Positive and negative implications of the causal illusion

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Abstract

The human cognitive system is fine-tuned to detect patterns in the environment with the aim of predicting important outcomes and, eventually, to optimize behavior. Built under the logic of the least-costly mistake, this system has evolved biases to not overlook any meaningful pattern, even if this means that some false alarms will occur, as in the case of when we detect a causal link between two events that are actually unrelated (i.e., a causal illusion). In this review, we examine the positive and negative implications of causal illusions, emphasizing emotional aspects (i.e., causal illusions are negatively associated with negative mood and depression) and practical, health-related issues (i.e., causal illusions might underlie pseudoscientific beliefs, leading to dangerous decisions). Finally, we describe several ways to obtain control over causal illusions, so that we could be able to produce them when they are beneficial and avoid them when they are harmful.

Keywords: cognitive biases, emotion, causal learning

1. Biased pattern-perception: Why we never err on the side of caution.

The dominant view in current psychology is based on the assumption that living organisms can be seen as machines capable of some type of information processing. Thus, our sense organs (eyes, ears) capture a constant flow of data and feed it to other systems that are able to transform it, elaborate it, and eventually extract whatever pattern or piece of information is relevant to a given task (e.g., to detect a predator, or to recognize a familiar face among a multitude of others). In other words, we turn mere data into knowledge. Although this view of organisms as information-processing machines is in many ways simplistic, it can still be used as a useful metaphor to understand how cognition works.

One important aspect is that the process of transforming the sensory input seemingly entails an inferential component. For instance, many have argued that visual perception is an action which involves prediction and error correction (Clark, 2013). But inference, as it consists of an interpretation, is not without risks, and mistakes can happen. This is, for example, why we sometimes "detect" a human face in a landscape or an inanimate object (a phenomenon known as pareidolia; Liu et al., 2014). In this context, the apparent errors and mistakes that people make when interpreting sensory input, such as those leading to pareidolia or optical illusions, can be very informative for researchers willing to learn how these processes work. In this paper, we are more interested in the consequences or implications of such errors, for both good and bad.

Consider the following example of pattern-perception that was described by Gilovich (1991; see also Griffiths & Tenenbaum, 2007). During the final years of World War II, the city of London was heavily bombed by German V-1 and V-2 flying bombs (an episode known as "The Blitz"), causing more than 43,000 deaths. As some noted, these bombs appeared to land in clusters, with significantly more bombs falling over the poor districts of the city. This belief raised the suspicion that there were spies informing the enemy to improve the accuracy of the attacks. Were these suspicions reasonable, given the actual data? Fortunately, the authorities kept a bomb census, recording the exact time and location of each bomb that was dropped on London during the Blitz, and these data can be publicly accessed as an interactive online map ("www.bombsight.org version 1.0," n.d.). If the bombing was completely random, one would expect that points would distribute evenly across the map, without visible clusters. However, a visual inspection of these maps still produces a powerful sensation that the bombs landed in clusters. When the experienced mathematician R. D. Clarke (Clarke, 1946) carefully analyzed the data after dividing the area into small squares and counting the number of impacts per square, he found that the distribution of the bombs closely matched a Poisson distribution, which indicates that they fell randomly. What appeared as clusters or groups of bombs falling close to each other were actually due to chance.

Still, anyone observing the maps from the Blitz may feel that there is a meaningful pattern in the distribution of the bombs. This sensation has been attributed to a cognitive bias called "clustering illusion", which is the perception of relationships between events that are actually randomly distributed (Gilovich, 1991). Another good example of this bias is the perception of winning or losing "streaks" in games strongly affected by chance that can mostly produce random sequences of wins and losses (see a related phenomenon called the "hot-hand bias", Gilovich, Vallone, & Tversky, 1985).

The clustering illusion, as in other cognitive biases, implies perceiving a meaningful pattern where there is actually random noise. It is very similar to the Type-I error (i.e., false positive) that researchers take into account when making inferences from their data. Quite interestingly, the opposite mistake, that is, observing an actually meaningful pattern and failing to perceive it (i.e., an equivalent to Type-II error), is far less common in the empirical literature, or has received little attention. We can shed light on why this asymmetry appears by examining the consequences of one and the opposite error, using the London bombing example.

First, detecting illusory patterns (Type-I error) leads to a mistaken belief that calls to action. Where there is a pattern, a meaning, there is an opportunity to exploit this knowledge. In our example, Londoners might believe that certain areas of the city are safer than others, and move accordingly. This is clearly a waste of energy and resources, as nothing they could possibly try would improve their chances of survival. On the other hand, while being mistaken, these people would feel, to some extent, that they are in control of the situation.

They at least keep on trying to escape, and hope that they will succeed. This is a positive consequence of committing a Type-I error, that it helps maintaining a positive mood and attitude.

On the other hand, Type-II errors entail very different consequences. In this case, the error would be in failing to realize that the bombs landed systematically more often on certain areas. The most serious consequence is, of course, that people had the opportunity to escape but they did not try because they thought it would be useless. There is also an emotional drawback, as people would feel depressed or sense of despair, because they do not have control over their lives anymore. A large body of empirical literature shows that feeling hopeless results in a variety of problems (including emotional, behavioral, and cognitive) (Abramson, Seligman, & Teasdale, 1978; Seligman & Maier, 1967).

Traditionally, researchers have claimed that natural selection favored biases in pattern perception that lead to Type-I errors such as the clustering illusion because they are the least-costly mistake (Haselton & Buss, 2000; Haselton & Nettle, 2006). In ancestral environments, with the pressure to make decisions and act quickly, it is probably the case that missing a meaningful pattern is costlier and less adaptive than illusorily perceiving one when there is none (e.g., it is better to run away upon sighting a potential predator than waiting until it is clearly visible, but too close for escape). Admittedly, the balance of the least-costly mistake can be reversed under particular circumstances that favor a more conservative criterion (i.e., a situation in which it is preferable to miss a valuable opportunity to succeed, instead of making the opposite mistake and developing an illusion). However, in this paper we are more interested in the emotional implications of both types of error. From this point of view, it is defensible that the emotional changes associated with developing an illusion (type-I error) are clearly superior to those of missing a real pattern (type-II error) (Haselton & Nettle, 2006). That is, it is better to feel hope, even if it is ungrounded, than feeling hopeless.

2. A bias in causal learning.

So far, we have illustrated one bias that operates in pattern-perception. Additionally, similar biases can affect other inferential processes that humans use extensively, thus exerting a great impact on their lives. One of these crucial processes is causal learning, and it will be the focus of the remainder of this paper.

How do people find out whether eating a given food item leads to an allergic reaction? How can scientists test hypotheses experimentally? Causal learning, the cognitive process underlying these activities, is the ability to extract causal knowledge from the information available. This allows for identifying and assessing causal relationships between variables (e.g., eating shrimp produces a skin rash, a new medical drug prevents bacterial infection, etc.). One key aspect in which causal learning resembles pattern-perception is that, in line with the currently dominant information-processing view in Cognitive Psychology, it implies extracting regularities and relevant features from the information captured by the sense organs. In other words, since causality is a property that cannot be directly observed, humans need to infer it from the information that they have available. Closing this gap from the information given to the causal interpretation is again subject to bias and errors.

The inference made in causal learning can be based on several features of the information that is directly available. In fact, there are three main principles which should guide normative causal inference, and they were described by David Hume (Hume, 1748). The first two principles, priority and contiguity, refer to the temporal ordering and the proximity of the stimuli that play the role of the potential cause and the potential effect. That is, if we

observe that two events occur sequentially and close in time, we might in principle be inclined to think that the former was the cause of the latter. This tendency has been observed since the early days in the history of Experimental Psychology (Rips, 2011), and today it is a well-known phenomenon thanks to a large body of experimental evidence (Buehner, 2005; Bullock & Gelman, 1979). However, we should be cautious. Although simple, these two principles are sometimes misleading: the fact that two events follow each other closely does not necessarily mean that they are causally related.

The third principle mentioned by Hume, contingency, states that causes and their effects must be correlated (in the complex real world, however, potential third variables might mask this correlation). Contingency appears to be one of the most relevant and valuable pieces of information that people use to learn about causality (Shanks & Dickinson, 1987; Wasserman, 1990), and, not surprisingly, it soon became the focus of a long tradition of experimental research that still flourishes today. To understand how contingency can inform causal learning, we will start by describing a typical procedure in human causal learning studies.

Alloy & Abramson (1979) conducted several experiments in which their participants sit in front of a simple device consisting of a button and a lightbulb. The aim of the participants was to find out the extent to which they could turn the light on by pressing the button. From time to time, a sign indicated that a new trial started. Then, the participant had two options: either to press the button (i.e., an action) or not. Immediately after, the light either came on (i.e., the outcome) or stayed off. We can condense this simple procedure into a 2-by-2 contingency matrix such as that displayed in Figure 1. The matrix contains the four trial types that can be observed in Alloy and Abramson's task: either the participant presses the button and the light comes on (trial a), or he presses the button and the light stays off (trial b), or he does not press the button but the light comes on (trial c), or he neither presses the button nor the light comes on (trial d).

	Outcome (light comes on)	~Outcome (light does not come on)
Action (to press the button)	a	b
~Action (not to press the button)	c	d

Figure 1. Contingency matrix containing the four types of trial (a, b, c, and d) that can be presented in a typical contingency learning task.

After a sequence of several trials, how could the participant assess the potential causal relationship between the button (action) and the onset of the light (outcome)? To do this, they could use the contingency information. If the onset of the light is more likely to be observed when the button is pressed than when it is not pressed, then the contingency between the two events (action and outcome) is positive, and we would have reasons to believe that they are causally related. A popular index to measure contingency more formally is ΔP (Allan, 1980), which is a contrast between two conditional probabilities that can be readily computed from the matrix (Equation 1):

$$\Delta P = P(\text{Outcome}|\text{Action}) - P(\text{Outcome}|\sim\text{Action}) = \frac{a}{a+b} - \frac{c}{c+d}. \quad (1)$$

The letters a, b, c, and d in Equation 1 refer to the frequencies of the trials in each cell of the matrix. Positive values of ΔP indicate a positive contingency, which points to a generative causal relationship (i.e., pressing the button makes the light onset more likely). However, when the two probabilities are identical, ΔP is zero and the contingency is null (i.e., there is no relationship between action and outcome).

Human and nonhuman animals seem generally fine-tuned to detect contingencies and, in the case of people, to use this information in their judgments about causality. Many experiments have reported this sensitivity to contingency manipulations in both rodents (Rescorla, 1968) and in humans (Allan & Jenkins, 1980; Shanks & Dickinson, 1987; Wasserman, 1990). On the other hand, researchers have also documented systematic departures from the ΔP rule that can be observed under certain conditions. Most of these biases appear when the experimenters manipulate the distributions of the trials in the contingency matrix. For instance, even when the actual contingency is null (i.e., $\Delta P = 0$), presenting frequent action-outcome co-occurrences, or trials a, leads to a strong overestimation of the actual relationship between the two events (see an example of a biased contingency matrix in Figure 2). This is called a “causal illusion”, because people develop the mistaken belief that there is a causal relationship where there are only random coincidences (see a review in Matute et al., 2015), much like people see clusters in the random pattern of bomb landings.

	Outcome (light comes on)	~Outcome (light does not come on)
Action (to press the button)	64	16
~Action (not to press the button)	16	4

Figure 2. Biased contingency matrix. The numbers represent the frequencies of each trial type. Although the objective contingency is null, there are many fortuitous co-occurrences between the action and the outcome (trials a).

Researchers identified two manipulations that consistently produce the causal illusion. First, increasing the marginal probability of the outcome by presenting many trials of type a and c produces higher causal judgments, even in the absence of contingency. This is known as the outcome-density bias (Alloy & Abramson, 1979; Buehner, Cheng, & Clifford, 2003; Musca, Vadillo, Blanco, & Matute, 2010). Second, increasing the marginal probability of the action (trials a and b) has a similar effect on the perceived causality, and it is known as the cue-density bias (Allan & Jenkins, 1983; Blanco, Matute, & Vadillo, 2011, 2012; Hannah & Beneteau, 2009; Matute, 1996; Perales, Catena, Shanks, & González, 2005; Wasserman, Kao,

Van Hamme, Katagiri, & Young, 1996). In fact, both manipulations have in common the possibility that they imply presenting many action-outcome co-occurrences, or trials a (Blanco, Matute, & Vadillo, 2013). When people are exposed to a situation in which a given action is frequently followed by the outcome — even if it is by chance — they tend to attribute the outcome to the action, thus showing a causal illusion.

This suggests that animals and people do not actually compute contingency to reach conclusions about causality (as would be rational), but instead use other pieces of information that are easier to obtain, such as the number of co-occurrences between action and outcome. Thus, the inference from the contingency information to the perception of causality might be based on heuristics.

Interestingly, traditional approaches to causal and contingency learning, which are mainly rooted in the associative learning field, are able to capture this biased behavior. For instance, the Rescorla-Wagner model of associative learning (Rescorla & Wagner, 1972) predicts accurate estimations of contingency under normal circumstances, but also pre-asymptotic overestimations when there are many action-outcome co-occurrences (Blanco & Matute, 2015). Therefore, these simple models are still valid in helping us to understand why and how causal illusions appear, and consequently they are frequently used in the literature.

Depressive realism

In this section, we examine the relationship between negative or dysphoric mood and the causal illusion, which has been matter of research for decades. As we will see, the nature of this relationship is not entirely clear in terms of whether positive mood facilitates illusions, or if it is the illusion which influences mood.

In their seminal paper, Alloy and Abramson (1979) assessed the depressive symptoms of their participants by means of the Beck Depression Inventory (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) before they were trained with the contingency learning procedure we described above. In line with others, these authors reported that people tended to overestimate a null contingency between the action and the outcome when the probability of the outcome was high (i.e., an outcome-density bias). Additionally, they found that the bias was dependent on the participants' mood, so that dysphoric participants were apparently less vulnerable to the causal illusion bias than non-dysphoric participants. This result was soon called the "sadder-but-wiser", or the "depressive realism" effect (Alloy & Abramson, 1979; Alloy & Tabachnik, 1984), and it instigated a fertile line of research that still generates novel findings to this day. Thus, depressed people have been found to be more realistic (less biased) when judging null contingencies or causal relationships (Alloy & Abramson, 1979; Blanco, Matute, & Vadillo, 2009; Msetfi, Murphy, Simpson, & Kornbrot, 2005), when predicting future events, when remembering past feedback (Dykman, Abramson, Alloy, & Hartlage, 1989), or when judging their own or others' performance (Soderstrom, Davalos, & Vázquez, 2011; Wood, Moffoot, & O'Carroll, 1998). It is true that, sometimes, the depressive realism seems to be a fleeting effect that is hard to replicate (Ackerman & De Rubeis, 1991; Baker, Msetfi, Hanley, & Murphy, 2012), but at least when we focus on the contingency learning procedure, it is a robust finding. For a complete review, see Moore & Fresco (2012).

The initial proposals to explain the depressive realism effect were based on motivational approaches (Alloy, Peterson, Abramson, & Seligman, 1984; Thompson, Armstrong, & Thomas, 1998). According to this view, non-depressed people tend to display a variety of "optimistic", self-enhancing biases. These would help to maintain a well-adapted and healthy psychological state. Depressed people, on the contrary, do not exhibit these biases (perhaps because they lack the motivation to do so) and consequently show a low mood (Taylor &

Brown, 1988). Although it is a popular account for the depressive realism effect, this motivational view is problematic for several reasons. First, it assumes a causal direction so that positive illusions influence mood, which is not clear (it could be the opposite). Second, it does not explain, for example, why depressed people's realism is restricted to certain specific situations (e.g., null contingencies with high probability of trials a, etc.).

In the last decade, other accounts for the depressive realism effect have emerged from the associative learning literature, and are helpful to contextualize the causal illusion within the contingency learning framework. Notably, Msetfi and colleagues (Msetfi, Murphy, & Simpson, 2007; Msetfi et al., 2005) proposed that depressive realism is linked to a poor contextual processing during the learning of contingencies. To understand Msetfi et al.'s proposal, we need to look more closely at the original procedure used by Alloy and Abramson (1979). In these experiments, the training phase was divided into trials: each trial started with the opportunity to press the button, and then either the light came on (i.e., the outcome appeared) or not, which finished the trial. As usual, there was an interval separating the trials (i.e., inter-trial-interval, or ITI), during which nothing happened and the participant just had to wait. Now, these ITIs are perceptually very similar to type d trials (see Figure 1), in which the button is not pressed and the light does not come on. Type d trials are actually cases that confirm the relationship between the action and the outcome. After all, if the button does produce the light onset, it is expected that not pressing the button would prevent the light from coming on (Equation 1 also shows how increasing the number of type d trials does increase the contingency). Msetfi et al. noted that, if people interpreted ITIs as extra type d trials based on their perceptual similarity, they would in fact perceive an inflated contingency. In line with this thought, they manipulated the ITI length, finding that longer ITIs (i.e., more opportunities to interpret them as additional type d trials) led to stronger illusions of causality. Moreover, they found that the sensitivity to the ITI length manipulation was present only in non-dysphoric participants. They concluded that depression could be linked to problems in contextual processing, so that depressed people do not normally interpret ITIs, or intervals in which neither the action nor the outcome occurs, as evidence supporting the causal relationship. On the other hand, non-depressed people would tend to inflate their perceived contingency by processing the ITIs as additional type d trials.

Another account of the depressive realism effect, which is compatible with the latter, was proposed by Blanco and colleagues (Blanco et al., 2009, 2012). We have mentioned that the causal illusion is probably due to the accumulation of type a trials, or coincidences between action and outcome. Thus, any manipulation that increases the chances of action-outcome coincidence should strengthen the illusion. The cue-density bias that we defined above is one such manipulation: in a null contingency setting, performing the action frequently leads to an overestimation of the relationship. Now, among the symptoms that characterize depression, we find behavioral passivity ("Psychomotor retardation", "Fatigue", and "Loss of energy", as stated in the DSM-V, 5th Edition; American Psychiatric Association, 2013). Depressed patients tend to avoid social interactions, physical activity, and adopt a passive lifestyle. In other words, they are less motivated to act, and this is one of the aspects that therapists include in their treatments (Hopko, Lejuez, Lepage, Hopko, & McNeil, 2003). Thus, in a contingency learning task such as that of Alloy and Abramson (1979), depressed participants might choose to press the button less often than non-depressed people. This results in fewer a and b trials, and, consequently, smaller chances of action-outcome coincidences, and weaker illusion. In other words, our proposal is that depressed people are more realistic in judging null contingencies because they tend to be more passive, or decide to act less often, than non-depressed people. In short the depressive realism effect is mediated by the frequency of the actions.

We tested this mediational hypothesis in several studies (Blanco et al., 2009, 2012). First, we used a procedure very similar to that employed by Alloy and Abramson (1979) to replicate the depressive realism effect. Depressed people were less likely to overestimate an actual null contingency between their actions and an outcome. Unlike in Alloy and Abramson's study, we collected and reported the number of trials in which the participants decided to perform the action. Overall, depressed participants tended to act on a smaller number of trials compared to non-depressed participants. Finally, a mediational analysis showed that the reason why depressed participants were less biased in their causal judgments was because they were more passive and produced action-outcome coincidences less frequently.

Contrary to other accounts of the depressive realism effect, our proposal offers a more general explanation of when causal illusions are expected to appear, instead of restricting our predictions to depressed people. That is, any manipulation that reduces the number of actions (be it depression, fatigue, etc.) should produce a realistic judgment. Thus, in another study (Blanco et al., 2012), we manipulated the probability of the participants' actions by means of instructional sets (as in Matute, 1996). Because this manipulation was conducted independently of the participants' mood state, it should abolish the depressive realism effect. In line with our predictions, asking people to press the button often led to stronger illusions, even in depressed participants. Likewise, asking them to press the button on half of the trials reduced the illusion and promoted realism for both depressed and non-depressed participants. This experiment provided further support for our mediational account of the depressive realism effect.

One of the advantages of our mediational hypothesis is that it fits well with the associative learning framework, without the need for any further assumptions. As already mentioned, the cue-density bias (the effect of the probability of actions on the judgments of causality) is readily explained by models such as that of Rescorla-Wagner (1972). We have conducted simulations that show this feature of the model (Blanco & Matute, 2015; Matute, Vadillo, Blanco, & Musca, 2007).

To sum up, depressed or dysphoric mood has been associated with a reduction of the causal illusion. Whereas some accounts assume a causal direction so that the illusion prevents negative mood (Taylor & Brown, 1988), others do not need such a strong assumption, as they rely on traits such as contextual processing abilities (Msetfi et al., 2007, 2005), or the tendency to produce responses (Blanco et al., 2009, 2012), instead of relying directly on mood. These traits are associated with dysphoria, but do not necessarily imply cause and effect.

3. Implications of the illusion

The London bombing example served to introduce some of the potential consequences or implications of making mistakes when examining patterns. Now, we can extend the analysis to the causal illusion bias. As we will see, the implications associated with the causal illusion bias will be both good and bad, thus encouraging a rational and careful analysis on the part of scientists.

Behavioral persistence

The causal illusion, as well as other contingency learning biases, is related to other phenomena studied in the behaviorist tradition. In particular, this illusion resembles the idea of superstition as presented by B. F. Skinner and others (Shermer, 1998; Skinner, 1948). In his seminal work, Skinner (1948) investigated the effects of accidental reinforcement in pigeons. Reinforcers were delivered according to a fixed-time schedule, non-contingent on

the pigeons' actions. Thus, the reinforcers followed the actions only by accident (i.e., adventitiously). Skinner reported that those pigeons under the reinforcement schedule started changing their behaviors: they showed consistently stereotyped responses that were described as "rituals", or superstitions. According to the researcher, these strange behaviors emerged because they were accidentally reinforced. Those reinforced behaviors became more likely in the future, thus increasing the chances that they would be accidentally reinforced again. Although other researchers directed serious criticisms toward Skinner's interpretation (Staddon & Simmelhag, 1971), further research featuring more appropriate controls appeared to confirm that accidental reinforcement can result in the fixation of random behaviors, just as Skinner suggested (Marques, Leite, & Benvenuti, 2012; Matute, 1994). It is easy to see a parallel between Skinner's accidental reinforcement schedule and the biased contingency matrix that was presented in Figure 2. In both cases, the outcome (or reinforcer) is not contingent on the actions (i.e., $\Delta P = 0$), although they might co-occur by coincidence. If this happens frequently, the belief that the action is causally related to the outcome would emerge, as we described above, creating the superstition and making the action more likely in the future. Recent research has even proposed that actual human superstitions (such as the belief in lucky charms) are associated with causal illusions (Blanco, Barberia, & Matute, 2015).

Thus, an overestimation of causality can lead to the fixation of behaviors, even if they are not objectively linked to the desired outcome. Counterintuitively, this is often a positive trait of illusions. For instance, research on the hot-hand bias suggests that assuming systematic behavior (e.g., positive auto-correlation) in actually random sequences, and making predictions accordingly, is in fact an advantage in most scenarios. If the sequence is actually predictable, then the assumption is correct and allows quick learning and predictions above chance level. If the sequence is completely unpredictable, believing the contrary would not worsen the performance (Scheibehenne, Wilke, & Todd, 2011). Other authors have similarly argued that assuming that one can exert control over important outcomes produces benefits beyond the mere ability to produce such outcomes, at least when compared to the costs of assuming that one cannot exert control (Harris & Osman, 2012).

As we saw in the London bombing example, passivity is seldom a good strategy to achieve a desired goal, and it can even impair successful learning. If the outcome is under the person's control (even weakly, or indirectly), then the actual relationship will never be found because the action is never performed. On the other hand, if the outcome is not controllable, persistently trying at least allows the discovery of potential ways to obtain the outcome. It has been shown that, when playing certain sports, carrying out unnecessary actions such as superstitious rituals (e.g., wearing a lucky charm, crossing fingers) can even improve performance indirectly, by increasing self-confidence and promoting relaxation (Damisch, Stoberock, & Mussweiler, 2010). It is true that the mistaken belief that fuels this behavioral persistence could be deleterious at times, but in uncertain situations with lack of sufficient information (as in many of our examples), the potential benefit pays off. Moreover, further exposure to the real contingencies and consequences of the actions (reinforcement) should end up, in principle, refining and correcting the mistaken belief. In any case, passivity, or not trying to obtain the outcome, makes it hard to find the actual relationships between actions and outcome. Learning by reinforcement is one of the more powerful ways to adapt behavior, and superstitions ensure that we keep trying so that our actions have the opportunity to be reinforced (Beck & Forstmeier, 2007).

Reduced anxiety

An additional benefit of persistently trying to obtain desired outcomes is that this behavioral style enhances people's feelings of control and reduces anxiety. Previous studies have found

associations between feeling a lack of control and anxiety (Mineka & Kelly, 1989; Ray & Katahn, 1968). In addition, people scoring high on desire for control (a construct that represents the necessity of exerting control over important outcomes) tend to develop superstitions (Keinan, 2002), which is sometimes interpreted as a way to compensate the aversive feeling of having no control. In this regard, there is evidence that the tendency to seek and detect illusory patterns or believe in paranormal phenomena can be prompted by priming uncontrollability (i.e., by having participants recall a situation in which they felt a lack of control) (Greenaway, Louis, & Hornsey, 2013; Whitson & Galinsky, 2008).

In sum, it appears that the sense of uncontrollability is aversive for most people, leading to feelings of anxiety and stress. In this context, certain biases can help reduce these undesired consequences. In fact, this is the framework in which the illusion of control (Langer & Roth, 1975; Langer, 1975) was initially presented. In her famous paper, Langer described the illusion of control as a cognitive bias aimed at producing a relieving sense of balance and comfort, and reinforcing the belief in a "just world" (Langer, 1975). These alleged benefits of perceiving illusory control could also apply to all types of causal illusions in general, because finding a potential cause to which outcomes can be attributed (even if it is by mistake) can provide a similar sense of predictability and certainty to the world.

Depression and mood

As we explained above, Alloy and Abramson's (1979) results indicate that illusions of causality are negatively associated with depressed symptoms (i.e., depressive realism). This association has been extensively studied in a wide variety of experimental settings.

With the extant evidence, we cannot conclude whether the link between the two variables means that the illusion prevents depressive symptoms, as is implicit in motivational theories of depressive realism, or the direction is the opposite (i.e., mood influences the development of illusions). Rather, it seems that the two variables influence each other, perhaps in a complex way. For example, we know that priming a sense of control over life outcomes produces a relaxing state that prevents anxiety and related emotional distress (Rutjens, van Harreveld, & van der Pligt, 2013), and that inducing a causal illusion can protect against laboratory and natural stressors and later depressive symptoms (Alloy & Clements, 1992). On the other hand, there is evidence that inducing dysphoric mood can reduce cognitive biases (Forgas, 1998), whereas priming a sense of comfort, power and relaxation can increase illusions of control (Fast, Gruenfeld, Sivanathan, & Galinsky, 2009). Thus, it is possible that positive/negative mood and the development of illusions are influenced by each other, so that illusions are facilitated by positive or non-dysphoric mood, and in turn these illusions protect against negative mood.

However, even if we assume that illusions and biases can influence mood, it might not be for the good in all cases. For instance, some have suggested that feeling in control (i.e., feeling that one's behavior can cause important outcomes) results in a cognitive style characterized by self-blaming (i.e., the individual feels that everything is a consequence of his/her actions), which is one key component of depression. That is, at least under some circumstances, developing illusions of control over uncontrollable outcomes could produce negative, rather than positive, emotional consequences (Abramson & Sackheim, 1977). Moreover, there are studies suggesting that illusory beliefs about academic achievement predict positive outcomes (including positive mood) in the short term, but negative outcomes in the long term (Robins & Beer, 2001). This further reinforces the idea that the associations between illusions and mood outcomes are highly complex.

Admittedly, many of the studies cited in this section do not focus on the causal illusion, but concern positive illusions, or unrealistic expectations more generally. We could make a more

specific comment concerning causal illusions. Unlike other types of illusion, causal illusions as described in previous sections are typically studied in controlled laboratory experiments, designed to identify the factors that lead to realistic and biased judgments with highly specific learning situations and, often, artificial materials. When the experimenters include a mood assessment, they usually treat it as a potential predictor or modulator of judgments, which are normally the main dependent variable in the study. From this viewpoint, at least when using the above described standard procedures to study causal illusions, we can argue that depressed/dysphoric mood is one factor that promotes realism in judging causality (Alloy & Abramson, 1979; Blanco et al., 2012; Msetfi et al., 2005). This means that, in the case of causal illusions studied in the laboratory, the causal direction between mood and illusion seems a bit clearer than in other instances of unrealistic beliefs. However, because these studies are focused in specific situations and used artificial materials, they do not generally offer the wider picture of the potential relationships between the implied variables (mood, judgment, learning) in more natural settings.

Causal illusions today: pseudo-medicine

As a type-I error, the causal illusion represents those situations in which people develop a mistaken belief that does not match real evidence. This goes beyond the emotional consequences that we have reviewed, because it has practical and serious implications. Researchers have proposed that causal illusions underlie many of today's widespread irrational beliefs, from superstitions (Rudski, 2001, 2004), to beliefs in the paranormal (Blanco et al., 2015), or pseudoscience (Matute, Yarritu, & Vadillo, 2011). But one of the domains in which causal illusions are more hazardous is the treatment of health problems. In this section, we will focus on one aspect of the problem, the use of pseudo-medicine.

Pseudo-medicine is a treatment for any health problem or condition that has not been proven to work beyond placebo, yet it is presented (and advertised) as a valid treatment. Pseudo-medicines can take many forms and claim to work by various causal mechanisms: from traditional, Eastern medicine, to supernatural energies (e.g., reiki), or implausible dilutions (homeopathy). They are typically presented to the public using technical jargon to appear scientific. Not surprisingly, pseudo-medicines of various kinds have become highly popular, to the extent that some public health systems include them in their offers despite the protests from the scientific community (Gray, 2013).

But if pseudo-medicines do not, by definition, produce any health benefit to patients, how are we to explain their popularity and widespread use, even in today's well-informed society? Why do people believe that a completely useless treatment actually works? There are a number of reasons for this (Astin, 1998; Lilienfeld, Ritschel, Lynn, Cautin, & Latzman, 2014), but among them, some researchers proposed that the belief in the effectiveness of the pseudo-medicine can have its origins in a causal illusion (Blanco, Barberia, & Matute, 2014; Matute et al., 2011; Yarritu, Matute, & Luque, 2015).

In fact, when one examines the problem, it is easy to realize that pseudo-medicines are used today in a way that maximizes the causal illusion. First, they are employed to treat mild diseases and health conditions (e.g., back pain, toothache), rather than serious illnesses. These conditions typically show fluctuations and spontaneous remissions of the symptoms. In other words, the potential outcome (i.e., feeling better) occurs with certain frequency, even if no action has been taken. This means that pseudo-medicines are used in settings in which there is a high probability of the outcome. Second, and more interesting, pseudo-medicines are usually advertised as free from side effects (which is often the case, as in homeopathic remedies). They are harmless, so they can be taken on the patients' demand, as often as they wish to do so. If a pseudo-medicine is taken very frequently, and, additionally, the health problem shows frequent spontaneous remissions, then there are

many opportunities for accidental coincidences between taking the pseudo-medicine and feeling better (trials a). As we explained above, this is known to produce causal illusions.

We tried to represent this situation in the laboratory (Blanco et al., 2014). In our experiment, the procedure of Alloy and Abramson (1979) was modified in the following way. Participants had to imagine that they were doctors trying to treat a fictitious disease. Then, they were exposed to a series of trials, each one representing the medical record of a different patient. For each patient, participants had the opportunity to decide whether or not to use a fictitious experimental medicine, "Batatrim", and then they saw if the patient felt better or not. Thus, the rationale of the task remains almost identical to the original Alloy and Abramson (1979) procedure: participants were free to perform actions (to give the medicine to the patient) and observe the outcome (whether the patient improved or not). As in the original task, the participants' actions were not able to produce the outcome. That is, there was no contingency between using the medicine and the patients' relief, which means that the medicine was completely useless, and not even capable of producing a placebo effect. The patients' remissions, on the other hand, occurred spontaneously with a high base rate (on 70% of the trials the patient felt better). These are conditions similar to those present in real situations in which pseudo-medicines are used.

The crucial manipulation was the undesired consequences of using the medicine. For half of our participants, the medicine Batatrim was described as being completely harmless and free from side effects, just as real pseudo-medicines are advertised (e.g., homeopathy). In contrast, the other half of our participants was told that the medicine Batatrim produced the side effect of a skin rash every time it was used (this effect was indeed visible during the task, as red dots covered the face of the patient after taking Batatrim). This mirrors the real situation of most conventional, allopathic medicine, which has proven therapeutic effects on health, but also produces undesired consequences (and they are advertised along with the medicine).

Not surprisingly, we found that participants tended to use the medicine that was free from side effects much more often than the other medicine. After all, it produced no harm, so there is nothing wrong in trying it. However, as we expected, this frequent use of the medicine did have consequences on the beliefs of effectiveness. After the experimental session, despite both medicines being completely useless, the medicine without side effects was judged as significantly more effective. A mediational analysis revealed that this result was mediated by the number of trials where participants decided to use the medicine. That is, people developed the mistaken belief that the medicine without side effects was effective because they were using it very often. The result can be understood again as a cue-density bias, as the frequency of the action is known to produce causal illusions (Blanco et al., 2011).

From this very simple experiment, we can deduce some implications for understanding the real consequences of the causal illusion and related biases, at least in the domain of health. First, to find out which treatments work and which do not, a rational analysis of causality demands controlled studies. This is expensive, tedious, and requires resources and extensive training. Thus, computing the actual contingencies to find the truth about a medicine's effectiveness is beyond the capabilities of most people (for practical reasons). Rather, we need to trust the professionals (e.g., the doctors) that conducted those studies and reached the conclusions. If, instead of that, we decide to trust our intuitions and use our heuristics, we will end up developing mistaken beliefs because pseudo-medicines are used in a way that promotes the illusion of causality (i.e., many potential action-outcome coincidences). Second, the problem of using pseudo-medicine is actually quite serious. Erroneously believing in the effectiveness of homeopathy, for example, often leads to the abandonment of actually valid conventional treatments, which can result in deaths that

could have been avoided (Freckelton, 2012). For example, researchers who were monitoring incidents of adverse events associated with pseudo-medicine use in Australian children concluded that this practice had the potential to cause significant morbidity and fatally adverse outcomes. In that study, all reported cases of death related to pseudo-medicine use were attributable to failure to use conventional medicine in favor of the alternative therapy (Lim, Cranswick, & South, 2010). From this perspective, this is one of the situations in which the causal illusion is no longer the "least-costly mistake".

4. Ways of influencing the bias

Once the implications of the causal illusion and related cognitive biases have been examined, we end this paper by describing some of the ways that have been proposed to control the bias. As we have seen, the illusion is associated with both desired and undesired implications. Therefore, sometimes we will be interested in promoting a healthy dose of illusion, and sometimes we will aim to prevent harmful or dangerous illusions. Fortunately, the literature describes ways to obtain both goals.

Promoting healthy illusions

The illusion of control, which is a causal illusion, was initially described as an optimistic, self-enhancing bias (Langer & Roth, 1975; Langer, 1975). Later, the finding that depressed or dysphoric people were less prone to this illusion reinforced this view (Taylor & Brown, 1988). Thus, there have been proposals to induce illusions in those people that seem naturally resistant to them, under the assumption that the illusion promotes positive mood (we have argued above that the direction of this association is not clear).

Recently, Msetfi and colleagues (Msetfi, Brosnan, & Cavus, 2016; Msetfi, Kumar, Harmer, & Murphy, 2016) have tested two procedures to induce causal illusions in depressed people. Recall that, according to these authors' hypothesis, non-depressed people develop illusions partly because they incorporate the contextual information of the ITIs as additional type d trials, which inflates the perceived contingency. In contrast, depressed people seem to be less efficient at processing contextual information, which reduces the biasing effect of ITIs (Msetfi et al., 2007, 2005).

One of the obvious ways in which the illusion can be promoted in depressed people consists of forcing them to process the contextual information contained in the ITIs. In a recent study (Msetfi et al., 2016), dysphoric and non-dysphoric participants were asked to judge the relationship between their actions (pressing a key in a remote control while they were visiting different rooms) and an outcome (hearing the music from the stereo system) that was actually uncontrollable. Additionally, half of the participants were asked to pay attention to the contextual information of the task (i.e., "It is important that you pay attention to the objects and features of the rooms in which each trial takes place"), whereas the rest of the participants were instead asked to focus on their own thoughts (i.e., "it is important that you pay attention to the thoughts you have during the task"). The results showed the habitual causal illusion in non-dysphoric participants, regardless of the instructions they received. However, the instructional manipulation did work to increase the illusion in dysphoric participants, neutralizing the depressive realism effect.

A second approach to the question was recently examined by the same research team (Msetfi et al., 2016). This time, they used a sample composed of both healthy and depressed individuals, and conducted a pharmacological intervention in a randomized double-blind design. The experimental task was very similar to that previously described. Additionally, half of the participants were administered escitalopram, a drug that works as a serotonin reuptake inhibitor. This drug was expected to enhance attention to background cues, and

therefore contextual processing. The results of the study showed that the pharmacological intervention did serve to increase the illusory belief that the actions were capable of producing the outcome in depressed participants. Moreover, this effect was again mediated by the probability of the action: that is, the drug also increased the number of occasions in which the participants decided to act, and this in turn contributed to strengthen the illusion. This detail seems to suggest that both Msetfi et al.'s (Msetfi et al., 2007, 2005) and Blanco et al.'s (Blanco et al., 2009, 2012) hypotheses for the depressive realism effect are compatible.

Given that causal illusions have been linked to positive mood states and well-being, these two interventions constitute a promising step towards helping depressed people. Admittedly, it is possible that these proposals, based on laboratory research, fall short of our expectations when applied to real situations. However, they represent a first step towards the application of this basic knowledge.

Preventing harmful illusions

But, even if causal illusions can sometimes be positive and healthy, we have argued that nowadays they can lead to erroneous beliefs that can even put our lives in danger, such as when we replace a conventional, useful medicine by a pseudo-medicine that does not actually work. Unsurprisingly, there is a growing interest in finding ways to "debias" people by means of different types of interventions (Lewandowsky, Ecker, Seifert, Schwarz, & Cook, 2012; Lilienfeld, Ammirati, & Landfield, 2009). In this section, we will comment on two proposals that are directly related to the causal illusion.

One simple intervention that can be conducted to prevent harmful illusions is to provide additional information about potential alternative causes of the outcome. This approach was tested by Vadillo et al. (Vadillo, Matute, & Blanco, 2013). They used a simple task in which participants had to learn the potential relationship between pressing a key and the onset of a light on the screen. Crucially, for half of participants (the Signal group), the outcome was always immediately preceded by the picture of a star. That is, the outcome was perfectly signaled by an external cue. The rest of the participants (No-Signal group) did not see this additional cue. The rationale behind the experiment is as follows. Providing a valid (perfect) alternative cause to which the occurrences of the outcome can be attributed should result in the discounting of the participant's actions, which are a less reliable signal of the outcome. In line with this prediction, the illusion was successfully prevented in the Signal group. Thus, one of the ways in which causal illusions can be fought in real life is by encouraging people to pay attention to potential alternative causes of the outcomes they are trying to obtain or predict. That is, maybe a pseudo-medicine just seems to predict the remission of the symptoms, but a conventional medicine is able to predict this outcome even better.

A second approach that we tested to prevent causal illusions makes use of one variable that seems to underlie most cases in which the illusion is found, i.e., the probability with which the action is performed. As explained above, performing the action with high frequency leads to many potential co-occurrences between the action and the desired outcome, which results in overestimations of the real causal relationship. This cue-density effect has been found recurrently in the literature, and in fact it underlies many of the studies we have described in this paper. Thus, it is possible to take control over the illusion of causality by manipulating the probability of the action.

With this logic in mind, we designed an educational intervention aimed at high school students (Barberia, Blanco, Cubillas, & Matute, 2013). The design of our study comprised three phases that took place in a one-hour session: a staging phase, a workshop phase, and a measurement phase. To test the effectiveness of the intervention, we conducted the

measurement phase before the rest of the session on half of our participants, which served as a baseline or control group.

In the staging phase, the experimenters introduced themselves to the classroom as scientists who had discovered a new synthetic material (i.e., graphene-based nanotubes) with wonderful properties. They claimed that, only by making contact with the user's skin, the material would be able to enhance all of the user's abilities (cognitive, physical, etc.). Students were allowed to use the material and perform exercises to test their strength, balance, and ability to solve crosswords. Importantly, these exercises were set up in such a way that students would not be able to unequivocally detect whether their performance was due to their use of the material or if it was due to other factors (chance, fatigue, practice). In other words, students were not allowed to perform a well-controlled test. Moreover, the researchers tried to influence the students' perceptions about the effectiveness of the material by telling them that people who wore the product in previous tests reported that they performed particularly well on the tasks.

In the subsequent workshop phase, the students were given a lecture on how experimentation works, with an emphasis on control methods. For instance, we presented them with a pseudo-medicine scenario and asked questions such as "If 80% of people who take the herb feel better, does this represent proof of the herb's effectiveness?" These examples illustrate the point that seeing frequent action-outcome co-occurrences does not necessarily imply the existence of a causal link. By the end of the workshop, we discussed with the classroom about how the material was being tested during the staging phase, revealing the flaws in such tests. Thus, they learnt in a practical way how a product's effectiveness should be tested, and why sometimes a completely useless product can appear to work.

The measurement phase took place after the workshop in the Experimental group, and before the workshop in the Baseline group, so that both could be compared. The measurement was based on a contingency learning task identical to that already described, in which participants imagine that they are medical doctors treating a series of patients (Blanco et al., 2011). As usual, the fictitious medicine did not work at all, but most patients spontaneously felt better (i.e., high probability of the outcome). If participants decide to give the medicine to most patients, then they will be exposed to many action-outcome co-occurrences. Our prediction was that the workshop on control methods should make participants in the Experimental group realize that giving the medicine to most patients is not a good strategy to find out whether or not the medicine works, because they lack a proper control condition.

In line with this prediction, we found that the Experimental group decided to give the medicine to around half of the patients, which allows for a fair comparison between what happens when the medicine is used and when it is not used. In contrast, the Baseline group tended to use the medicine much more frequently, thus biasing the information they obtained during the task. This behavior affected the judgments of effectiveness. Although the medicine was completely useless, participants in the Baseline group developed a causal illusion and overestimated its effectiveness, whereas participants in the experimental group gave significantly lower judgments.

5. Conclusions

The existence of certain cognitive biases suggests that people are prone to detecting patterns where there is only random noise. This applies to visual perception (e.g., clustering illusion, hot-hand bias) as well as to causal learning. One of the reasons why people tend to

make these types of mistakes is that they often entail good consequences, at least in emotional terms. They help them to feel in control, reduce anxiety, and are negatively associated with depressed mood.

In this paper, we have focused on the causal illusion, which is the tendency to believe that two events (typically, the person's actions and a desired outcome) are causally related even when they are not. This illusion has been traditionally linked to positive outcomes, to the point that it was considered a self-enhancing bias. However, the causal illusion can also be problematic, particularly when it guides decisions concerning important issues such as health.

Finally, we have described a few ways in which we can gain control over the illusion of causality. In particular, this can be achieved by manipulating the frequency with which the actions are performed. Higher frequencies are associated with stronger illusions. Thus, making people adapt their behavior should result in the best of both worlds; they could promote the illusion wherever it is beneficial, and prevent it when it is harmful.

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