of appropriate actions from the Precaution Repertoire – and this, in most circumstances, should produce enough of a closure or satiety experience (Szechtman & Woody 2004) to preclude reiteration. However, the closure experience probably is the outcome of continuous changes in the relevant circuitry, leading to various degrees of repetitiveness and anxiety about proper performance. So, in our model, it is not the ritualized behavior but the Precaution system itself that constitutes a cognitive-motivational adaptation. It has the hallmarks of such adaptations, such as a specific class of inputs, a specific mode of operation, a particular series of fitness-enhancing consequences, a non-trivial functional design – and, in this particular case, a specific neural implementation as well as specific impairment.

9.2. Phylogeny: Rituals and displays

What is the connection between human and other animal "ritual"? We use scare quotes here, as the term is stretched to encompass highly disparate forms of behaviors (Gluckman 1975). Nevertheless, one should comment on the obvious similarities between human rituals and various forms of animal communication, notably in the context of agonistic and sexual displays where stylized behavior, repetition, and redundancy are clearly present. Is this evidence for the deep phylogenetic ancestry of ritual? In our view, this question suffers from several ambiguities:

First, although we may sometimes follow a "same effects, same causes" rule of thumb, this is rather misguided if it leads us to confuse observable behaviors with the neuro-cognitive systems that support them (Povinelli et al. 2000). Indeed, even in the limited domain of human rituals, apparently similar behaviors (in patients and in cultural ritual participants) actually stem from very different cognitive processes. This should *a fortiori* be expected when comparing widely different species.

Second, the question downplays the extent to which certain features of behavior are constrained. Consider OCD patients for instance. They are not motivated by a positive urge to ritualize. Rather, ritualized behavior happens to constitute an optimal response to the anxiety produced by cognitive impairment. Other forms of behavior would not seem appropriate given the anxious concerns; they would not produce temporary relief. So the redundancy, et cetera, in this case stems from the properties of action-parsing and precaution systems in humans. Now consider animal displays. They are strongly constrained too, in this case by the logic of signaling processes. For instance, signals must be clear and distinct enough to preclude ambiguities, which typically results in redundancy (Rowe 1999). The evolution of attentive receivers requires that signals maintain a relatively high level of accuracy (Bradbury & Vehrencamp 2000; Silk et al. 2000) and that the content of the signals be directly related to the fitness dimensions they advertise (Zahavi & Zahavi 1997). In other words, in both human rituals and animal displays, features like stylization, redundancy, and repetition are the outcome of external constraints, but these seem to be different in the two cases.

This would support the tentative conclusion that the presence of "ritual" in both cases is a case of behavioral analogy rather than the index of similar capacity and processes. (Obviously, this is not to deny that humans like other animals do engage in stereotypical displays, in situations of courtship or aggression). This is tentative in the sense that we do not know much about the phylogenetic history of ritualization (in the precise sense used here) in the hominin line. The evidence so far simply does not support the notion of a direct evolutionary homology.

9.3. Epilogue

It is a cognitive and evolutionary puzzle that humans perform rituals, given the waste of time and resources involved. We aimed to solve the puzzle by piecing together the evidence from neuroimaging, neuropsychology, clinical psychology, developmental studies, and evolutionary anthropology. Ritualization may be seen as an occasional by-product of specific precaution systems and action-parsing capacities in humans.

This explanation however compels us to discard the common intuition that there is a natural kind of phenomena called "rituals." If valid, our model does not explain "rituals" but a highly specific form of behavior that is found in many of them and occurs *for different reasons* in the behavior of most normal children and obsessive patients, on the one hand, and in the context of collective rituals, on the other.

Discarding misleading categories of behavior (like "ritual" – but there are many others) may well be the inevitable consequence and benefit of proposing *integrated* explanations. Our model is an attempt to bring together neural systems, evolutionary background, behavioral manifestations, and developmental trajectory to the understanding of action-ritualization. We consider this indispensable. True, much work remains to be done to understand the phenomenon. For instance, the cognition of children's ritual is still largely unexplored; the connections between ritual performance and anxiety relief in patients need a proper neurophysiological study; the persuasive power of cultural rituals is not properly explained. But we are confident that all these and other puzzles will be solved by the kind of "general behavioral science" that transcends fields and discipline boundaries.

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Open Peer Commentary

Why ritual works: A rejection of the by-product hypothesis

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Abstract: We argue that ritual is not a by-product as Boyer & Lienard (B&L) claim, but rather an evolved adaptation for social communication that facilitates non-agonistic social interactions among non-kin. We review the neurophysiological effects of ritual and propose neural structures and networks beyond the cortical-striato-pallidal-thalamic circuit (CSPT) likely to be implicated in ritual. The adaptationist approach to ritual offers a more parsimonious model for understanding these effects as well as the findings B&L present.

Why humans engage in "irrational," costly rituals is a perplexing evolutionary question. Boyer & Lienard's (B&L's) attempt to answer this question through the integration of evolutionary, neuropsychological, and neuroimaging evidence is an important first step in understanding both the proximate and causal mechanisms of ritual. Their inclusion of childhood, life cycle, and pathological rituals focuses attention on significant developmental, ecological, and population elements of ritual heretofore ignored. Moreover, their consideration of underlying neurophysiological components offers insights into specific neural pathways implicated in ritual behaviors. These elements are significant advances in the evolutionary study of ritual. Unfortunately, the model developed from this promising foundation fails to fulfill the potential of their approach. Most significantly, the authors' conclusion that "ritualization may be seen as an occasional by-product of specific precaution systems and action-parsing capacities in humans" (target article, sect. 9.3) does not adequately explain the data presented throughout their discussion or advance our understanding of why ritual occurs so ubiquitously and frequently across species. We argue that a more compelling approach views ritual as behavior evolved for social communication that optimizes appraisal and learning, and facilitates non-agonistic social interactions among non-kin.

Laboratory experiments have shown that the core elements of ritual, that is, formality, pattern, sequence, and repetition, heighten and focus attention, promote associational learning, and enhance long-term memory (Rowe 1999). As noted by B&L, ritualized behaviors are neither routine, nor automatic, but instead require "high cognitive control." B&L argue that such control results in the "swamping" of working memory which permits the temporary suppression of intrusive thoughts. They claim, however, that ritual performed on a long-term basis has the "ironic outcome" (sect. 7.3) of actually strengthening such thoughts. In contrast, we view this effect of ritual to be a functional adaptation rather than an "ironic outcome." Neuroimaging studies have shown that tasks of sustained attention or vigilance increase activation of right hemisphere prefrontal and superior parietal cortices (Pardo et al. 1991). Increased right hemisphere activation has several important consequences: it promotes social-emotional information processing (Tranel et al. 2002); it forefronts negative appraisal systems (Cacioppo et al. 2002); and, it elicits holistic, gestalt thinking. Recent research has also shown that the right posterior association cortex is particularly important in the processing of new information, as well as in anticipating consequences and determining emergency reactions (Schutz 2005). Ritual's ability to engage these various right hemispheric functions, and its promotion of associational learning and strengthening of long-term memory would be particularly important in relation to complex social decisions involving unrelated and potentially dangerous conspecifics. It is precisely under such circumstances that ritual occurs in humans and nonhumans alike. In addition to right hemispheric dominance effects, the core elements of ritual are also likely to activate neural structures and pathways specific to the brain's vigilance and reward systems.

B&L review neuroimaging evidence regarding the cortico-striatal circuits implicated in obsessive-compulsive disorder (OCD) ritualization. Although they propose a specialized "Precaution/Hazard" brain module, their discussion of neurophysiological pathways stops short of incorporating mesolimbic and corticolimbic vigilance and reward networks associated with the cortical-striato-pallidal-thalamic circuit (CSPT) (Cardinal et al. 2002; Dehaene & Changeux 2000). These pathways encompass limbic structures, such as the amygdala, which are critical for evaluating stimuli in relation to both physical and social threat (Adolphs 2002; Dolan 2000). They also include structures fundamental to the brain's reward system, such as the nucleus accumbens. While the amygdala has been shown to be critical for social judgments of trust (Adolphs 2002; Morris et al. 1998), recent neuroimaging studies show that the nucleus accumbens and other reward system structures are activated during episodes of mutual cooperation (Rilling et al. 2002). Both the amygdala and the nucleus accumbens are critical components in motivational pathways for approach/avoidance (Cardinal et al. 2002; Dehaene & Changeux 2000). These structures also provide evaluative input to the orbitofrontal cortex that is critical for both social judgment and effective personal decision-making (Dehaene & Changeux 2000; Schoenbaum et al. 2003). The dopaminergic corticostriatal associational networks that encompass orbitofrontal, limbic, and basal ganglia structures undergo a developmental shift during adolescence (Spear 2000). As we have discussed elsewhere (Alcorta & Sosis 2005), these pathways constitute likely neural networks for learning and emotionally valencing both the signals and symbols of ritual. These pathways encompass the neurophysiological counterpart of the "Precaution/Hazard" brain module proposed by B&L. In sharp contrast