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The Cognitive-Evolutionary Model of Surprise: A Review of the Evidence

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Final Version:

Date: July 16, 2017

Words (without references): 9645

Abstract

Research on surprise relevant to the cognitive-evolutionary model of surprise proposed by Meyer, Reisenzein, and Schützwohl (1997) is reviewed. The majority of the assumptions of the model are found empirically supported. Surprise is evoked by unexpected (schema-discrepant) events, whereas the novelty and the valence of the eliciting events probably do not have an independent effect. Unexpected events cause an automatic interruption of mental processing that is followed by attentional shift and attentional binding to the events, which is often followed by causal and other event analysis processes and by schema revision. The facial expression of surprise postulated by evolutionary emotion psychologists has been found to occur rarely in surprise, for as yet unknown reasons. A physiological orienting response marked by skin conductance increase, heart rate deceleration and pupil dilation has been observed to regularly occur in the standard version of the repetition-change paradigm of surprise induction, but the specificity of these reactions as indicators of surprise is controversial. There is indirect evidence for the assumption that the feeling of surprise consists of the direct awareness of the schema-discrepancy signal, but this feeling, or at least the self-report of surprise, is also influenced by experienced interference. In contrast, facial feedback probably does contribute substantially to the feeling of surprise and the evidence that surprise is affected by the difficulty of explaining an unexpected event is, in our view, inconclusive. Regardless of how the surprise feeling is constituted, there is evidence that it has both motivational and informational effects. Finally, the prediction failure implied by unexpected events sometimes evokes a negative feeling, but there is as yet no convincing evidence that this is always the case, and we argue that even if it were so, this would not be a sufficient reason for regarding this feeling as a component, rather than as an effect of surprise.

The Cognitive-Evolutionary Model of Surprise: A Review of the Evidence

As is true for much psychological research, the study of surprise deals with a phenomenon that is familiar from everyday experience and implicit common-sense psychology (e.g., Bartsch & Estes, 1997; Heider, 1958) and that has attracted the interest of thinkers long before the advent of academic psychology. First descriptions of surprise as a mental and behavioral phenomenon, as well as first attempts at theory-building, date to Aristotle (about 350 B.C.). Among the first to discuss surprise in modern times were the empiricist philosophers Hume (1739) and Smith (1795). Their ideas were taken up and elaborated further after psychology had established itself as an independent discipline in the second half of the 19th century, by theorists such as Darwin (1872), Ribot (1896), Wundt (1906), McDougall (1908) and Shand (1914). As can be verified by perusing the table of contents of an early review of surprise research by Desai (1939), by 1920 most of the questions about surprise that can be asked from a noncomputational perspective had already been formulated, and even first experimental studies had been conducted. During the behaviorist era of psychology (about 1920-1960), research on surprise abated again; however, it was immediately taken up again after the cognitive revolution of the early 1960s. At that time, aspects of surprise first came to be discussed again under the headings of “orienting reaction” (Sokolov, 1963) and “curiosity and exploration” (Berlyne, 1960). Surprise as a phenomenon in its own right was first discussed anew by evolutionary emotion theorists Tomkins (1962) and Izard (1971). Referring back to Darwin (1872), these authors proposed that surprise is a basic emotion that serves essential biological functions. One of these functions—surprise as an instigator of epistemic (specifically causal) search and a condition for learning and cognitive development—came to be particularly emphasized by developmental psychologists (Charlesworth, 1969). In the 1980s, this suggestion was taken up by social psychologists interested in everyday causal explanations, who proposed that unexpectedness is a main instigator of spontaneous causal search (e.g., Pyszczynski & Greenberg, 1987; Weiner, 1985a). At about the same time, cognitive psychologists (e.g., Kahneman & Tversky, 1982; Rumelhart, 1984), including cognitively-oriented emotion theorists (e.g., Meyer, 1988; Ortony, & Partridge, 1987) became interested in surprise. Since then, research on surprise has steadily increased. Today, it is carried out by researchers in several subfields of psychology, as well as in neighboring fields such as artificial intelligence (see Macedo, Cardoso, Reisenzein, Lorini, & Castelfranchi, 2009) and neuroscience (e.g., Preuschoff, 't Hart, & Einhäuser, 2011). Readers looking for research on surprise should note that part of the relevant literature is listed under different headings, such as: spontaneous attention, orienting, novelty, expectations, prediction error, coincidences, belief-updating, Bayesian inference, schema-revision, emotions, humor, facial expression, metacognitive experiences, curiosity, spontaneous attributional search, sense-making, and others.

In this article, we present a review of theoretical and empirical research on surprise, focusing on data and hypotheses relevant to a cognitive-evolutionary model of surprise proposed by Meyer et al. (1997; see also Meyer, 1988; Reisenzein, Meyer, & Niepel, 2012).

A Cognitive-Evolutionary Model of Surprise

The cognitive-evolutionary model of surprise resulted from the attempt to integrate and elaborate the modal views of previous surprise theorists (see above) and attributional analyses of reactions to unexpected events (e.g., Pyszczynski & Greenberg, 1987) within the framework of schema theory (Rumelhart, 1984; Schank, 1986).

The starting point of the cognitive-evolutionary model is the basic assumption of schema theorists that human perception, thought and action are to a large extent controlled by complex, organized knowledge (or better, belief) structures, called schemas. Schemas can be regarded as cognitive representations of humans' informal, unarticulated theories about objects, events, event sequences (including actions and their consequences) and situations.

Schemas serve the interpretation of present and past, and the prediction of future events, and thereby, the adaptive guidance of action. To be able to fulfill these functions, a person's schemas or informal theories about the world must be at least approximately correct. This in turn requires—because knowledge of the environment is usually incomplete, and because the environment can change—that schemas are continuously monitored for their compatibility with newly acquired information and, if necessary, are updated.

According to the cognitive-evolutionary model, the surprise mechanism plays a crucial role in this context. As conceptualized in the model, the surprise mechanism is an innate, hardwired information-processing device that operates at an unconscious level of processing, where it continuously and automatically (without the person's intention) compares the currently activated cognitive schemas (beliefs)—which together constitute the person's working-memory model of her present situation and its future development—with newly acquired information (perceptions, beliefs). As long as the schema-discrepancy detector registers congruence between schema and input, meaning that the newly acquired information (beliefs) conforms to the person's explicit or implicit expectations, the person's informal theories are supported by the evidence, and there is hence no need to revise them. In contrast, if the surprise mechanism detects a discrepancy between the activated schemas and the newly acquired information—indicating that these schemas may be invalid and can therefore no longer be relied on to guide action—it generates a sensation-like, nonpropositional signal (see Oatley & Johnson-Laird, 1987) whose quality codes the detection of a schema-discrepancy, and its intensity, the degree of the schema-discrepancy. This signal is regarded as the theoretical referent of surprise in the cognitive-evolutionary theory (Reisenzein et al., 2012).

It is assumed that, if the schema-discrepancy signal exceeds a certain threshold, then ongoing information processing is automatically (unintentionally) and inevitably interrupted, central resources are reallocated to (i. e., attention is shifted to) the unexpected event, and the unexpectedness signal becomes conscious as a feeling with a characteristic phenomenal quality and intensity: the feeling of surprise. These processes—interruption, attentional shift, the occurrence of the feeling of surprise—serve to enable and instigate effortful processes of event analysis plus, if this analysis suggests so, immediate reactions to the unexpected event and/or an updating of the beliefs or schemas that gave rise to the schema discrepancy. In more detail, it is assumed that the interruption of processing and the subsequent shift of attention to the unexpected event *enable and prepare* the ensuing event analysis (by freeing cognitive resources and reallocating these to the unexpected event), whereas the feeling of surprise serves to *communicate* the occurrence of the schema-discrepancy system-wide (see Oatley & Johnson-Laird, 1987) and to provide a *motivational impetus* for the analysis of the unexpected event, by eliciting curiosity about is nature and causes. However, as is true for all goal-directed actions, the intensity and duration of the event analysis also depends on other factors, in particular the estimated costs and benefits of information search, the difficulty of the event analysis and the available time (Stiensmeier-Pelster, Martini, & Reisenzein, 1995; see also, Pyszczynski & Greenberg, 1987; Foster & Keane, 2015). Depending on the results of the event analysis, the background schema that gave rise to the schema-discrepancy can be more or less extensively updated. In particular, the schema may be changed to include a sub-schema for the unexpected event that stores its properties as well as the results of the event analysis (e.g., information about the causes of the unexpected event or about its action relevance). As a consequence, the analysis of subsequent instances of the same or similar kinds of events can be substantially abbreviated.

Finally, it is assumed that, like the described mental processes, the observable behaviors that sometimes occur in episodes of surprise (e.g., a reorientation of the sense organs to the source of surprise, verbal requests for information, eyebrow-raising), subserve, for the most part, the overarching evolutionary function of the surprise mechanism. In summary form, this function can be described as follows: (1) to *detect schema-discrepancies* and, once they have been detected (2) to *enable and motivate the short-and long-term adaptation to them*.

In the remainder of this article, we present a summary of theoretical and empirical research relevant to the cognitive-evolutionary model of surprise. Specifically, we review (1) data that support basic assumptions of the model; (2) hypotheses or findings that help to refine or elaborate the model; and finally, (3) hypotheses or data that challenge certain assumptions of the model. Readers should note that in our review, we use the self-report of surprise as the central indicator of surprise, for three reasons. First, many authors, following common-sense, identify surprise with the subjective experience of surprise; and this experience is most directly assessed by self-report. Second, even if surprise is not straightforwardly identified with the feeling of surprise, but—these are the two main alternatives—with a probabilistic syndrome of mental (and possibly also behavioral) reactions (cf. Reisenzein, 2000b), or with a theoretical mental state that causes these reactions (as done in the cognitive-evolutionary model, where surprise is identified with the signal produced by the schema-discrepancy detector), the self-report of surprise is currently still the most unambiguous and sensitive indicator of the presence and intensity of that syndrome or theoretical state (see the section *The effects of surprise*). Third—be it for the reasons mentioned or simply out of convenience—in many of the reviewed studies only self-reports of surprise have been collected.

The Cognitive Cause of Surprise

According to the cognitive-evolutionary theory of surprise (1) the cognitive process responsible for surprise about an event is exclusively the appraisal of the event as schema-discrepant or unexpected; that is, as conflicting with—explicit or implicit—expectations or beliefs; and (2) the intensity of surprise increases monotonically with the degree of schema-discrepancy or unexpectedness (cf. Macedo et al., 2009; Meyer, 1988). These assumptions agree with the implicit theory of surprise contained in common-sense psychology (see e.g., Smedslund, 1990), as well as with most traditional and contemporary scientific theories of surprise (Reisenzein, 2000a; see also, Barto, Mirolli, & Baldassarre, 2013). In fact, in most empirical surprise research, these assumptions are taken for granted, in that they constitute the (if sometimes implicit) theoretical basis of the methods used to induce surprise. So strong is the perceived link between unexpectedness and surprise that several theories of surprise, including the cognitive-evolutionary model, *identify* surprise with the appraisal of unexpectedness (e.g., Ortony, Clore, & Collins, 1988; see Macedo et al., 2009) or with the signal generated by the schema-discrepancy detector (Reisenzein et al., 2012; note, however, that the unexpectedness signal can still be regarded as the cause of the surprise *feeling*). Nevertheless, these assumptions about the cognitive cause and the nature of surprise have not gone unchallenged. In this section and in the later section on the experience of surprise, we will therefore also consider several proposed alternatives. To simplify the discussion, we will continue to speak of unexpectedness as the cognitive cause of surprise.

Specifically, three at least partial alternatives to the unexpectedness hypothesis have been advanced: (1) surprise is evoked by attributions to luck rather than by unexpectedness (Weiner, 1985b); (2) surprise is elicited by the detection of novelty instead of, or at least in addition to, unexpectedness; and (3) surprise is influenced by the valence of unexpected events in addition to their unexpectedness. The first of these hypotheses has however been empirically refuted (Gendolla, 1997; Stiensmeier-Pelster et al., 1995) and was subsequently abandoned by its author; it will therefore not be considered further.

Unexpectedness as the Cognitive Cause of Surprise

Qualitative version of the unexpectedness-surprise hypothesis. The assumption that surprise is elicited by unexpected events (which are meant to cover both events that disconfirm explicitly held expectations and those that contradict implicit beliefs; see Macedo et al., 2009; Reisenzein et al., 2012) is a central component of the implicit common-sense theory of surprise. For this reason, at least this qualitative version of the unexpectedness-surprise hypothesis could be regarded as not being in need of empirical verification (cf. Smedslund, 1990). Indeed, in most empirical studies on surprise, this assumption has not been at issue, but served as an unquestioned background assumption that formed the basis of the surprise-induction methods used.

In the majority of laboratory experiments on surprise, expectations were first induced and then disconfirmed. The *repetition-change paradigm* has been used most often for this purpose. In this paradigm, which exists in many variants, participants are first exposed to a series of homogenous baseline (or "habituation") trials that serve to establish, typically but not exclusively (e.g., Horstmann & Schützwohl, 1998; Niepel, 2001) through incidental learning, a schema or set of expectations about the kind, the properties and the temporal sequence of the stimuli that occur in the experiment. In the subsequent "surprise trial", one or more of these expectations are disconfirmed by changing one or more properties of the stimuli presented in the baseline trials or by presenting an entirely novel stimulus. This method has been shown to reliably induce surprise of at least moderate intensity in the great majority of the participants, as indexed both by self-reports and by indirect behavioral indicators of surprise (discussed later), for a wide variety of unexpected stimulus changes. These include a color change of a simple visual stimulus (e.g., Meyer, Niepel, Rudolph, & Schützwohl, 1991), the change of the voice of a speaker from male to female (Niepel, Rudolph, Schützwohl, & Meyer, 1994), the appearance of the participant's own, secretly photographed face as the last picture in a face-judgment task (Reisenzein, Bördgen, Holtbernd, & Matz, 2006, Exp. 6 & 7), the violation of a rule concerning the temporal sequence of the stimuli, previously induced via a rule-learning task (Horstmann & Schützwohl, 1998; Reisenzein et al., 2006, Exp. 3) and the nonoccurrence of an announced stimulus change (Niepel, 2001). Manipulation checks included in several repetition-change experiments confirmed that the stimulus changes staged in the surprise trials were not only experienced as surprising, but were also perceived as unexpected by the participants. In contrast, no surprise is reported if the stimulus changes are fully expected because they already occurred in the habituation trials (e.g., Meyer et al., 1991; Schützwohl, 1998).

Outside the repetition-change paradigm, surprise has been successfully induced, for example, by arranging for unexpected success at a difficult task (Stiensmeier-Pelster, Martini, & Reisenzein, 1995, Exp. 3), by presenting unexpected solutions to quiz items (Reisenzein, 2000b), by presenting unexpected lottery outcomes (e.g., Juergensen, Weaver, Burns, Knutson, Butler, & Demaree, 2014; Reisenzein & Macedo, 2006) and by exposing the participants to a novel, strange room when they exited the door of the laboratory (Schützwohl & Reisenzein, 2012).

Semi-quantitative version of the unexpectedness-surprise hypothesis. The second, semi-quantitative hypothesis about the relation between unexpectedness and surprise mentioned above—surprise intensity increases monotonically with the degree of unexpectedness or schema-discrepancy—has also been supported in numerous studies, both correlational and experimental. For example, Stiensmeier-Pelster et al. (1995, Exp. 1) obtained an interindividual correlation of .65 between the judged unexpectedness of remembered academic successes and self-rated surprise about them, and a correlation of .73 for remembered failures; and Reisenzein (2000b) obtained an average intraindividual correlation of .78 between the degree of surprise caused by solutions to quiz items and the degree of unexpectedness of the solutions, inferred from prior ratings of certainty about the chosen answers.

These correlational findings are substantiated by studies in which the degree of schema-discrepancy was experimentally manipulated. In the repetition-change paradigm, this has been done by varying the number of regular trials preceding the surprise trial (e.g. Schützwohl, 1998, Exp. 1 & 4), the number of schema-discrepant components of the surprise stimulus (Reisenzein et al., 2006, Exp. 1) or the variability of the stimulus pattern presented in the baseline trials (Schützwohl, 1998, Exp. 3); by giving the participants different amounts of verbal information about an upcoming stimulus change (Niepel, 2001; Reisenzein & Ritter, 2000, Exp. 2; Schützwohl & Reisenzein, 1999, Exp. 3); and by repeating the stimulus change (e.g., Meyer et al., 1997; Niepel, 2001; Reisenzein et al., 2006, Exp. 1 & 4). These manipulations of the degree of unexpectedness were, with few exceptions (e.g., Schützwohl, 1998, Exp. 1), found to increase or decrease the intensity of experienced surprise, as well as reaction time delay on parallel tasks, in predicted ways. Outside the repetition change-paradigm, experimental manipulations of the communicated probability, and hence unexpectedness, of lottery wins and losses have been shown to cause parallel changes in the intensity of self-rated surprise about the outcomes (Brandstätter, Kühberger, & Schneider 2002, Exp. 2; Juergensen et al., 2014; Reisenzein & Macedo, 2006).

Quantitative surprise models. Moving beyond common-sense, several attempts have been made to refine the hypothesis of a monotonic relation between unexpectedness and surprise into a quantitative model of surprise intensity. The starting point of all these models is to interpret the strength of expectations or beliefs as subjective probability, an assumption that is well compatible with the schema-theoretic model of surprise (see e.g., Horstmann & Schützwohl, 1998). On this interpretation, the schema-discrepancy detector compares the schema-based subjective probability of an event with its perception- or inference-based probability after new information relevant to the event has been obtained; in most studies, this information leads to certainty that the event has occurred (Reisenzein, 2009b).

The simplest quantitative surprise model assumes that the intensity of surprise about an event A, S(A), is proportional to its improbability 1-P(A), where $P(A) \in [0, 1]$ is the subjective probability of A (e.g., Mellers, Schwartz, Ho, & Ritov, 1997; Macedo & Cardoso, 2001). This model fits many surprise situations very well, such as surprise about quiz solutions (Reisenzein, 2000b) or about the outcomes of binary lotteries (e.g., Juergensen et al., 2014; Reisenzein & Macedo, 2006). Theoretical considerations (Reisenzein, 2009b) suggest that this model should fit situations where the outcome space is cognitively represented as comprising only two incompatible outcomes {A, B}, where B implies not-A.

However, if more than two outcomes are possible and explicitly considered by the person, the situation becomes more complicated. Macedo, Reisenzein, and Cardoso (2004; see also, Macedo & Cardoso, 2012; 2017) proposed that at least in some of these situations, the intensity of surprise is also influenced by the subjective probability of the most probable alternative outcome M (the outcome that is typically actively expected to occur). A very similar "contrast model" of surprise was proposed before by Teigen and Keren (2003), who also reported supportive results from several studies. Macedo et al. (2004) quantified the contrast model by proposing that S(A) is a nonlinear (specifically, a logarithmic) function of the difference between the subjective probability P(M) of the most likely outcome and the probability P(A) of the actual outcome; or more precisely, that $S(A) = \log_2 (1+P(M) - P(A))$. This model was found to fit surprise ratings in several kinds of multiple-outcome scenarios reasonably well.

The third approach to the computation of surprise intensity from belief strength assumes that the intensity of surprise about an event A is a function of the difference between the distribution of the subjective probabilities across the possible outcomes {A, B, ...} prior to the acquisition of new information (evidence, E) relevant for A, and after the Bayesian updating of the distribution (see e.g., Darwiche, 2009) following the acquisition of the evidence (Itti & Baldi, 2009; Storck, Hochreiter, & Schmidhuber, 1995). Itti and Baldi (2009) applied this "Bayesian" model of surprise to the detection of changes in the visual system, and found that it predicts attention (gaze shifts) of observers watching videos. Although the Bayesian surprise model has to our knowledge not been evaluated for ratings of experienced surprise, this would be an interesting task for future research. For the time being, we would like to point out (1) that, in our view, the three probability-based surprise models can be regarded as different quantitative specifications of the schema-discrepancy theory of surprise, and (2) that the improbability model and the contrast model can be construed as special, restricted versions of the Bayesian model. Specifically, these models result from the Bayesian model if three assumptions are made (Reisenzein, 2009a):

- Only the probabilities of the actual outcome A and its complement not-A (improbability model), or of A and the most probable alternative outcome M (contrast model) are considered.
- The newly acquired information relevant for A leads to certainty about A, i.e. the posterior P(A) = 1 (as mentioned, this is typically the case in surprise experiments) and hence, the posterior P(not-A) and P(M) = 0. To achieve this "maximal" updating, one needs to assume that P(E|A) = 1 and hence P(E|not-A) and P(E|M) = 0, for then Bayesian updating (conditionalization) gives the desired posteriors. The prior probabilities that enter the computation of surprise intensity are thus (P(A), P(not-A)) for the improbability model and (P(A), P(M)) for the contrast model, and the corresponding posterior probabilities are (1, 0).
- The function used by Itti and Baldi (2009) to measure the difference between the prior and posterior distributions, the Kullback-Leibler divergence, is replaced by a simpler

distance function, either the mean of the absolute differences between the prior and posterior probabilities (improbability model) or the binary logarithm of the sum of the absolute differences (contrast model). This results in $S(A) = [|1-P(A)| + |0-(1-P(A))|]/2 = 1-P(A)$ for the improbability model and in $S(A) = \log_2(|1-P(A)| + |0-P(M)|) = \log_2(1+P(M)-P(A))$ for the contrast model.[1]

Apart from situations where an unexpected event disconfirms a single belief (e.g., the person expects to see a red square, but a green square is presented instead), a comprehensive quantitative model of surprise also needs to consider situations where the unexpected event disconfirms several beliefs; either simultaneously, or sequentially (Macedo et al., 2009). For example, if instead of the expected red square, a yellow circle is presented in the surprise trial, then the two part-expectations contained in the expectation "a red square will be shown"—the expectations "a red object will be shown" and "a square object will be shown"—are simultaneously disconfirmed. In addition, an unexpected event A often disconfirms not only beliefs about A and the alternatives to A, but also more general background beliefs. For example, a person who is surprised by an unannounced stimulus change in a repetition-change experiment may, as a result, also have her beliefs about the purpose of the experiment disconfirmed, and be surprised again (e.g., Reisenzein et al., 2006; see Macedo et al., 2009).

Novelty as a Cause of Surprise

According to a number of theorists, surprise is evoked by novelty instead of, or at least in addition, to unexpectedness (e.g., Berlyne, 1960; Scherer, 2001; Teigen & Keren, 2003; for reviews see e.g. Barto et al., 2013; Vachon, Hughes & Jones, 2012). To evaluate

[1] If the process of acquiring the new belief P(A) is construed as Bayesian updating (conditionalization), then some minimal schema-update already takes place *before* surprise. However, this is not inconsistent with the cognitive-evolutionary model because the schema update postulated to occur after surprise in this model is meant to refer to subsequent processes of changing background beliefs. Furthermore, the complete updating process also includes the deletion of the prior belief, which can only take place after surprise has been

this proposal, one needs to define novelty in a way that is clearly distinct from unexpectedness, which is often not done: Many authors interpret novelty as unexpectedness (see Barto et al., 2013, for examples) or define it in a way that includes unexpectedness (e.g., Gati & Ben-Shakhar, 1990). The most viable (and common) proposal for distinguishing the two concepts seems to be the following: Whereas *unexpected* events are those that disconfirm expectations (beliefs), *novel* events are events that are not represented in the person's schema or episodic event memory for the current situation (and perhaps in no schema at all). On the basis of this qualitative concept of novelty, a quantitative concept of novelty—the *degree of novelty* of an event—can be defined as the *dissimilarity* of the event (computed as a function of its common and distinctive features, or as the distance in a multidimensional space) to the relevant schemas or memory representations, which can either be an average prototype or a set of exemplars (see Smith & Medin, 1981) (cf. Barto et al., 2013; Gati & Ben-Shakhar, 1990; Macedo & Cardoso, 2012; Teigen & Keren, 2003). Presupposing this understanding of novelty, unexpected events can be novel as well as familiar (example: a previously encountered stimulus in a repetition-change experiment occurs at an unexpected time), and hence at least a partial distinction between novelty and unexpectedness is possible. It then becomes meaningful to ask: What is then responsible for the occurrence and intensity of surprise elicited by an event, its unexpectedness, its novelty, or both?

Most existing studies do not allow one to answer this question with certainty because the unexpected events presented to the participants were also to some degree novel. Nevertheless, the consideration of everyday cases plus a few relevant studies suggest the following conclusions: (1) Unexpected events are usually more surprising, the more they differ from those experienced before in the same situation (e.g., Reisenzein et al., 2006, Exp. 1; Teigen & Keren, 2003, Exp. 5). However, this finding falls short of demonstrating an

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computed. Therefore, even the initial belief-update takes place *in part* after surprise (see also Reisenzein, independent effect of novelty on surprise, because—as mentioned above when discussing the disconfirmation of single vs. multiple beliefs—changing increasingly more features of the unexpected event increases not only the novelty but also the total unexpectedness of the event (see also Vachon et al., 2012). (2) Novelty is *not necessary* for surprise, as even familiar events can elicit surprise if they are unexpected, for example because they have a low occurrence probability or occur at an unexpected time. Experimental surprise events that match this description include repeatedly occurring, unexpected lottery outcomes (Juergensen et al., 2014), unexpected solutions to quiz items that were shown to the subjects beforehand as possible answers (Reisenzein, 2000b) and the nonoccurrence of an announced stimulus change (Niepel, 2001). (3) The question of whether novelty is *sufficient* for surprise is more difficult to answer, because the strongest test case (an event that is expected but novel) is hard to find. Indeed, it can be argued that it is impossible for an expected event (one that matches expectations) to be novel, for expecting the event (e.g., that one will see a green bar in the next trial) requires holding a representation of it in memory, meaning that it is no longer novel when it occurs. For further discussion see Barto et al. (2013) and Vachon et al. (2012).

Outcome Valence as a Partial Cause of Surprise

Several studies obtained findings which could be taken to mean that the judged surprise about an event is not only influenced by the event's unexpectedness, but also by its valence (positive vs. negative) (e.g., Gendolla, 1997; Juergensen et al., 2014; Teigen & Keren, 2002). However, the direction of this valence effect is not uniform: In lottery contexts, where the outcomes are beyond the person's control, winnings are often more surprising than losses; in achievement contexts, where outcomes are controllable, failures are usually more surprising than successes (Teigen & Keren 2002), at least if the outcomes are important

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2009b).

(Gendolla, 1997); and in the repetition-change paradigm, Schützwohl and Krefting (2001) and Schützwohl and Borgstedt (2005) found that positive and negative unexpected pictures were experienced as equally surprising. This context-dependence of the valence-surprise effect suggests that the valence manipulations also influenced another variable; and this variable, we submit, is most likely the perceived probability of the outcome. According to this hypothesis, due to intrusions from schemas of similar everyday situations, or due to other cognitive as well as motivational biases, lottery gains and achievement failures are typically perceived as less likely than lottery losses and achievement successes, even if the experimenter provides information about objective probabilities that suggests otherwise (this possibility is acknowledged by Teigen & Keren, 2002, pp. 265-266). Support for this interpretation has been provided by Gendolla (1997) and Gendolla and Koller (2001) for achievement outcomes and by Mandel (2008) and Bilgin (2012) for uncontrollable outcomes (see also Juergensen et al., 2014).

Before moving on to the discussion of the nature of the surprise experience, it will be helpful to first consider the remaining processes postulated in the cognitive-evolutionary model, because several of these processes have been posited, by one or another theorist, to influence the experience of surprise. This also includes feedback from bodily changes.

The Effects of Surprise

Interruption and Attentional Shift

Surprising events cause fairly robust performance decrements on ongoing parallel tasks. Depending in part on the nature of the tasks, these performance decrements include action delays (e.g., Horstmann, 2005; Meyer et al., 1991; Reisenzein et al. 2006), an increased error rate (Reisenzein & Studtmann, 2007, Exp. 2 & 3) and a deterioration of the conscious perception and memory (“surprise induced blindness”) for stimuli immediately following the surprising event (e.g. Asplund et al., 2010; see also Reisenzein et al., 2006, Exp. 4 & 5). These findings support the assumption of the cognitive-evolutionary model, as well as other surprise models (e.g., Itti & Baldi, 2009), that the unexpectedness signal interrupts ongoing processes and causes an attentional shift. However, the data do not allow one to decide whether the performance decrements were caused exclusively by interruption and attentional shift or were also due to the subsequent processes postulated in the cognitive-evolutionary model (event analysis and schema-update). Furthermore, the findings are compatible with the hypothesis that interruption and attentional shift are not really two separate processes (with the first being a necessary precondition for the second), but that interruption is simply a consequence of attentional shift.

However, recent research in the repetition-change paradigm provides more specific evidence that supports the sequence interruption → attentional shift to the surprising event → attentional binding by the event. Evidence that interruption and attentional shift are indeed two separate processes was obtained in a series of studies by Horstmann (2006). In these experiments, different signals prompted participants to start, continue, or stop a continuous movement (fast tapping at about eight key presses per second). Tapping was chosen as the parallel task because it can be executed simultaneously with perception, with hardly any competition between the two processes. In the surprise trial, novel, unexpected objects were presented on previously empty screen locations during a "continue tapping" signal. Despite the fact that there was very little competition for resources between perception and action execution, the surprising stimuli again caused an interruption of the parallel task, and this interruption occurred as early as 200 ms. These findings suggest that surprise-induced action interruption is indeed independent of, and prior to, attentional shift.

Specific behavioral evidence for the *attentional shift* caused by surprising events was obtained in a series of eye-tracking studies which found that surprising stimuli attract gaze in a visual search task (Horstmann & Herwig, 2015; Horstmann & Herwig, 2016; see

Horstmann, 2015, for a review of the surprise-attention link). The average latency of the first gaze contact with the surprising stimulus occurred around 400 ms, which is consistent with the time course of detection deficits caused by surprising events in a rapid serial visual presentation task (e.g. Asplund et al., 2010). In addition to supporting the hypothesis of a surprise-induced *shifting* of attention, these studies also obtained evidence for the subsequent *binding* of attention: Events are looked at longer when they are surprising than when not (e.g., Horstmann & Herwig, 2015; Horstmann, Becker, & Ernst, 2016; Retell, Veining, & Becker, 2015, Exp. 1; see Horstmann, 2015). When multiple objects with a schema-discrepant feature are presented the preference for this feature may extend over multiple fixations (Horstmann & Herwig, 2016).

The shift to and binding of attention caused by surprising events explains, at least partly, why these events are better memorized (e.g., Meyer et al., 1991; Niepel et al. 1994; see also, Pyszczynski & Greenberg, 1987) and why inattentional blindness can be reduced for expectancy-discrepant events (Horstmann & Ansorge, 2016).

As already emphasized by early surprise theorists (see Reisenzein, 2000a), the interruption and attentional shift plus attentional binding caused by surprising events also manifests itself in consciousness: When asked, most participants in the repetition-change paradigm report that the surprising event was experienced as interfering with an ongoing parallel task and that their attention was drawn to the surprising event (e.g., Reisenzein et al., 2006, Exp. 2 & 4; Reisenzein & Studtmann, 2007, Exp. 2 & 3; Schützwohl & Krefting, 2001).

Event Analysis and Schema Revision

According to the cognitive-evolutionary surprise model, the event analysis processes instigated by surprising events comprise, in the typical case: the verification of the schema discrepancy, the analysis of the causes of the unexpected event, the evaluation of its implications for well-being, and the assessment of its action-relevance. The most extensive evidence exists for the proposed causal analysis process. In an early study, Isaacs (1930) found that children ask why-questions particularly in situations where something unexpected occurs. Parallel findings have been obtained for adults in numerous studies including recalled achievement situations (e.g., Stiensmeier-Pelster et al., 1995; Wong & Weiner, 1981; see the summaries in Pyszczynski & Greenberg, 1987; Weiner, 1985) and laboratory studies using the repetition-change paradigm. For example, in studies by Reisenzein et al. (2006, Exp. 6 and 7), where subjects were surprised by the appearance of a picture of their own face at the end of a face-rating task, the majority reported that they searched for an explanation of the unexpected event, and most showed evidence for either a visual search for its cause (searching for the hidden camera) or a verbal search (asking the experimenter about the surprising event).

There is also some experimental evidence for the remaining processes postulated in the cognitive-evolutionary surprise model. The *verification of the schema-discrepancy* (which is suggested by such everyday phenomena as taking a second look to make sure one has seen right) is supported by findings from Horstmann and Becker (2008). The authors reasoned that no further processing of the surprising event will occur unless its presence can be verified. Supporting this prediction, no attentional and reaction time effects of surprising stimuli were found if they were presented very briefly (100 ms), presumably too briefly to be verified, despite the fact that the great majority of the participants reported that they had seen the changed stimuli. Indirect evidence for the *well-being check* was obtained by Schützwohl and Krefting (2001, Exp. 2) and Schützwohl and Borgstedt (2005), who found longer reaction times for negative than positive unexpected pictures. Reaction time evidence for the *action-relevance check* was reported by Meyer et al. (1997) and Schützwohl and Krefting (2001). Finally, the occurrence of the *schema-revision process* is indirectly supported by the finding that both subjective and behavioral surprise reactions in the repetition-change paradigm are greatly reduced if the unexpected stimulus change is presented a second time. More direct evidence for the schema-revision process was obtained by Schützwohl (1998, Exp. 2) and Reisenzein et al. (2006; see also Reisenzein & Ritter, 2000), who found that the repetition of the surprising event also causes a reduction of perceived unexpectedness, which furthermore was found to statistically mediate the reduction in reported surprise and behavioral interference (Reisenzein & Ritter, 2000).

Expressive and Physiological Reactions to Surprising Events

According to the theory of basic emotions proposed by Tomkins (1962), Izard (1971), Ekman (1972) and others, surprise belongs to a small set of biologically basic emotions characterized, among others, by emotion-specific facial expressions. In the case of surprise, the facial expression comprises, in full-fledged form, eyebrow-raising, eye-widening, and mouth opening/jaw drop (Darwin, 1872; Reisenzein, 2000b). Basic emotion theorists assume that the emotion-specific expression is shown whenever the corresponding emotion is present and the expression is not deliberately inhibited; and that the intensity of the expression increases monotonically with the intensity of the emotion. If these assumptions are correct, the facial expression of surprise could serve as a highly specific and sensitive behavioral indicator of surprise.

Alas, however, numerous studies (reviewed in Reisenzein, Studtmann, & Horstmann, 2013) have found that surprised people hardly ever show a full-fledged surprise expression and that even partial expressions (most often consisting of eye-brow raising) are only shown by a minority—about 10% in the repetition-change paradigm (Reisenzein et al., 2006), and about 30% in response to highly surprising quiz items (Reisenzein, 2000b) and the exposure to a novel, strange room (Schützwohl & Reisenzein, 2012). Complementing these findings, the correlation between the self-reported intensity of surprise about quiz solutions and a composite index of the facial expression of surprise was found to be low even on the intraindividual level (average $r = .46$; Reisenzein, 2000b). Still, the fact that at least components of the surprise expression are shown by some people in response to unexpected events, and that the frequency of the surprise expressions varies somewhat between different settings, points to the possibility that the surprise expression may simply require certain additional conditions to reliably emerge. These additional conditions, if they exist, have not yet been identified. However, the available evidence suggests that an insufficient intensity of surprise and attempts to inhibit the expression cannot explain the low observed frequency of surprise expressions (Reisenzein et al., 2006). Nor has the surprise expression been found to occur more frequently if the surprising event is valenced, has a longer duration, or exceeds the visual field (Reisenzein et al., 2006; Schützwohl & Reisenzein, 2012). It is noteworthy, however, that a similarly low coherence between emotion and facial expression has also been found for other "basic emotions" (happiness, sadness, disgust, anger, and fear). The exception is smiling when amused, but amusement is not usually considered a basic emotion (Reisenzein et al., 2013).

In addition to a facial expression, surprising events are often assumed to elicit a physiological orienting reaction (see Öhman, Hamm, & Hugdahl, 2000; Reisenzein et al., 2012), whose most often measured peripheral components are a temporary increase in skin conductance (indicating increased sweat-gland activity) and a deceleration of heart rate. These responses are indeed fairly reliably evoked by surprising stimuli in the standard repetition-change paradigm (e.g., Niepel, 2001; Siddle & Jordan, 1993; see also, Siddle & Spinks, 1992), as are pupil dilations (e.g., Maher & Furedy, 1979; Reisenzein et al., 2006, Exp. 2). Pupil dilations to unexpected events have also been found in other experimental surprise paradigms (e.g., Kloosterman et al., 2015; O'Reilly et al., 2013; Preuschoff, 't Hart, & Einhäuser, 2011). However, the specifity of these physiological reactions as indicators of surprise is under debate (e.g., Niepel, 2001; O'Reilly et al., 2013). Specifically regarding skin conductance and heart rate responses in the repetition-change paradigm, Niepel (2001) concluded, on the basis of two studies, that these reactions reflect the changed appearance of the stimuli presented in the critical trial, rather than their unexpectedness. On the other hand, results by Siddle, Lipp and Dall (1994) could be taken to mean that unexpectedness also contributes to the skin conductance response.

For information on candidate brain responses evoked by surprising events, see Armony (2013), Barto et al. (2013), Öhman et al. (2000), O'Reilly et al. (2013), and Schröger (2005).

The Nature of the Experience of Surprise

The Awareness of Unexpectedness Hypothesis

The cognitive-evolutionary model identifies surprise with the output of the schema-discrepancy detector, which is conceptualized as a nonpropositional signal (Oatley & Johnson-Laird, 1987) that, when sufficiently intense, becomes conscious as a qualitatively unique feeling: the feeling of surprise. This hypothesis is consistent with the above-reported findings that (1) manipulations of unexpectedness influence the intensity of self-reported surprise and (2) that surprise intensity ratings correlate strongly with the prospectively estimated (Reisenzein, 2000b) and retrospectively scaled unexpectedness of the eliciting events (e.g., Reisenzein et al., 2006; Reisenzein & Ritter, 2000; Stiensmeier et al. 1995). However, even a very high correlation between surprise and unexpectedness does not exclude the possibility that the experience of surprise also comprises, or is even constituted by, other components. Three at least partially different theories of the nature of the surprise experience, for which data are available, are considered below: The mental interference hypothesis, the facial feedback hypothesis, and the explanatory difficulty hypothesis.

The Experienced Interference Hypothesis

Several classic surprise theorists (e.g., Shand, 1914) proposed that the feeling of surprise, rather than consisting of the direct, phenomenal awareness of unexpectedness, is actually the “metacognitive” experience of the interruption of mental processes caused by surprising events; or at least, that surprise contains this experience as a central element (see Reisenzein, 2000a). Supporting this hypothesis, several studies found that increasing the experienced interruption caused by a given unexpected event by increasing task load, intensifies self-reports of surprise (Müller & Stahlberg, 2007; Reisenzein & Ritter, 2000 [see also the summary in Reisenzein, 2000a]; Reisenzein et al., 2006, Exp. 2; Reisenzein & Studtmann, 2007, Exp. 2 & 3). The same effect was found by Schützwohl and Krefting (2001, Exp. 1) using a different method to manipulate interference (changing the action-relevance of the surprising event). However, the strength of these causal effects, as well as the size of the correlations between self-rated interference and surprise, are too low to justify the conclusion that surprise *is* the feeling of interference. Indeed, these effects do not even show with certainty that feelings of interference *are a component of* the experience of surprise. Rather, feelings of interference may just be used as a piece of metacognitive information for gauging the intensity of surprise. This hypothesis would make sense if one assumes that self-ratings of surprise are not simple “read-outs” of current feelings, but active inferences to an underlying, latent state of surprise, that is regarded as the cause of these feelings (see also Laird, 2007).

The Facial Feedback Hypothesis

Inspired by James’s (1890) bodily feedback theory of emotion, several authors proposed that feedback from the facial expression of surprise contributes to the experience of surprise (the same has also been proposed for physiological feedback, but empirical tests of the latter hypothesis seem to be lacking). In support of the facial feedback hypothesis, Lewis

(2013, Exp. 2) found that experimenter-instructed surprise expressions intensified self-reports of surprise about unexpected quiz solutions. Earlier studies also reported surprise-intensifying effects of the experimenter-instructed expression of fear, which is similar to that of surprise (e.g., Duclos et al., 1989; see Reisenzein & Studtmann, 2007, for a summary). However, no support for the facial feedback hypothesis was obtained when unobtrusive manipulations of the surprise expression were used (Reisenzein & Studtmann, 2007). Furthermore, as mentioned before, surprised people rarely show a surprise expression; for this reason alone, it seems, facial feedback cannot play a prominent role for the experience of surprise.

The Explanatory Difficulty Hypothesis

Maguire, Maguire, and Keane (2011) and Foster and Keane (2015) proposed that the feeling of surprise evoked by an event is primarily a "metacognitive sense of explanatory difficulty" (Foster & Keane, 2015, p. 78), that is, a feeling of difficulty of finding an explanation for the event. If an explanation is readily found, then the sense of explanatory difficulty and hence surprise is low, whereas if an explanation is found only with difficulty or not at all, then surprise is high. In support of this hypothesis, the authors found that manipulations which facilitated finding an explanation for an unexpected event (presenting an unexpected event of a kind for which explanations are readily available, providing a partial explanation for the event, or asking subjects to generate an explanation) reduced self-rated surprise.

In our view, there are several problems with this hypothesis, however. First, it has difficulties accommodating some of the above-reported findings on the effects of unexpectedness and interference on surprise. To account for these effects in terms of explanatory difficulty, one must assume that the experimental manipulations also changed the difficulty of explaining the surprising events. In our view, this is plausible for some unexpectedness manipulations but not for others. Specifically, it is implausible that the difficulty of explaining a stimulus change in the repetition-change paradigm increases, like surprise, with the number of schema-discrepant components of the stimulus (Reisenzein, 2006, Exp. 1) or that the difficulty of explaining repeatedly occurring, binary slot-machine lottery outcomes increases with the improbability of the outcomes (Juergensen et al., 2014). Likewise, it seems implausible to us to that the difficulty of explaining unexpected stimulus changes increases with the degree of mental interference caused by them (e.g., Reisenzein & Studtmann, 2007). The reason is in all cases that the explanation of the surprising event was the same (e.g., the experimenter's intent, or chance), and finding this explanation was therefore presumably equally difficult, in the different experimental conditions. Furthermore, a "natural" variation of explanatory difficulty detected in a study by Schützwohl and Reisenzein (1999, Exp. 1 and 2)—children had much greater difficulties explaining a surprising stimulus change than adults—was not paralleled by differences in the participants' surprise judgments.

Second, even more so than the interference hypothesis of surprise (at least when interpreted as claiming that surprise is *exclusively* the experience of interference), the explanatory difficulty hypothesis seems to conflict with the intuition, shared by many surprise theorists, that the feeling of surprise has a distinctive phenomenal quality, a specific character of "what it is like" to have it. For presumably, qualitatively identical feelings of difficulty to those experienced in surprise are also experienced in other contexts, for example if an unsurprising event is found difficult to explain, if a math puzzle is found difficult to solve, or if a stimulus is difficult to discern.

Third, as the authors of the explanatory difficulty hypothesis acknowledge, it is possible that their manipulations of explanatory difficulty influenced surprise because they changed the subjective probability, and hence the unexpectedness, of the surprising events or their possible alternatives. Foster and Keane (2015) discuss this alternative explanation of their experimental effects in depth and conclude that it is (a) implausible on theoretical grounds and (b) unable to explain the complete pattern of their findings, in particular the finding of comparatively low and partly nonsignificant correlations between judgments of probability and surprise obtained in some kinds of hypothetical scenarios (Maguire et al., 2011; Foster & Keane, 2015).

Regarding first the empirical findings, Maguire et al. (2011, Exp. 4) obtained a correlation of -.52 between judgments of surprise and probability and Foster and Keane (2015, Exp. 6c) a correlation of -.83 for one group of scenarios. Given that these correlations were computed with scenarios as the units of analysis and, in the case of Foster and Keane (2015), are based on a low N (6), they are in our view still within the range of correlations suggested by previous studies (e.g., .78 in Reisenzein, 2000; and about .70 in Stiensmeier-Pelster et al., 1995). Although for three other sets of scenarios, Foster and Keane (2015, Exp. 6c) obtained nonsignificant correlations, a recent replication attempt using subjects as the unit of analysis and a larger N (72) found again strong correlations between retrospective unexpectedness judgments and surprise ratings (Reisenzein, 2017). Taken together, the currently available empirical data therefore provide no compelling reason for rejecting the belief-disconfirmation model.

Regarding their theoretical objections to the belief-disconfirmation explanation of the effects of manipulations of explanatory difficulty on surprise, a main argument of Foster and Keane (2015) is that for many surprise situations, people are unlikely to have formed explicit antecedent expectations about the outcome that could have been disconfirmed. Therefore, they conclude, a belief-disconfirmation account of the explanatory difficulty effects is ruled out. However, the belief-disconfirmation theory is not committed to the assumption that the belief that not-A, that is disconfirmed by the occurrence of an unexpected event A, is explicitly present in the cognitive system at the time when A occurs. Rather, as discussed in more detail in Macedo et al. (2009) and Miceli and Castelfranchi (2015), the belief that not-A can also be computed—that is, derived from background knowledge—after the fact. In the latter case, the computation of the belief that not-A is usually *instigated* by the acquisition of the belief that A. If one accepts this, it becomes possible to explain how, for example, providing a partial explanation for A can reduce the unexpectedness and thus the intensity of surprise about A even if the expectation that not-A was not formed prior to the occurrence of A: The partial explanation changed the post-hoc derived probability of not-A.

The Functional Role of the Surprise Experience

Regardless of how the feeling of surprise is exactly constituted, the cognitive-evolutionary model assumes that it has motivational and informational functions: It instigates event analyses processes and it provides information (about the occurrence of a schema-discrepancy) to other cognitive subsystems (e.g., the belief-formation and action systems). Both assumptions are empirically supported.

In support of the *motivational hypothesis*, Stiensmeier-Pelster et al. (1995) and Gendolla and Koller (2001) found that the effect of unexpectedness on the intensity of causal search was statistically mediated by experienced surprise. Furthermore, Frensch and co-workers (e.g., Haider & Frensch, 2009; Rünger & Frensch, 2008; Schwager, Rünger, Gaschler, & Frensch, 2012) provided evidence that the occurrence of task errors in implicit sequence learning tasks prompts a conscious search for the causes of the errors, which can lead to the acquisition of explicit knowledge of the implicit regularity. Although the authors do not explicitly say so, it is likely that the causal search was proximately instigated by the feeling of surprise and/or interference caused by the unexpected task errors.

Support for the *informational function* of the feeling of surprise stems from research which suggests that the feeling of surprise (or possibly, of surprise-associated interference) is used as a piece of information for making hindsight judgments (e.g., Müller & Stahlberg, 2007; Pezzo, 2003; Nestler & Egloff, 2009) and retrospective inferences about the intensity of one's facial reaction to a surprising event (Reisenzein & Studtmann, 2007, Exp. 2 & 3). These findings dovetail with research on the informational effects of other cognitive, as well as affective, feelings (for a summary, see Greifeneder, Bless, & Pham, 2011).

Is Surprise an Emotion?

Although surprise is often regarded as an emotion (e.g., Ekman, 1972), it differs in some respects from paradigmatic emotions such as joy, anger, and fear. One or the other of these differences has led some emotion theorists to deny the status of an emotion to surprise (e.g., Lazarus, 1991; Ortony et al., 1988). The most frequently given reason is that in contrast to paradigmatic emotions, surprise is (intrinsically) hedonically neutral, rather than pleasant or unpleasant, and—corresponding to, and explaining, this difference in feeling tone—that surprise does not presuppose the appraisal of the eliciting event as positive (motive-congruent) or negative (motive-incongruent) (see Reisenzein et al., 2012).

Against this argument, two objections have been raised. The first accepts that proper emotions must have a hedonic tone, but claims that surprise is, in fact, hedonically negative rather than neutral (e.g., Miceli & Castelfranchi, 2015; Noordewier & Breugelmans, 2013; Topolinski & Strack, 2015). One basis of this claim is the assumption, popular in social psychology (see Gawronski & Strack, 2012), that humans have a desire for consistency and predictability. This desire, it is argued, is frustrated by the occurrence of unexpected events, because these events constitute a prediction failure; and this causes a negative feeling. Hence, it is concluded, surprise always involves a motive-incongruence appraisal and is, at least initially, hedonically negative. And therefore, surprise is a proper emotion after all.

The hypothesis that surprise is intrinsically negative receives support from the finding that pleasant and unpleasant surprising events seem to generate a similar prediction error signal in the brain (e.g., Alexander & Brown, 2011); from retrospective reports about the immediate hedonic reactions to unexpected events (Noordewier & Breugelmans, 2013, Exp. 1); and from the finding that the immediate facial reaction of some subjects to unexpected events is frowning (Topolinski & Strack, 2015; see also, Reisenzein et al. 2006, Exp. 7). However, these data constitute, in our view, only weak support for the hypothesis that surprise is intrinsically negative. It is certainly true that people are sometimes concerned about the correctness of their predictions and experience distress when these predictions turn out to be false. The reported data confirm this. However, the data do not show that prediction failures are *always* experienced as aversive, even if being right is completely unimportant (i.e., if no explicit prediction goal is present).

However, Miceli and Castelfranchi (2015) have argued that prediction failures are aversive even in the absence of an explicit prediction goal. To make this plausible, they advance the hypothesis that humans have what could be called hardwired set-points that specify the parameters of the optimal functioning of their cognitive system. One of these set-points, the "pseudo-goal" of making correct predictions (Miceli & Castelfranchi, 2015, p. 49), is frustrated by the experience of the schema-discrepancy signal; and perhaps another hardwired set-point, the pseudo-goal of processing information fluently, is frustrated by the mental interruption caused by unexpected events. As a consequence, the occurrence of these mental events automatically and inevitably elicits a negative feeling, much the same way a bad taste does.

Although this is an intriguing hypothesis, in our view both evolutionary considerations and some empirical observations argue against it. While it is plausibly adaptive to minimize prediction errors overall and in the long run (see also Friston & Stephan, 2007), it is in our view much less plausible to assume that it is adaptive to minimize them in all situations, as doing so conflicts with exploration and the acquisition of new knowledge structures. For this purpose, it is much rather adaptive to seek out situations that promise to be surprising (Macedo & Cardoso, 2012). Supporting this reasoning, everyday experience suggests that humans are motivated to, at least sometimes, seek out situations that have the potential to surprise them (e.g., visiting a famous town about which one has little specific knowledge) and that the surprise experienced in these situations is usually pleasant. Likewise, surprising turns in novels and surprising changes in music are frequently experienced as pleasant, and lottery winnings are experienced as more pleasant, the more unexpected they are (Mellers et al., 1997).

Possibly even more important, however, is the following consideration: Even assuming that prediction failures, or the surprise they cause, always induce a negative feeling, this would not be a sufficient reason for regarding this feeling as a *component* of surprise, rather than as what it—according to the cited author's own account—is: a negative feeling caused by the (metacognitive) recognition that a belief has been disconfirmed, or perhaps directly by the experience of surprise and interruption (Miceli & Castelfranchi, 2015).

The second objection to the claim that surprise is not an emotion accepts that surprise is intrinsically neutral, but denies that this is a sufficient reason for regarding surprise as nonemotional (Reisenzein et al., 2012; Reisenzein, 2009b). This objection is based on the proposal that the decisive criterion for regarding a mental state as an emotion is that it is generated by the same mechanism that generates paradigmatic emotions. Now, it is generally accepted that surprise co-determines the quality of several unquestioned emotions, such as relief and disappointment (which are caused by the nonoccurrence of expected negative and positive events, respectively) and that it intensifies other hedonic emotions such as joy and sadness (Mellers et al., 1997). This suggests, and theoretical analysis confirms, that the belief-disconfirmation detector is intimately conjoined with the goal-discrepancy detector in the mental machinery that generates emotions (Reisenzein, 2009b). Because emotions are the products of this mechanism, and surprise is one of its products, surprise is an emotion.

Predictive Coding Theory and the Cognitive-Evolutionary Model of Surprise

In recent years, the hypothesis has gained popularity, particularly in cognitive neuroscience, that the brain is a prediction device (e.g., Clark, 2013; Friston & Stephan, 2007; Hohwy, 2014). According to this hypothesis, a (or even the) basic function of the brain is to minimize the mismatch between predictions or expectations and sensory input; or in other words, to minimize surprise. A hierarchical Bayesian network architecture, combined with discrepancy (unexpectedness) detection mechanisms at all levels of the hierarchy, has become the main computational specification of this hypothesis. The cognitive-evolutionary model of surprise, while formulated in the framework of the older schema theories developed in the 1970s, is generally in line with predictive coding theory; indeed, it can be argued that it anticipates basic ideas of this theory. Nevertheless, there are also some important differences: The cognitive-evolutionary model assumes a more modular cognitive architecture than the predictive coding theory, it explicitly builds on the belief-desire psychology of common-sense, and it assigns a prominent role to the conscious feeling of surprise. A detailed discussion of these differences must await another occasion (meanwhile, see e.g., Drayson, 2017; Dewhurst, 2017).

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