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# Causal Beliefs and Perception of Temporal Order: The 'Reordering Effect'

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**Abstract**
Empirical research on the relationship between temporality and causation is mostly dominated by the question of how temporal information constrains causal cognition. However, Bechlivanidis and Lagnado (2013, *Psychol. Sci.*, *24*, 1563–1572; 2016, *Cognition*, *146*, 58–66) recently claimed to have discovered the 'reordering effect', in which causal beliefs have an influence on perception of temporal order. This paper argues for an attentional interpretation of this effect and suggests a solution to the circularity that arises from the mutual constraint between causal assumptions and perception of temporal order. Finally, it is shown how the reordering effect may challenge certain philosophical accounts of temporal illusions.

**Keywords**
Causal assumptions, causal beliefs, causal cognition, reordering effect, temporal order, time perception

## 1. Introduction

Empirical research on the relationship between temporality and causation has, for the most part, been dominated by studies of the influence of temporal information on causal cognition. More specifically, special attention has been given to the role of temporal contiguity and, to a much lesser degree, to the role of temporal priority (i.e., the idea that causes precede their effects) in building causal beliefs (see Note 1). However, in recent years, psychologists have studied the way in which causal beliefs themselves influence time perception, which has led them to the discovery of the 'temporal binding' effect, wherein causal assumptions influence our perception of duration. Experiments have shown that the perceived time

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between two events is shortened in cases where there is an assumption that they are causally linked (Buehner, 2012; Buehner & Humphreys, 2009; Humphreys & Buehner, 2009, 2010; for a review, see Faro et al., 2013). But, more astonishingly, studies conducted in recent years also seem to point to an influence of causal beliefs on the perception of temporal order. Bechlivanidis and Lagnado claim to have discovered a 'reordering effect', which consists of an inversion of the objective temporal order so as to match an expected causal order (2013, 2016). Their work sought to demonstrate that causal assumptions produce not only quantitative distortions of time perception (as is the case in 'temporal binding', where duration is affected), but also qualitative changes whereby order is affected (2016, p. 59). Similar conclusions can be found in an earlier study by Fernbach and colleagues (Fernbach et al., 2007).

These findings show that the relationship between causal assumptions and the perception of temporal order cannot be understood purely in a bottom-up manner, that is to say, where the perception of temporal order provides relevant information for the formation of causal assumptions. Rather, the results of these experiments highlight a mutual constraint between causal assumptions and perceived temporal order, a mutual constraint that seems ensnared in a certain circularity (Fernbach et al., 2007, p. 273), to wit: if temporal precedence is a crucial cue towards causation, as several studies have shown (Bramley et al., 2014, 2018; Lagnado & Sloman, 2004, 2006; Rottman & Keil, 2012; White, 2006), how can causal beliefs distort the perception of temporal order? In light of this, the present paper has three core aims. First, to suggest an interpretation of the reordering effect. Second, to argue that this interpretation is consistent with the idea of temporal priority serving as a cue to causal cognition, and to offer an explanation of the mutual constraint of the perception of temporal order and causal attribution. Finally, to provide a brief sketch of how the discovery of the reordering effect may have an impact on contemporary philosophical discussions about temporal illusions.

I pursue the first aim in sections 2 and 3, in which I assess the empirical findings at our disposal and provide an interpretation of the reordering effect as resulting from an attentional mechanism. More specifically, in the second section, I consider the first empirical study on this temporal distortion (Fernbach et al., 2007), and address two concerns that arise in Bechlivanidis and Lagnado's experiments (2013), which, in my view, pose problems to their interpretation of the effect. In section 3, I argue for the plausibility of an attentional explanation of the reordering effect and discuss its rejection by Bechlivanidis and Lagnado in their 2016 paper.

In section 4, my principal concern is the second aim, namely identifying the implications of the discovery of the reordering effect for our understanding of causal cognition. In this section, I show how the attentional explanation of the effect has the advantage of providing a plausible picture of the mutual constraint between causal beliefs and the perception of temporal order. More specifically,

I argue that we must draw a line between the conditions in which the perception of temporal order constrains causal beliefs in a bottom-up manner, and the conditions in which causal assumptions have a top-down influence on perception of temporal order. Such a distinction should allow us to move beyond the noted circularity that arises from the mutual constraint of causal beliefs and the perception of temporal order.

Drawing on these results, in the final section, I tackle the question of how the discovery of the reordering effect challenges the contemporary philosophical debate about time perception. I argue that the reordering effect provides another kind of temporal illusion to those that are commonly discussed in recent literature.

## 2. Temporal Order Reversed by Causation: A Question of Perceptual Uncertainty?

To the best of my knowledge, there are only three published studies on the influence of causal beliefs on the perception of temporal order: Fernbach et al. (2007), and Bechlivanidis and Lagnado (2013, 2016) (Note 2). My aim in sections 2 and 3 is to suggest that these three studies provide evidence for the existence of a 'reordering effect', which, to my mind, occurs in conditions of perceptual uncertainty about temporal order. Whereas Bechlivanidis and Lagnado profess to rule out this interpretation of the reordering effect, such a view is not excluded by Fernbach et al. (2007). In what follows, I will argue that Bechlivanidis and Lagnado's experiments do not demonstrate that the effect can occur without conditions of perceptual uncertainty, contrary to what they claim. I will establish this point by noting two problems in their interpretation of the experiments reported in their 2013 paper (section 2), and by arguing against their rejection of the attentional explanation in their 2016 paper (section 3).

I will begin by briefly considering the experiments reported in Fernbach et al. (2007), before moving on to the analysis of Bechlivanidis and Lagnado's experiments. Fernbach et al. conducted an experiment in which they induced causal beliefs in participants through an interventional learning task about the movements of three slider bars on a computer screen (Note 3). After the participants had learned the causal structures of three causally dependent slider bars, they were shown the same sliders in a temporal order that corresponded (or not) to the causal structures they had learned previously. Fernbach et al. found that the participants' reports about temporal order displayed a bias consistent with the temporal relations of the causal models they had learned. An important point, as highlighted by Fernbach et al., is that the movements of the sliders on the computer screen "occurred quickly enough to leave participants with some uncertainty about temporal order" (2007, p. 269). The sliders moved either simultaneously or there was a delay of 100 ms between their movements. Fernbach et al. maintain that their experiments offer evidence for the fact that, given an uncertainty about

what happens, abstract beliefs about what should have happened are deployed to make a judgment. The results can be interpreted as a case of the influence of prior knowledge (in this case, causal models) on the experience of temporal order: predictions about the causal relations between the bar sliders provide information about their temporal relations in the case of uncertainty about temporal order. Arguably, this is a very general observation and, in order to understand the precise mechanism at play, further empirical work is needed (some suggestions in this regard are proposed in section 3 of this paper). Still, there are some crucial points mentioned by Fernbach et al. 2007 that are worth considering. First, they are right to point out that it is not possible to decide whether what we have here is a case of perceptual bias (i.e., the causal belief would prompt people to perceive the events in the inverse order), or one of response bias (i.e., the causal model would affect the participant's report of the temporal order), although all participants stated that they relied on temporal order information for their answers. Indeed, in cases where perceptual stimuli occur in very short timescales, it is hard to draw a strict line between perceptual and response bias. Therefore, one cannot rule out the possibility of it being an example of response bias, in which the participants are unaware of having had an ambiguous or incomplete perceptual experience (and, indeed, Fernbach et al., 2007, p. 273, acknowledge this possibility). Second, Fernbach et al. put forward the possibility of an attentional mechanism to explain how causal beliefs affect one's experience of temporal order. I will come to this in the next section.

In their 2013 article, Bechlivanidis and Lagnado's conclusion is somewhat similar to that of Fernbach et al.'s study: they state that there is evidence for the fact that causal beliefs can constrain the perception of temporal order such that the objective temporal order of events is reversed. However, their conclusion differs from that of Fernbach et al. in one crucial regard. Contrary to Fernbach et al., who assume that the perceptual input was somehow ambiguous given the rapid movements experienced by the subjects, Bechlivanidis and Lagnado (2013) claim to have discovered an inversion of temporal order through causal beliefs in the presence of discriminable temporal input. In order to provide evidence for this, the authors used a control group to verify that the presented temporal order of events was discriminable. In what follows I describe and assess their experiments.

In the first experiment (Note 4), 31 participants in the group were confronted with a software-based 'physics world'. In the training phase, experimenters induced causal beliefs about the relationships between the objects, in that participants played a game that required them to learn a new causal model (by way of an interventional learning task). The causal model to which the subjects became acquainted in the training phase was the following: the collision of a green square with a black platform causes the transformation of a red rectangle into a star (let us call this the first relationship), which in turn causes the star to enter a purple box (let us call this the second relationship). In the test phase, participants

watched a video clip lasting approximately 2.5 s, viewing it only once, in which the temporal order of events differed from their expected causal order: the red rectangle enters the purple box before its transformation into a star (which happens approximately 160 ms later), and this precedes the collision of the green square with the black platform, which occurs approximately 200 ms afterwards. The 35 participants of the control group viewed this clip without having had a training phase, and their responses, according to Bechlivanidis and Lagnado, would allow the experimenters to verify that the temporal order of events was discriminable.

Regarding the results of the experiment for the first relationship, 67.7% of the trained participants reported an order consistent with the causal belief induced: they reported perceiving the collision of the green square with the black platform before the transformation of the red rectangle into a star, thereby inverting the order of events, since the collision follows the transformation of the red rectangle by 200 ms. The percentage of the control group that gave this answer was lower (37.1%) than in the trained group.

Concerning the second case of the relationship between events (the transformation of the red rectangle into a star and its entering the box), the percentage inverting the temporal order was rather low in the control group (only 11.4%), but the percentage of participants who reported an inverted order in the trained group was also lower (51.6%) when compared to the equivalent case in the first relationship (i.e., 67.7%). Interestingly enough, in a way that resembles the experiment run by Fernbach et al., the majority of participants (here about 85.7% from the trained group) stated that the order they reported was the order they saw.

In my view, the results seem to provide evidence for a 'reordering effect', but I am not convinced by Bechlivanidis and Lagnado's interpretation, according to which this effect occurs in conditions of perceptual discriminability of temporal order. Indeed, the reasons the authors give in support of their view suffer from two flaws. First, Bechlivanidis and Lagnado judge that they have used, in their experiments, "long temporal intervals" between the events in the range of 150–200 ms, which, they state, "were at least twice the length of detectable intervals in visual-order-judgment tasks" (2013, p. 1570). In support of this statement, they cite a study by Hirsh and Sherrick (1961), as well as a more recent one by Kanabus et al. (2002). Nevertheless, if one takes a closer look at these studies, it is clear that they investigate the length of detectable intervals between two static stimuli (in the case of the visual stimuli, there are two flashes of light). Therefore, it is far from obvious that their results should apply to cases of non-static stimuli and to cases in which there are more than two events to be distinguished, which is exactly the case in the experiments carried out by Bechlivanidis and Lagnado. Furthermore, it should be noted that, in the experiments of Bechlivanidis and Lagnado, there are two objects that start to move at the same time at the beginning of the clip (both the red target rectangle and the green square move at the same time towards the purple box), which represents a much larger amount of information to

be processed than in the case of the experiments carried out by Hirsh and Sherrick (1961) and by Kanabus et al. (2002). It is to be expected that, with an increased load of perceptual information, the order threshold (OT), i.e., "the minimal inter-stimulus-interval (ISI) between two successive stimuli for correctly reporting their temporal order" (Kanabus et al., 2002, p. 264), will be higher than in the case of the experiments reported in Hirsh and Sherrick (1961) and in Kanabus et al. (2002) (Note 5). There is thus not enough evidence for the fact that, in the experimental conditions reported by Bechlivanidis and Lagnado in their 2013 paper, there is perceptual discriminability of temporal order.

Furthermore, regarding the first relationship (namely that between the transformation of the red rectangle and the collision of the green square with the black platform), there is a problematic detail of the experiment. In fact, also in the training phase, the transformation of the red rectangle precedes the collision of the green square with the black platform by 100 ms. Bechlivanidis and Lagnado justify this detail on account of the need to prevent any habituation to a certain sequence (2013, p. 1565). The problem with this, however, is that if participants were trained by interaction with the software such that "the collision between the green square and the black platform effectively acted as a switch, transforming the red rectangle into a star" (Bechlivanidis & Lagnado, 2013, p. 1565), even though the first happened after the second, then one can say that participants were already trained to see an event taking place 100 ms after the effect as being its cause. In light of this, participants are confronted, in the test phase, with a delay of 100 ms between the cause and the effect if compared with the same sequence in the training phase. In fact, the temporal difference of the sequence of the first relationship (that is, the relationship between the collision of the green square with the black platform, on the one side, and the transformation of the red rectangle, on the other side) in the experimental phase compared with the one of the training phase is not 200 ms, but 100 ms (Note 6).

As such, while Bechlivanidis and Lagnado operate with temporal delays that exceed the 100 ms between the bar movements of Fernbach et al.'s experiment, these are still very short timescales: the 'cause' in the first relationship takes place after the effect, only 100 ms later, if compared with the same sequence in the experimental phase and, regarding the second relationship, the 'cause' occurs 160 ms after the 'effect'. In light of such short timescales between several moving objects, it is not clear why we should rule out the possibility of a perceptual ambiguity concerning the temporal order of the stimuli.

Second, the results provided by the control group, in my view, do not decide the matter as to whether there is perceptual discriminability of the temporal order of events. As Bechlivanidis and Lagnado themselves note (2013, p.1567), the fact that the control group presented levels of reordering higher than expected is a problematic issue (as I mentioned early, this is 37.1% for the first relationship, and 11.4% for the second one). Bechlivanidis and Lagnado interpret this as evidence

for the fact that the untrained participants are also using a causal interpretation of the sequence, which influences their perception of temporal order. Even if we grant this, the question remains as to why these participants were providing a causal explanation of the sequence, since they were not trained to acquire the causal belief of the trained group. In other words, the question is why participants do not rely on the perception of temporal order to make a report. The use of a causal explanation of the sequence by the control group attests to the fact that the perceptual input is not as easily discerned as the experimenters would wish. The plausible explanation is that the participants draw on abstract assumptions (causal beliefs) in order to provide a report of the temporal order, since the temporal order between events is not clearly perceived.

It is therefore my view that, although Bechlivanidis and Lagnado provide evidence for a 'reordering effect', there is not enough evidence for the fact that this effect occurs in conditions of perceptual discriminability of the temporal order of events. As I argue in the next section, their 2016 paper also fails to provide sufficient evidence for this.

## 3. A Plausible Explanation of the Reordering Effect: An Attentional Mechanism

In the first experiment reported in Bechlivanidis and Lagnado's 2016 paper, they presented the participants only once with a movie clip, displaying a "three-object-pseudo-collision" (2016, p. 59): object A starts to move towards B at a speed of 30 mm/s and stops adjacent to B. Immediately afterwards, object C starts to move at the same speed. After 350 ms object B starts to move to the right at the same speed and stops to the left of C's original position. The clip ends when object C has covered 35 mm. As is obvious, the difference between this 'pseudo-collision' and a realistic collision is that the third object C starts to move before the second object B. As with their experiments reported in their earlier paper, Bechlivanidis and Lagnado wanted to ensure that the order of events was perceptually distinguishable, so they used what they considered to be a long delay between the events (350 ms) and introduced a control condition, whereby the first object is absent but the rest of the clip remains exactly the same. The authors predicted that, in the absence of A, participants would report the objective order of events, since in A's absence there would be no explicit causal direction (2016, p. 59). Consistent with their interpretation of the reordering effect in their 2013 paper, Bechlivanidis and Lagnado state that the reordering effect "is not due to limitations of the perceptual system" (2016, p. 63). However, in my view there is not enough evidence for the fact that the temporal order of the events is clearly perceived, and therefore there is not enough evidence on which to reject a plausible candidate (inattention) for explaining the conditions under which the reordering effect occurs. More specifically, according to an 'attentional explanation', the reordering effect arises because

the participants do not accurately perceive the temporal order between events. In what follows, I argue in favor of this explanation.

The results obtained in the first experiment show that the majority of the 29 participants (82.76%) in the first condition (with A present) reported an order that is consistent with their causal impression. In fact, most participants stated that B made C move, which seems to speak in favor of the "causal basis of the reordering effect" (Bechlivanidis & Lagnado, 2016, p. 61). In the second condition (when A was absent), a majority (83.33%) of the 30 participants reported the veridical temporal order. Bechlivanidis and Lagnado believe that the long delays between events (350 ms) and the veridical ordering in the second condition indicate that the temporal order of events is clearly perceived. Nevertheless, they mention another possible explanation (which they want to reject) for the difference between the results in the first and second condition by way of a "lack of information due to perceptual load or split attention" (2016, p. 61). Indeed, there is a bigger perceptual load in the first condition (the sequence in the second condition only features objects B and C), and it is possible to admit that participants overlook B's behavior because their attention is drawn to the onset of C's motion. If this were true, it would mean that there is an attentional explanation of the mechanism at work in the reordering effect.

Bechlivanidis and Lagnado reject this explanation, drawing on the results of a second experiment. In this second experiment, there were again two conditions. In the first condition, they showed the same three-object sequence only once, as in the first experiment, and then presented the same sequence again side-by-side with a realistic collision (the order of events is consistent with their causal relationships) and asked the participants to identify which of the two sequences they had just seen. In the second condition, they presented participants with a similar sequence, but with the difference that object B did not move at all. The results show that, in condition 1 (with B moving), 37.93% of participants selected the correct clip they saw, whereas in condition 2 (with B static), 72.41% did so. According to Bechlivanidis and Lagnado, this provides evidence that B's motion is, in fact, detected and that this detection is a condition for the reordering effect to take place. They state: "When B remains stationary in condition 2 the majority of participants detect it and thus are able to correctly identify the clip they saw. This means that in condition 1, where B does move towards C, albeit late, its motion is in fact noticed and the subsequent reordering does depend on that detection" (2016, p. 63).

Although I agree with Bechlivanidis and Lagnado insofar as the differences in identifying the correct clip in both conditions of the second experiment show that, in the first condition, B's motion is detected and that this is crucial for the reordering effect to take place, I do not see how this undercuts an explanation of the reordering effect by lack of attention to B's behavior. What the second experiment shows is that, if B remains stationary, participants are able to correctly

identify the clip they see, by distinguishing it from a realistic collision. This implies that participants in the first condition (when B moves) must in fact detect B's motion, since only this explains the difference in their judgment, namely that they do not select the correct clip and prefer the clip featuring the realistic collision. But what the second experiment does not show is that participants detect that B is static before C's movement. In other words, as long as it is not clear *when* they detect B's motion, one cannot reject the attentional explanation of the effect. The attentional explanation of the reordering effect does not require that participants completely miss B's behavior; rather, it only requires that they not perceive it completely. In short, the attentional explanation predicts that participants miss B's static behavior (thus missing some information about B's behavior, namely when it started to move). More specifically, according to the attentional explanation, it is plausible to assume that participants' attention in the first condition is attracted by C's onset of motion, failing thereby to notice B's static behavior. Participants may afterwards detect B's behavior. The point at which participants may detect B's behavior might be the onset of B's motion, which, in this case, would mean that participants are observing the veridical order of events (Note 7). Even in this case, participants might not interpret B's onset of motion as such and make the plausible interpretation that B's onset of motion occurred prior to C's onset of motion (Note 8), since the earlier perception of A moving favors the interpretation of the events as a launching sequence. Because causal beliefs carry implicit temporal assumptions (namely that the cause is prior to the effect) and B's static behavior is missed through inattention, the information system draws on causal beliefs (in this case, an abstract representation of successive collisions) to make the plausible assumption that B's onset of movement (cause) takes place prior to C's (effect). The preference for the causal clip can thus be explained by this offering the most plausible order of the sequence for the participants.

The experimenters could object to my interpretation as follows: But if the attentional explanation is the correct one, why do participants in the first condition choose the realistic condition? If the perceptual system does not detect B's behavior thoroughly because it is attracted by C's, how is it that participants in the first condition of the second experiment can detect a difference between two clips (the one they saw and the realistic collison) when asked which clip was seen earlier (and give their preference to the realistic collision)? Now, the fact that they choose the realistic collision and not the one they saw earlier speaks for the fact that they do differentiate between them.

Here I think that it is plausible to assume that, because subjects are allowed to see the two clips as many times as they want before deciding which of the two they saw earlier (whereas they are presented with the critical clip only once), they had the possibility of concentrating on different objects during several repetitions of the clip. Thanks to these repetitions, participants could become aware that, in a given clip, B starts to move after C. I predict that if subjects were presented with

the two clips after the first clip only once, there would not be a marked difference for the causal clip. In other words, without unlimited viewing, I predict that the response pattern of the participants would be random. Indeed, it is likely that subjects would not be able to distinguish between both clips. The general assumption behind this prediction is that if participants are confronted with relevant clips several times, this increases the accuracy of their perception. This is what has been observed in Tecwyn et al. (2019). According to the authors, including practice clips reduces susceptibility to the reordering effect compared with in a 'one-shot' experiment where participants only see the critical clip (Tecwyn et al., 2019, p. 30).

Therefore, I think that repeating the second experiment with a modified condition (namely that participants are presented with all clips only once), would shed light on whether or not there is clear perceptual input about B's behavior. Another way of clarifying the issue concerning the accuracy of the attentional explanation would be to employ eye-tracking methods (Note 9). Indeed, for the reasons set out above, I think that the next step towards clarifying the conditions under which the reordering effect occurs should entail an investigation of the attentional issue.

In conclusion, the experiments reported in Bechlivanidis and Lagnado's papers provide evidence for the existence of a reordering effect, but, to my mind, further empirical work is needed to decide the matter about whether or not this effect is the result of an incomplete percept, in which the missing information is filled in by way of causal assumptions. This incomplete percept can be explained by perceptual overload and failures of attention. This explanation is consistent with both the cases of a perceptual bias and a response bias. In both cases, the temporal order of events is not clearly perceived. If there is a perceptual bias, prior beliefs about the temporal order of events are used to fill in this missing information. If there is a response bias, the order of events is estimated using prior beliefs to make a report at the time of response (a similar interpretation of the perceptual and response bias is given by Fernbach et al., 2007, p. 273).

It is not possible to settle the question of whether the attentional mechanism tells us the whole story about how causal beliefs can affect the perception of temporal order, since this requires further empirical investigation. Nevertheless, it remains a plausible explanation. Indeed, there are three aspects of the experiments reported that signal an attentional issue. First, subjects have an expectation about the temporal order of the events, so it is plausible to assume that they attend first to what they expect. And since the events to which one attends appear to take place before unattended events (this is the so-called 'prior entry effect', see Titchener, 1908, p. 251; for the influence of attention on temporal perception, see Spence & Parise, 2010), this might explain, at least in part, the reordering effect in Fernbach et al.'s (2007) and Bechlivanidis and Lagnado's (2013) experiments (Note 10). Second, in Fernbach et al.'s (2007) and Bechlivanidis and Lagnado's (2013) experiments, there is clearly a perceptual load at a very small timescale

(sliders moved either simultaneously or with a delay of 100 ms in Fernbach et al., 2007; there was an interval of 160 ms between the entrance of the red rectangle in the purple box and its transformation into a star, and 100 ms (Note 11) between the transformation into a star and the collision of the green square with the black platform in Bechlivanidis and Lagnado, 2013), which is an ideal condition for attentional overload. Third, since onset of motion attracts attention, it is plausible to assume that, in Bechlivanidis and Lagnado's (2016) experiments, the onset of C's motion may have drawn participants' attention, thereby conducting them to miss a part of B's behavior.

## 4. Causal Beliefs and Temporal Order: A Problem of Circularity

The interpretation of the reordering effect outlined above — that is, as occurring in conditions of perceptual uncertainty due to an attentional issue — possesses not only plausibility in view of the results of the experiments, as I argued in previous sections, but, as I will argue here, it also has the advantage of offering a coherent picture of the interplay between causal assumptions and the perception of temporal order.

The challenge of explaining such an interplay lies in avoiding a certain circularity. Indeed, the relationship between causation and perception of temporal order is typically described in psychology via the idea that temporal order is a cue or indicator for causation. But the discovery of the reordering effect shows that not only is it the case that temporal priority can elicit a causal assumption in a bottom-up process, but also that causal beliefs themselves can affect top-down perception of temporal order. In light of such a conception, the influence of causal beliefs on perception of temporal order (which the new findings on the reordering effect point out) exhibits a certain circularity, to wit: if causal beliefs can constrain our perception of temporal order, how can temporal order be considered a reliable cue in the formation of causal assumptions? In other words, if it is both the case that we draw on temporal order information to form causal assumptions and that causal assumptions 'distort' our perception of temporal order, this mutual constraint seems to undermine the soundness of our causal reasoning.

I propose an answer to this puzzle based on the assessment of the empirical results presented in the preceding sections. In this context, it will prove helpful to elucidate, in the first place, what it means for temporal order to be considered a 'cue' for causation. The idea of temporal order as a cue in causal cognition has its historical forerunner in Hume's idea that there are some rules by which we make causal judgments (1739–'40/1978, 1.3.15, p. 173). The first three rules Hume mentions in *A Treatise of Human Nature* are traditionally considered in the psychological literature to be three cues from which one forms causal beliefs. These cues are: spatial and temporal contiguity, that is, the idea that cause and effect

co-occur in spatial and temporal proximity; temporal priority, that is, the idea that causes precede their effects; and 'constant union' (also called 'contingency', 'covariation', 'cooccurrence' in the psychological literature), that is, the idea that cause and effect co-occur regularly. Certainly, the Humean idea of 'rule' does not play a role in contemporary psychology, where the concept of 'cue' corresponds rather to a piece of information considered to elicit a causal impression or to a piece of information on which we draw to make judgments or to form assumptions (Note 12).

The first thing to ask, in this context, is under what conditions does the perceptual temporal order information function as a cue for causal cognition? Unfortunately, despite the crucial role that temporal order information plays in the formation of causal assumptions (Note 13), temporal order has received much less attention than other cues such as temporal contiguity and contingency. Buehner states that the temporal priority cue "seldom subjects to empirical investigation" (2014, p. 4), and more recently he has pointed out that temporal priority as a cue towards causation has been taken as self-evident and has not been studied extensively (2017, p. 550). In 2006, Lagnado and Sloman reported that "[d]espite its potential to both inform and mislead our causal inferences, the role of temporal order has been assumed rather than investigated in the recent psychological literature" (2006, p. 451), while Bramley et al. have recently observed that "to date there has been little work on the role of temporal order" (2014, p. 236). Nevertheless, a closer look at what is considered to be, in the psychological literature, the role of a cue as a 'guide' in causal cognition will suffice for our present purposes of drawing a line between cases where temporal order functions as a cue on the one hand, and cases where causal assumptions constrain our perception of temporal order on the other.

One crucial aspect of cues as 'guides' in the detection of causal relationships is their function as 'indirect indicators' of causal mechanisms that are not observable (White, 2014, p. 39), as well as their function in determining "which event relationships will be judged as causal" (Young, 1995, p. 83). As such, cues provide the information needed for causal identification (White, 2014, p. 61). White highlights the problem that there may be many events that stand as candidates for the role of cause of a specific effect, which creates a condition of 'uncertainty' regarding causal attribution. In such cases, cues provide useful information in discerning causal attribution. This conception of the cue as a guide to identify causes that are not directly perceived, or in contexts where there are several events which, by virtue of their mechanical properties, may apply to the role of cause of a certain event, is clearly a very general claim. It applies not only to temporal precedence information, but also to other cues. The role of temporal priority as a cue is, in this context, similar to the role that temporal contiguity has as a cue in causation: it helps to disambiguate relations between events by providing a guide for the selection of which event(s), from a group of multible possible causes, will be

considered potential causes of the effect (Hagmayer & Waldmann, 2002, p. 1129). Temporal priority information is thus used to reduce the space of the candidate causes (Bramley et al., 2018) by eliminating events occurrring after the relevant effect (Note 14).

Findings from developmental psychology confirm that temporal precedence is used as a cue in selecting relevant causes from an early age. Experiments show that the majority of children between five and seven years of age rely on relations of temporal order when making a causal judgment (Note 15). Arguably, the extent to which temporal priority information determines a causal judgment depends on several factors. While we lack a systematic study of this for temporal order information, we might think here of the study by Woods et al. (2012) in which it is demonstrated that context modulates people's sensitivity to temporal and spatial contiguity in judgments of causality (Note 16). It is plausible to think that this also applies to temporal priority.

What is important for our purposes here is that the studies cited converge on the idea that temporal order information is a crucial piece of information that is used to form causal beliefs in cases where there is uncertainty about the cause. Now, according to my interpretation of the reordering effect, as sketched out in the previous sections, this effect occurs in conditions of perceptual uncertainty concerning the temporal order of events. The object of uncertainty here is therefore not the cause itself, but rather the temporal order. This interpretation allows us to solve the puzzle that may arise regarding the mutual constraint of the perception of temporal order and causal assumptions. Indeed, if we accept that the reordering effect can be described as an effect occurring in a context of uncertainty concerning temporal order, in which causal beliefs are used to obtain temporal order information, then we can distinguish it from the opposite case, where perceptual time information is accurate and provides a cue to form causal beliefs when the cause is uncertain.

Indeed, a common feature of the three studies mentioned above about the reordering effect is that they investigate the influence of already acquired causal beliefs on the perception of temporal order: in both Fernbach et al. (2007) and Bechlivanidis and Lagnado (2013), the causal beliefs are induced by the experimenters before the test phase. Although this is not the case in Bechlivanidis and Lagnado's 2016 paper, they report experiments using lauching sequences. It is to be expected that lauching sequences prompt familiar causal representations of collisions in the subjects. Whether we have recently learned causal relations (in Fernbach et al., 2007 and in Bechlivanidis & Lagnado, 2013), or established beliefs about collisions (Bechlivanidis & Lagnado, 2016), there are, in the three studies, prior beliefs about causal relations, which can influence reports about temporal order (Note 17).

This kind of scenario (in which there is some form of prior knowledge) is therefore distinct from those contexts where temporal priority becomes a more

crucial cue for causation. Once beliefs are acquired, they may override temporal information, since they carry implicit expectations and predictions. In cases of perceptual uncertainty concerning temporal order, the information system can draw on abstract representations to solve ambiguities in perception. This picture is similar to the one suggested by Buehner (2014) to explain the 'two-way street' between temporal contiguity and causal beliefs (Note 18). Temporal contiguity is, like temporal priority, a cue that the information system draws on in order to form causal assumptions, but causal beliefs also have a top-down influence on the perception of duration in the 'temporal binding effect' (Buehner, 2012; Buehner & Humphreys, 2009).

In this picture, there is no contradiction or circularity in believing, on the one hand, that temporal priority is a crucial cue for causal learning, and, on the other, that there is the possibility of distortion in time order perception through abstract representations. When causal beliefs are not yet formed, but are emerging from our experience of events, temporal priority functions as a crucial cue to causal attributions. If the causal belief is already formed, this may influence, in turn, future attributions of causality and, therefore, judgments related to the cause — such as judgments about temporal precedence — since causal representations carry implicit temporal assumptions. This interpretation is consistent with the view that people use cues in proportion to the reliability of these cues. For instance, Lagnado and Sloman predict that if there is reduced reliability of the temporal cue, people assign less weight to this cue (2006, p. 459).

In sum, the fact that the mutual constraint between causal assumptions and perception of temporal order can be explained, as I argue, by drawing a line between two different cases depending on the object of uncertainty (whether cause or temporal order), renders plausible my interpretation of the reordering effect as occurring in conditions of perceptual uncertainty.

## 5. *Reordering* the Philosophical Debate on Temporal Perception

In the previous sections, I have been concerned with the consequences of the discovery of the reordering effect for causal cognition. More specifically, the reordering effect shows that temporal priority information is not always used by the information system as a reliable cue for the formation of causal beliefs, and that causal assumptions can override such features. I argued that this does not contradict the view of temporal priority as a crucial cue towards causation, and suggested briefly how the interplay between causal assumptions and the perception of temporal order can be understood in light of these new findings. In this section, I want to take note of some of the potential consequences of the discovery of the reordering effect for the current philosophical debate on time perception. I suggest that the reordering effect is a different kind of temporal illusion about temporal order from those that are typically discussed in the contemporary

literature on time perception, and, as such, it presents novel challenges to existing philosophical theories.

In the current philosophical discussion, arguments based on temporal illusions play a significant role in the defense and criticism of theories of time perception. For instance, Grush states that one standard tool for investigating the extent and nature of the 'interpretative' aspect of perception is the perceptual illusion (2009, p. 597). The contemporary debate about illusions involving temporal order is principally dominated by the discussion of the kind of illusions put forward by Dennett (1991) and by Dennett and Kinsbourne (1992). Their discussion is directed against theories of time perception, which, according to these authors, do not acknowledge the interpretative dimension of time perception, and, therefore, assume that the brain passively registers temporal information. More recently in this line of thought, Grush has analyzed some illusions in order to demonstrate that processes of perception are "infused by theory and expectation" (2009, p. 597). The kind of illusions that, according to these authors, signal the active and interpretative aspect of time perception are the so-called 'postdictive' phenomena, in which a stimulus presented later affects the perception of an initial stimulus. Examples of such phenomena include the 'cutaneous rabbit' (Geldard & Sherrick, 1972) and the 'flash-lag effect' (Eagleman & Sejnowski, 2000). Both of these temporal illusions have the common feature of occurring at very small temporal scales.

In the case of the cutaneous rabbit, 15 small taps (each with a duration of 2 ms) are produced in rapid succession (with each tap separated by 40 to 80 ms) at three points on the subject's arm (at the wrist, then 10 cm away from the wrist, and then near the elbow). If only five taps are delivered at the wrist, the subject experiences them accurately as being located at the wrist. But if the 15 taps are produced, the subject reports experiencing them as distributed more or less uniformly from the wrist to the third point near the elbow. In the case of the flash-lag effect, a small flash and a moving ring in the same location are presented to a subject. The perception of the subsequent motion of the ring has an effect on whether the subject accurately perceives the flash in the middle of the moving ring or inaccurately perceives the moving object ahead of the flash (Note 19).

Dennett, as well as Grush, asserts that this illusion shows that a stimulus is interpreted according to what we experience after the stimulus. In other words, the brain does not passively register the temporal order of events, since something that is presented later can influence the experience of a stimulus presented earlier. Philosophical theories after Dennett, which refrain from assuming that the brain somehow provides an 'interpretation' of the perceptual input, have taken up the challenge of explaining these postdictive phenomena. It is beyond the scope of the present paper to provide a detailed account of these explanations and their validity. It will suffice, for our purposes here, to briefly show how these explanations do not capture the illusion of temporal order in the reordering effect. What I want to stress here is the novelty of the reordering effect.

There are two categories of explanation to these illusions found within contemporary theories of time perception, which refrain from acknowledging an 'interpretative' dimension in perception of temporal order: one common explanation for the postdictive phenomena is that our experience lags 'behind' the occurrence of the stimulus, meaning that information processed at a later stage within a very short timescale (80–100 ms) can change the way the initial stimulus is experienced. Dennett calls this explanation the "Stalinesque account" (Dennett & Kinsbourne, 1992, pp. 196–197) (Note 20). It corresponds to the explanation of the postdictive phenomena provided by the philosophy of Dainton (2008, p. 382). Another way of interpreting the postdictive phenomena present in contemporary literature on the philosophy of time is to argue that experience cannot be analyzed down to instants (or very brief durations) (Phillips, 2014a, p. 151). The idea is that "a subject's experience at a time is logically dependent on facts about experience at later times (…)" (Phillips, 2014b, p. 136). Concerning the phenomenon of the cutaneous rabbit described above, Phillips maintains that the puzzlement arises only when one asks what the subject feels *at a specific time*. He argues that the question of what the subject feels at a given instant in the second trial (that is, the 15 taps) is not a legitimate one. In line with this, Hoerl also esteems that one strategy of response to arguments based on this kind of temporal illusion is to state that experiences cannot be sliced arbitrarily finely (2009, p. 10). Both explanations (the 'delay explanation' and the 'non-analyzable experience explanation') try to get away with an account of the temporal illusion in the postdictive phenomena without assuming a top-down influence on the perception of temporal order.

None of these accounts (neither the 'delay explanation' nor the 'non-analyzable experience explanation') can be transferred to the reordering effect. The 'delay explanation' is only applicable if we have two different answers depending on the (non-)existence of subsequent stimuli. And the 'non-analyzable experience' explanation is applicable in cases where there is a slicing of experience into very short instants. In contrast, in the case of the reordering effect, the illusion does not arise from the division of the experience in small blocks and there are not two different answers depending on the temporal point of the report as in the 'cutaneous rabbit'.

Indeed, the reordering effect has two features, which distinguish it from the usually discussed illusions, namely the postdictive phenomena. The first is that the reordering effect is actually an illusion about temporal order, whereas the postdictive phenomena mentioned earlier are illusions that exhibit a temporal dimension. If we take temporal illusions to mean that temporal features, i.e., temporal properties and relations, are illusory (Power, 2011, p. 18), then the postdictive phenomena are not temporal illusions in this sense. The content of the illusion is not temporal, although they somehow involve temporal order. Take, for instance, the case of the cutaneous rabbit. Since what is accurately or inaccurately

experienced is the tap's location, we have here a spatial illusion (Note 21). In other words, it is the spatial property of the tap that is the object of illusion. Nevertheless, as Grush rightly points out, although it may seem that we are dealing here with a spatial illusion, there is a temporal aspect to it (2007, p. 32). Indeed, Grush states, we do not only ask where the subject feels the second tap, but where the subject feels the second tap *when the second tap is produced* (2007, p. 32). If the second tap is delivered in the context of the first five taps at the wrist, the subject will feel the tap at the wrist. But if 15 taps are delivered, the second tap will not be felt at the wrist like the first tap. In other words, the perception of the location of the second tap is modified by a perception that comes later. There is, therefore, a temporal dimension in this illusion and indeed such illusions are depicted in the psychological literature as "spatiotemporal illusions" (Asai & Kanayama, 2012, p. 103). Differently to the postdictive phenomena, in the reordering effect, the temporal aspect of the illusion does not concern what a subject perceives at an instant (the *when* of the perception), but that the subject reports actually having perceived another temporal order to the one presented to him. With the reordering effect we have an illusion of the perception of temporal order, which does not fit into the kind of temporal illusions discussed in the contemporary philosophy of time perception.

Second, as argued in the previous section, the reordering effect exemplifies how abstract representations can influence the perception of temporal order. As such, the reordering effect challenges philosophical theories that do not recognize such mechanisms in the perception of temporal order. The account of the temporal illusions in postdictive phenomena hinted at above disregard an influence of expectations and predictions in our perception of temporal order. Even if one grants that it is not necessary to assume an influence of expectations and predictions in our perception of temporal order for an account of the postdictive phenomena (and I leave this question open here), it is not possible to explain the reordering effect without taking the influence of prior beliefs (in this case, causal beliefs) on our perception of temporal order, because only this can explain the effect. The fact that perception may be delayed or that it is not analyzable into small instants may account for the fact that information taking place after one stimulus will have an influence on the perception of this stimulus (Note 22), but it cannot account for the influence of prior causal beliefs on our perception of temporal order. In this sense, the reordering effect challenges contemporary philosophical theories of time perception, which do not explicitly take into account a top-down influence on perception when explaining temporal illusions.

Whether these theories can meet the challenge of the reordering effect is, in my view, fundamental to their plausibility. Of course, one could argue that not all philosophical theories of time perception must give an account of temporal illusions such as the reordering effect, if their aim is not to undercover the mechanisms at play in the perception of temporal order. But certain theories at least ought to be

capable of accommodating these new findings, in particular those theories that have sought to explain the postdictive phenomena such as Phillips' mirroring view (Note 23), and which, therefore, maintain the ambition of accounting for the empirical findings about temporal perception.

It has been argued that philosophers do not often refer to psychological experiments because their approach is phenomenology-based, whereas psychologists are interested in the mechanism behind the phenomenology, that is, they are performance-based (Arstila, 2011, p. 2; see also Hoerl, 2009, p. 12). To a certain extent, one is inclined to agree with this distinction. Indeed, the experiments on the reordering effect do not bear, for instance, on the claim of Phillips' mirroring view on time perception, according to which the temporal properties of the experience match the temporal properties of the perceived objects as experienced. This is because, regardless of the mechanism at stake, the subjects reporting the reordering effect consider that the order reported is the order they have perceived, and that is what the mirroring view predicts. Bechlivanidis and Lagnado (2016) briefly refer to the mirroring view and seem to acknowledge at the beginning of their paper that their findings do not present a counter-argument to this theory. Yet, later, they state that their findings appear to discredit the mirroring view, because the order in which events are experienced does not match the order in which they occur (2016, p. 63). Phillips' mirroring view, however, does not imply that the order of the events experienced is the order in which they occur. The central claim of the mirroring view — namely that the temporal properties of the experience match the temporal properties of the perceived objects as experienced — expresses something about phenomenology and not about the relationship between our experience and the structure of the world. Therefore, I do not think that the new findings have any consequences for the philosophical debate on time perception in the way suggested by Bechlivanidis and Lagnado. Rather, I think that the challenge for philosophical theories comes from the fact that the reordering effect implies a top-down influence on the perception of temporal order. Indeed, if the relationship between temporal features of perception and temporal features of the perceived should have explanatory power (as Hoerl, 2009 states), then it seems that facts about the phenomenology of our experience should have a theoretical role in explaining our time perception. More specifically, the challenge for the mirroring view regarding the reordering effect is that of explaining how the mirroring claim relates to an explanation of the fact that, in the reordering effect, the order of the perceptions does not determine the reporting about their order.

## 6. Conclusion

In this paper, I have argued for an attentional explanation of the reordering effect and have briefly considered its implications for our understanding of causal cognition and for the contemporary philosophical debate on time perception.

By assessing the experimental design and the results obtained, I argued that subjects were presented with a big perceptual load within a small amount of time and therefore were not in a position to attend accurately to the temporal order of all events. Furthermore, I stressed that the subjects in the experiments were in possession of established causal beliefs. These two conditions (perceptual uncertainty and strong causal expectations) favor an attentional explanation of the mechanism behind the reordering effect.

I showed that this explanation of the reordering effect has the advantage of solving the circularity of the interplay between causal assumptions and the perception of temporal order. Indeed, the puzzlement that can arise from the mutual constraint of causation and perception of temporal order can only be solved if one distinguishes between the conditions under which one case — i.e., temporal order constrains causal assumptions — and the converse case — i.e., causal assumptions influence temporal order — obtain. This is consistent with the idea that people rely on cues in proportion to their reliability: when temporal order information is not accurately perceived, subjects attach less importance to this information and draw on causal assumptions about a sequence of events to fill in the missing information about temporal order.

The paper ended with a brief sketch of how the discovery of the reordering effect may have an impact on the current philosophical debate on time perception. Contrary to other temporal illusions discussed in the philosophical literature about time perception (postdiction effects), the reordering effect is an illusion concerning the temporal properties of the events and, furthermore, illustrates, in a new way, how prior beliefs serve to shape our perception of temporal order.

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**Notes**

1. I will not discuss in this paper the concept of causation itself, but it is worth clarifying here what is meant by 'causal beliefs' or 'causal assumptions'. What makes a belief or assumption a causal one is its specific explanatory function. In this regard I adhere to the idea that '(...) what makes a concept a causal concept is just that it has to do with explaining why something happened; why an event or state of affairs occurred, or came about, or persisted; what produced some event or state of affairs; why a particular thing behaved as it did, or why that kind of thing generally behaves as it does; and so on' (Child, 2011, p. 174).

2. Apart from these three studies, there is a paper currently under review (Tecwyn et al., 2019), which investigates whether causal beliefs can affect children's temporal perception. I am very grateful to a reviewer for having drawn my attention to this paper. There are also a few recent studies which seem to have identified an effect similar to the 'reordering effect' in the context of agency: the person's belief that an act of hers is the cause of an event can have a top-down influence on the perceptual experience of the temporal order of the act and of the event interpreted as 'effect' (Desantis et al., 2016; Rohde et al., 2014). In my paper, I focus on observational contexts.
3. This means that participants learned the causal relationships by interacting with the sliders.
4. Bechlivanidis and Lagnado report a second experiment, which reproduces and develops the findings of the first. Given the constraints of the present paper, I shall not discuss it here.
5. According to the study by Kanabus et al., the order threshold of two acoustic or two visual events is above 40 ms (2002, p. 267).
6. In Experiment 2, this problematic detail of the design of Experiment 1 is absent. Nevertheless, it is still the case that there are very short temporal intervals in Experiment 2, which speaks in favor of the temporal uncertainty of the sequence. Indeed, in the test clip (incongruent with the causal beliefs induced) of the Training Group A, the transformation occurred approximately 165 ms before the collision. In the test clip of the Training Group B, it is not a collision that is the event causally linked with the transformation of the red rectangle into a star, but rather its entrance into the purple square. This entrance also occurs 165 ms after the transformation (of the red rectangle into a star) in the test clip incongruent with the causal beliefs induced.
7. I am grateful to a reviewer for having drawn my attention to this point.
8. In contrast to my view, Bechlivanidis and Lagnado assume that, when B's motion is detected, participants have an accurate perception of its onset as such.
9. Bechlivanidis and Lagnado mention the possibility of using such methods, but still insist that their experiments rule out an attention-based explanation of the reordering effect. On this basis, they reject the idea that the causal schema (here the abstract representation of successive collisions) may be used to fill in missing information of an incomplete percept. For the reasons given above, I think that they cannot rule out this idea. They suggest two further roles for the causal schema in the reordering effect: to influence perception, and to distort working memory (which corresponds either to a misperception or a misremembrance interpretation of the basis of the reordering effect). They consider this alternative to be undecidable. A fourth

possible role of the causal schema that they also mention is that of enabling one to infer temporal order. Nevertheless, as Bechlivanidis and Lagnado point out, such an interpretation of the role of the causal representation would presuppose a rather radical assumption about perception of temporal order — namely the idea that there is no spontaneous temporal order judgment taking place in the experiments (2016, p. 64).

10. A reviewer has drawn my attention to the fact that if this also applies to the launching sequence of Bechlivanidis and Lagnado (2016), then participants should have attended first to B moving. Nevertheless, in my view, there is a difference between the experiments in Bechlivanidis and Lagnado's 2013 paper and their 2016 paper with regard to expectations. Whereas in the 2013 paper they train participants in causal beliefs which carry expectations about the order of events, in the 2016 paper they do not induce such expectations in participants. In this sense, participants do not necessarily expect a launching sequence in Bechlivanidis and Lagnado (2016) before being exposed to it. In this case, it is plausible to assume that their attention is not driven by an expectation about B's movement, but by the onset of C's motion. As I stated earlier in the paper, it is not possible to decide this matter without further empirical investigation.
11. As I hinted at earlier in section 2, although there is a difference of 200 ms between the transformation of the red rectangle into a star and the collision of the green square with the black platform in the test clip, in the training phase the transformation of the red rectangle into a star already occurs 100 ms before the collision of the green square with the black platform. This means that the temporal difference of the sequence of the first relationship in the experimental phase compared with the one of the training phase is not 200 ms, but only 100 ms.
12. The exact role of temporal priority as a cue for causation differs whether one believes that causation is an object of perception or not. Proponents of the perceptual nature of causation would rather spell out the role of temporal priority as a cue in terms of temporal priority providing information which is 'read off' by the information system and which, alongside other features, enables a perception of causation. Proponents of the idea that causation is inferred pin down temporal priority as a cue in the sense of information that allows one to infer a cause which is not perceived.
13. Lagnado and Sloman (2004) show that temporal order cues improve causal learning; Lagnado et al. (2006) found that there is a strong influence of temporal order information on participants' causal judgments, such that temporal order cues may override statistical covariation; White (2006) carried out experiments in which participants were asked to infer the causal structure

from cooccurrence information. Results show that temporal order information may be preferred as cue to causal structure over patterns of cooccurrence. For the importance of the temporal priority principle in causal beliefs related to agency, see Rohde et al. (2014).

14. Also in the construction of initial causal models, temporal order cues are used in identifying the possible causes, as Lagnado et al. suggest (2006).
15. Whether and to what extent younger children are sensitive to this principle is a matter of debate. In a study, Shultz and Mendelson (1975) offer evidence for the fact that three-year-old children may not follow precedence in causal judgments. This study is contradicted by Bullock and Gelman (1979). Rankin and McCormack (2013) found that four-year-olds' judgments rarely violate the temporal priority principle, while three-year-olds do not perform as well as the four-year-olds. Rankin and McCormack provide two possible explanations for this: (1) three-year-olds may be trying to use the temporal priority priciple, but they do not remember the order of the events in some trials (processing explanation); (2) three-year-olds do not have an explicit grasp of the significance of the temporal priority principle (reasoning explanation).
16. Brown and Miles (1969) have also showed that context modulates causal perception. I would like to thank a reviewer for this reference.
17. It is in fact widely acknowledged among psychologists that prior knowledge can influence causal attributions. For the role of prior experience, see Young (1995).
18. Buehner further offers a Bayesian interpretation of the mutual constraint between causality on the one hand, and temporal and spatial contiguity on the other: "Causal binding in time and space actually follows from a Bayesian interpretation of Hume's principles: if it is the case that temporal or spatial contiguity increase the likelihood that we form a causal connection between two events, then it is also true that once we have formed such a connection, it is also more likely that cause and effect are relatively contiguous in space-time. Because human time perception is inherently ambiguous and noisy, the mind can attempt to resolve some of this ambiguity by drawing on higher level knowledge of causality between the constituent events" (2014, p. 7).
19. For a study about postdiction in causal cognition see Choi and Scholl (2006).
20. Alongside the Stalinesque account, Dennett refers to the "Orwellian revision" (1991, pp. 115–126), which explains the postdictive phenomena in the following way: the first stimulus is accurately experienced, but it is later overwritten by a subsequent experience. I do not mention this account, because it is not popular among philosophers.

21. Bechlivanidis and Lagnado briefly mention postdiction effects, stating that there is no distortion of temporal order, but "rather of the properties of events or objects" (2016, p. 59).
22. I do not mean that these accounts of the postdictive phenomena are correct (to discuss this is beyond my present purposes), but rather that it is not evident that a top-down mechanism must form part of these explanations of postdiction. In the case of the reordering effect, there is empirical evidence that the illusion is taking place because there is a top-down influence of causal beliefs on the perception of temporal order.
23. According to Phillips' mirroring or naïve view (Phillips, 2014a,b), the temporal properties of perceptual experience match the temporal properties of the objects perceived.

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