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Causal Illusions: A Dual-Process Hypothesis of Causal Reasoning

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An abstract of
A thesis submitted to the Faculty of the
James T. Laney School of Graduate Studies of Emory University
in partial fulfillment of the requirements for the degree of
Master of Arts
in Psychology
2016

Abstract

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According to existing accounts of causation, people rely on a single criterion or process to identify the cause of an event. The phenomenon of causal illusions raises problems for such views. Causal illusions arise when a particular factor is perceived to be causal despite knowledge indicating otherwise. According to what we will call the Dual-Process Hypothesis of Causal Identification, identifying a cause involves two cognitive processes: 1) an automatic, intuitive process that identifies possible causes on the basis of perceptual cues, temporal cues in particular, and 2) a slow, reflective process that identifies possible causes on the basis of causal inference, in particular, a consideration of possible mechanism. Consistent with this hypothesis, we found that in response to a causal illusion shown in a naturalistic setting, people's initial judgments of causation were higher than their ultimate judgments of causation (Experiment 1). Using an online measure of the time-course of people's causal judgments, we found that people initially view animations of causal illusions as causal before concluding that they are non-causal (Experiment 2). Finally, we obtained similar results using a deadline procedure, while also finding that the lower the cognitive reflectiveness (as measured by the CRT), the stronger people's impressions of causation were (Experiment 3). Implications for different classes of theories of causation are discussed.

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Introduction

In 1977, New York City experienced a major blackout. Remarkably, some individuals felt, at least momentarily, that the blackout was caused by their own actions. For instance, Sparrow (1999) reports a child who hit a ceiling light fixture with a paddle ball at the exact moment the lights went off, and an opera singer who touched a door just as the power went out. One person exclaimed after plugging in a toaster, “I blew out the whole neighborhood!” (Sparrow, 1999). In situations such as this, people may experience strong feelings of causation while at the same time knowing that such feelings are unwarranted. They may experience what we will refer to as a *causal illusion*.

The fact that people can have conflicting judgments about the existence of a causal relationship is consistent with the idea that judgments of causation may be based on two, not one, kinds of processes: 1) a fast and intuitive process that identifies potential causes on the basis of perceptual cues, temporal cues in particular, and 2) a slow and reflective process that identifies potential causes on the basis of causal mechanisms, and in particular, how the entities in an event might be spatially arranged in order to allow for the transmission of energy or force (Wolff & Shepard, 2013). According to what we will call the *Dual-Process Hypothesis of Causal Identification*, these two processes occur regularly in people’s analyses of everyday events. The two processes may not be easily recognized as distinct processes because in most cases they lead to the same conclusion. In the case of causal illusions, however, the conclusions of the two processes diverge, and hence their presence is revealed. The aim of this paper is to use the case of causal illusions to test the dual-process hypothesis of causal identification.

Dual-Process Theories in Psychology

The dual-process hypothesis is supported by the success of a number of dual process theories of cognition (Sloman, 1996; Evans, 1984; Stanovich, 1999; De Neys, 2012; Kahneman, 2003). Dual-process theories argue that people have two fundamentally different ways of approaching thinking and reasoning problems. First, people frequently use cognitive shortcuts called heuristics to answer difficult questions by simplifying the question (Tversky & Kahneman, 1974). An example is the representativeness heuristic, where people judge the probability that something is the case by judging how much it represents the outcome (Tversky & Kahneman, 1972). Second, people can use deliberate, rule-based reasoning. An example of rule-based reasoning is the use of probabilities to explicitly calculate the probability of a particular outcome. Dual-process theories argue that these two kinds of reasoning are supported by dissociable cognitive processes: an *intuitive* process that performs heuristic-based reasoning, and a *deliberative* process that performs rule-based reasoning.

Dual process theories have been used in the explanation of a number of cognitive phenomena, such as moral judgment (Greene 2001, 2007; Greene, Morelli, Lowenberg, Nystrom, & Cohen, 2008) and persuasion (Perry & Cacioppo, 1986; Chaiken, 1987). Interestingly, such theories have not been applied to the understanding of causal reasoning. A reason why this might be case is because there are multiple ways in which dual process theories can be realized, making such explanations nearly as problematic as the phenomenon they are used to explain. A brief discussion of some of these variants will help highlight the ways in which dual process theories can be used to account for causal cognition.

A key question that dual process theories of cognition need to explain concerns the temporal relationship between the two kinds of processes (Evans, 1984). There are two prominent options for how dual processes might be related to each other. In serial models, one of the processes begins and ends before the second process is initiated. It is typically assumed in serial models that the first process to begin involves intuitive processes, whereas the second process concerns deliberative processes. According to Evans (1984), the intuitive process is preattentive and serves to select which aspects of a decision are relevant for further processing. In Stanovich's (1999, 2011) default-interventionist model the later deliberative process serves the function of monitoring the initial intuitive process, intervening when a potential conflict is detected between the two processes.

In parallel models, the two processes overlap in time, although the intuitive process is assumed to run faster than the deliberative process (Sloman 1996, 2015). Parallel theories argue that the major difference between intuitive and deliberative processes is computational: the intuitive system performs associative reasoning, while the deliberative system performs rule-based reasoning (Sloman, 1996). Some recent accounts have also proposed a hybrid between parallel and associative theories (De Neys, 2012; Evans, 2009).

A second key question that dual process theories must contend with is whether the deliberative process is really one or two processes. Stanovich and West (2008) point out that the deliberative process really performs two separate functions: deciding to override the intuitive system, and rule-based reasoning. According to some recent models (Stanovich, 2011; Evans, 2009), these separate functions are really two dissociable cognitive processes. The *reflective mind* detects conflicts between intuitive and deliberative responses and decides to whether to override the intuitive system. The *algorithmic mind* performs cognitive decoupling, i.e. the actual rule-based computations, as well as the inhibitory control required to inhibit an intuitive response while computing a reflective response.

Existing Accounts of Causal Reasoning

The dual-process hypothesis of causation differs from most accounts of causation in that it assumes more than one cognitive process. Most other theories of causation posit a single cognitive process only, although there is disagreement about what this single process is.

Dependency accounts argue that causal reasoning is reasoning about whether an effect depends on a cause. This dependency can be probabilistic (Kelley, 1973; Cheng & Novick, 1992), logical (Goldvarg & Johnson-Laird, 2001), or counterfactual (Wells & Gavanski, 1989). Recently, dependency accounts have been formalized using causal Bayesian networks (Gopnik et al, 2004; Glymour, 2003; Pearl, 2009).

A difficulty for dependency accounts is that people have difficulty learning causal relationships using dependencies alone. Rather, participants usually require information about perceptual cues (Lagnado & Sloman, 2006; Lagnado, Waldmann, Hagmayer, & Sloman, 2007) or causal mechanism (Lagnado & Sloman, 2006; Griffiths & Tenenbaum, 2009) to learn causal relationships. Additionally, when dependency information conflicts with information about causal mechanisms, participants usually learn the causal structure consistent with mechanism, not dependency, information (McCormack, Frosch, Patrick, & Lagnado, 2015; Schlotmann, 1999). This difficulty in using dependency alone in causal learning suggests that a single process may not be sufficient to explain causal induction.

Perceptual cue accounts argue that people use spatial and temporal perceptual cues to judge whether A causes B (Michotte, 1963; Scholl & Tremoulet, 2000). Consistent with the predictions of perceptual cue accounts, manipulations of spatial (White, 2011; Yela, 1952; Rolfs, Dambacher, & Cavanah, 2013) and temporal (Shanks, Pearson, & Dickinson, 1989; Bullock & Gelman, 1979; Lagnado et al, 2007) cues, as well as object velocity (White, 2007), affect participants' reports of causality.

The existence of a variety of top-down effects on causal perception may suggest that a perceptual process alone cannot fully account for causal induction. Participants' beliefs about causality can distort their perception of temporal order (Bechlivanidis & Lagnado, 2016; Faro, Leclerc, & Hastie, 2005) or the length of a temporal delay (Buehner & Humphreys, 2009a, 2009b). The presence of a causal or non-causal context event can bias causal perception (Scholl & Nakayama, 2002; Choi & Scholl, 2004). Participants' knowledge about the underlying event can lead them to be more tolerant of temporal delays (Buehner & May, 2002; Buehner, 2005). The presence of numerous top-down effects on causal perception may be more consistent with a multiple-process account, where additional processes in addition to perception are relevant to causal induction.

Process accounts argue that causal reasoning is about determining whether there is a plausible force, process, or mechanism linking cause to effect. Process accounts are supported by research on participants' question-asking (Ahn, Kalish, Medin, & Gelman, 1995), ratings of causal strength (Lomborozo, 2010; Walsh & Sloman, 2011), and the above-mentioned research that mechanism information dominates dependency information in causal learning (McCormack, Frosch, Patrick, & Lagnado, 2015). Process accounts have been formalized in the force dynamics account, which extends both its computational power (Wolff, 2007) and ability to represent the linguistic extension of causal verbs (Wolff & Song, 2003; Wolff, 2007). While process accounts have enjoyed much success in accounting for causal induction, a challenge for process accounts may be fully accounting for more abstract cases of causation (Wolff, 2007), as well as a limited number of cases in which participants successfully learn domain-general causal relationships from dependency alone (Gopnik, Glymour, Sobel, Schultz, Kushnir, & Danks, 2004). Again, positing more than one cognitive process may help address this worry.

Causal illusions present a case – rare in the causal reasoning literature – where many people reason in a non-normative way. While the normative response is that causal illusions are not causal, in a series of three experiments we will show that many people initially give the non-normative response that such illusions are causal. The major claim of the dual-process hypothesis is that such departures from normative reasoning can provide insight into the normal functioning of the causal reasoning system. Just as visual illusions can provide insight into the way the visual system normally works, so too we argue that causal illusions may provide insight into how the causal reasoning system normally works.

Experiment 1: “Jedi Powers”

In Experiment 1, we aimed to establish the phenomenon of causal illusions, and to begin to investigate the time-course of causal identification. In this study participants experienced an unexpected causal illusion on their way to our lab: a man appeared to open an elevator door by merely gesturing with his hands (Figure 1). Importantly, the man made no physical contact with the doors or with any of the buttons in the elevator. Unbeknownst to the participants, the doors were opened by a confederate outside of the elevator pushing the elevator button. Our main prediction was that the intuitive system would lead to feelings of causation that would ultimately be reduced by the reflective system. Participants' impressions of causation were measured in the subsequent interview, which included a short questionnaire.

Methods

Participants. Twenty-three undergraduate participants were recruited for a study on perception and tested in groups of 1-4. One participant was excluded because they personally knew the confederate.

Causal Illusion. Participants were informed that the study would take place in our lab on another floor and followed a research assistant to the building elevator. There, a confederate pretended to re-open the elevator doors using only his hands (see Figure 1). The confederate re-opened the doors a total of three times, and maintained a neutral expression. In reality, the doors were controlled by an unseen confederate; no participants reported discovering the unseen confederate.

Causality Ratings. After the causal illusion, participants completed two sets of written ratings. (A) *Causality Description*: participants answered three questions about their experience: "what do you think you saw?," "please describe how this impression unfolded over time," and "did you think the man caused the elevator doors to open?" (B)

Time-Course Ratings: participants rated the following statements on a 1-5 Likert scale: "to what extent did you [feel for a moment / ultimately conclude] that the man caused the elevator doors to open?"

Causality Coding. Two raters unfamiliar with the experiment coded participants' written descriptions for two features. (A) *Link Rating*: did the written descriptions mention a link between the man and the doors opening? (B) *Causality Rating*: did the written descriptions attribute causality to the man in causing the doors to open?

Results

Causality Descriptions. If causal illusions are in part causal, participants should spontaneously attribute causality to the Jedi in their causal descriptions. Participants' written descriptions frequently attributed causality to the confederate. Example descriptions were that "A man was controlling the doors of the elevator with his hands," "The man in the elevator kept causing the door to stay open on the wrong floor, like magic," and "A man […] was able to open the doors simply by moving his hands." Coders rated a mean of 87% of written descriptions as causal (inter-rater reliability=89%, kappa=0.33), suggesting that participants spontaneously perceived causal illusions as causal.

Time-Course Ratings. According to the dual-process hypothesis, causal illusions should create a strong *initial* impression of causality, but weaker *subsequent* impression of causality, due to the conflict between intuitive and reflective systems. Participants' time-course ratings supported this account: participants rated a stronger initial than ultimate impression of causality, $t(21)=3.72$, $p<0.01$ (Figure 2). This difference in causality ratings was consistently observed in individual participants. A majority of participants (13/22) rated a stronger initial than ultimate impression of causality, while just 2 participants rated a stronger ultimate than initial impression.

Because the number of participants varied from trial to trial, we conducted an additional analysis to ensure that participants' ratings were not driven by the impressions of other participants. There was no effect of the number of participants on either participants' initial impression of causality, $F(3,18)=1.10$, $p=0.37$, or on their ultimate impression of causality, $F(3,18) < 1$, n.s..

Discussion

There are two main results of Experiment 1. First, the results show that causal illusions give rise to impressions of causality, even in the absence of a possible mechanism, at least initially. The majority of participants' written descriptions attributed causality to the confederate, and causal illusions received high initial ratings of causality. Second, the results provide initial support for the predictions of the dual-process hypothesis. Causal illusions created a stronger initial than ultimate impression of causality, consistent with a conflict between a fast intuitive system using perceptual cues and a slower reflective system using background knowledge. This effect was consistent across participants and rarely occurred in the other direction.

A limitation of Experiment 1 is that we were only able to measure participants' impressions of causation well after the occurrence of the event, rather than as they actually unfolded in real-time. The results are vulnerable, then, to the possibility that participants really did not have a strong initial impression of causation, but merely attributed this impression after the fact. In Experiment 2, this limitation was addressed through the use of a real-time measure of participants' impressions of causation.

Experiment 2: Time Course

In Experiment 2, participants viewed three kinds of events: causal, non-causal, and causal illusions (see Figure 3A). The temporal unfolding of the three kinds of events was exactly the same, except for the position of the causer in the scene. For example, in one set of animations, participants saw a record begin to turn (Figure 3A). In the causal version, the hand made physical contact with the record. In the non-causal version of the event, the hand did not move. In the causal illusion version of the event, the hand moved, but did not make physical contact with the record. The experiment included six different sets of animations. As participants watched an animation, they indicated the degree to which they felt the event was causal or non-causal by how far they turned a dial to the right (causal) or left (non-causal) (see Figure 3D). Participants could change how far they turned the response dial at any point during the presentation of the animation. The dual-process hypothesis predicts that for the causal event, participants should move and keep the dial in the cause direction. For the non-causal event, participants should move and keep the dial in the non-causal direction. Critically, for the causal illusions, the dual-process hypothesis predicts that participants should *initially* move the response dial to cause, but *later* move the response dial to non-cause.

Methods

Participants. Sixty adult participants were tested individually in the lab. Three participants were excluded for failing to respond to at least 2 animations.

Animations. Animations were constructed using 3D Studio MAX animation software and rendered in Mental Ray or VRAY to increase realism. Six experimental animations were created (Figure 3A, 3B); each animation had a causal, non-causal, and causal illusion variant. All animations were matched at the single-frame level for duration (7s) and for when the resulting effect occurred (4s). Animations were displayed at a rate of 30 frames/s. An additional 5s of a still first frame was added to the beginning of the animations to allow participants to orient to the scene. 6s of a still last frame was also added to the end of the animation to allow the causal impression additional time to unfold. Six practice animations were created with clear cases of causation and non-causation to allow participants to become comfortable with the procedures in the experiment.

Trial Structure. The experiment was conducted on lab computers using a javascript application. Participants first completed 6 practice trials with clear causal or non-causal animations. Before the animation played, one of the objects in the scenes was named. Participants were instructed to evaluate the causality with respect to this object (see Figure 3C). Participants then viewed the animation, and were instructed to use a response dial to judge causality in real time. Participants responded “yes” or “no” by moving the dial right and left, respectively. Dial position was recorded as a continuous variable from +15 (yes) to -15 (no) every 10 ms. Participants were instructed that the position of the dial should always reflect their current opinion of whether a particular event was caused by the named object.

Data Analysis. Data analysis was conducted using custom Python scripts. For each participant, we averaged the responses to causal, non-causal, and causal illusion animations separately to create a single average decision for each animation type. We considered only data recorded at or after the time the effect occurred, resulting in 3 separate 13s-long decision functions, 1 for each animation type, with position recorded every 10 ms.

Results

The average decision function for each type of animation is shown in Figure 4. Significance tests were conducted by binning decisions at the group level using 100 ms bins, and testing whether the mean of that bin (which could range from +15 to -15) differed from 0 (i.e., no decision), using single-sample t-tests, α=0.05, 2-tailed.

As expected, causal animations were quickly judged as causal, with decisions differing significantly from 0 beginning 800 ms after the effect occurred. Non-causal animations were quickly judged as non-causal, with decisions differing significantly from 0 beginning 1,200 ms after the effect occurred. Critically, the predictions of the dual-process hypothesis were also supported for the causal illusions, provided the analyses are restricted to only the first causal illusion participants saw. In particular, for the 1st causal illusion, as seen in Figure 4A, causal illusions were *initially* judged as causal 1,160 ms after the effect occurred, and then later judged noncausal at 12,700 ms after the effect occurred. The results from all of the causal illusions show a similar pattern, but are not significantly different from 0. The results suggest that participants viewed the animations in a more reflective manner once they saw one of the causal illusions. In particular, participants may have been able to use remembered knowledge about the 1st causal illusion to suppress the causal impression of the 2nd causal illusion. This result is consistent with the dual-process hypothesis, since prior inferences may have had a chance to interact with perceptually-based judgments.

Discussion

The main predictions of the dual-process hypothesis were supported. For causal illusions, but not for clear causes or non-causes, participants made two opposite decisions over the course of the single trial. Participants initially judged the 1st causal illusion to be causal, but subsequently judged it to be non-causal. In addition to providing evidence for the existence two kinds of processes, the results from this experiment provide some indication about when in time the two kinds of causal processes take place. In particular, it appears that the results of the intuitive process become available at around about 1000 ms, whereas the results from the reflective process might not be felt until 1300 ms. With these temporal benchmarks in place, we can test the dual-process hypothesis using a standard method for examining the temporal time-line of processing, as demonstrated in the next experiment.

Experiment 3: Thinking Styles

Experiment 3 had two aims. First, we aimed to provide converging evidence for the existence of multiple processes in the interpretation of causal event using a deadline methodology. Second, we examined whether people's impressions of causation might depend on their cognitive reflectiveness.

As in the previous experiment, participants viewed causal, non-causal, and causal illusion animations. In the current experiments, however, participants were prompted to make a decision about causation after either a short or long response deadline (Figure 5A). The dual-process hypothesis predicts that participants will be more likely to judge causal illusions as causal under a short than long response deadline.

In addition to completing a deadline procedure, participants also completed a measure of reflective thinking style, specifically the Cognitive Reflection Test (CRT7; Toplak, Stanovich, & West, 2014). It has recently been argued that the CRT may measure the degree to which reflective processes are able to suppress intuitive processes (Sloman, 2015). On this view, participants high in cognitive reflectiveness should be less likely to judge causal illusions as causal, because they are participants who tend to resolve the conflict between perceptual and inference cues in favor of the reflective response.

Methods

***Participants*.** Fifty-one adult participants were tested individually in the lab.

Stimuli. Stimuli were the animations used in Experiment 2, as well as 4 new animations (Figure 8B) for a total of 10 different animations, each with a causal, non-causal, and causal illusion variant.

Deadline procedure. The deadline procedure is outlined in Figure 5A. Participants were first prompted which events to judge. Participants were then presented with an animation with the same time-course as in Experiment 2, except that the animation terminated 1s after the effect occurred. Participants then used the left and right arrow keys arrow keys to judge (yes/no) whether the first event caused the second event. Half of participants (*short-deadline* group) had 1s to respond; half of participants (*long-deadline* group) had

10s to respond. Response deadline was manipulated between participants because of possible order effects discovered in Experiment 2. All participants saw each of 30 animations twice in random order, for a total of 60 trials.

Cognitive Reflection Test. After the deadline task, participants completed other tasks in our lab, and then completed the revised 7-item version of the Cognitive Reflection Test (CRT-7; Toplak, West, & Stanovich, 2014). The intervening tasks were used to reduce demand characteristics by presenting the surveys as an unrelated new task.

Results

Just as predicted by the dual-process hypothesis, ratings of causation were higher for causal illusions when the deadline was short (M = 25.0%) than long (M = 18.2%), $t(9) = 3.76$, $p < 0.01$. In contrast, ratings of causation did not differ between the two deadlines for the animations showing clear cases of causation, $t(9) = 1.33$, $p = 0.215$, or non-causation, $t(9) = 1.33$, $p = 0.215$.

We next analyzed participants' individual differences using the Cognitive Reflection Test. In these analyses, we correlated participants' CRT7 scores with the percent of times participants judged causal illusions as causal. As shown in Figure 6, cognitive reflectiveness correlated negatively with ratings of causation, $r(50) = -0.579$, $p < 0.001$. The effect was specific to causal illusions: cognitive reflectiveness was unrelated to judgments of causation in response to the causal, $r(50) = 0.03$, $p = 0.036$, and non-causal stimuli, $r(50) = -0.247$, $p = 0.081$. This pattern of results supports the idea that causal illusions are in part driven by the "reflective mind" interpretation of deliberative processes (Stanovich, 2011).

An additional question about any dual-process proposal is whether the cognitive architecture is serial or parallel in nature (Sloman, 1996; Evans, 1984; Evans & Stanovich, 2013). While more experiments are needed to fully answer this question, our data may tentatively support a parallel architecture for causal illusions. One test case proposed for differentiating parallel and serial theories is *incorrect-heuristic* trials, e.g. belief-logic conflict trials where participants give the heuristic response (De Neys & Glumicic, 2008). In our experiment, this corresponds to trials where participants judged causal illusions as causal, which can be compared to heuristic-only trials, e.g. clear cases of causation. Serial and parallel theories make different predictions about reaction times to incorrect-heuristic trials. Serial theories predict that only the heuristic process was engaged, and therefore predict no difference in response times between incorrect heuristic trials and heuristic-only trials. By contrast, parallel theories predict that both deliberative and heuristic processes were engaged, but the deliberative process failed to inhibit the heuristic process. Parallel theories thus predict slower reaction times for incorrect-heuristic than for heuristic-only trials due to response competition. To address this question, we performed a post-hoc analysis of reaction times for trials where participants judged causal illusions as causal (incorrect-heuristic trials) and causal control trials (heuristic-only trials). In both deadline conditions, median response latencies were longer for incorrect-heuristic than heuristic-only trials: short response deadline, $t(28)=2.461$, $p=0.02$; long response deadline, $t(26)=4.060$, $p<0.001$. This pattern of reaction times provides tentative support for a parallel cognitive architecture for causal illusions.

General Discussion

In a series of three experiments, the predictions of the dual-process hypothesis were supported. In Experiment 1, we documented the phenomenon of causal illusions outside the lab. We showed that participants had a strong initial impression of causation, but a weaker ultimate impression of causation, supporting the claim that two cognitive processes are involved in causal reasoning. In Experiment 2, we replicated this dual pattern of response using a novel online measure of decision-making. Additionally, we showed an order effect, where participants were most susceptible to causal illusions for the very first illusion viewed. Finally, in Experiment 3, we demonstrated the same dual pattern of response using a deadline procedure. Additionally, we showed individual differences in susceptibility to causal illusions, where individuals high in reflective thinking were less susceptible to causal illusions.

The results have implications for theories of causal identification. Theories of how people identify causes fall into three categories: 1) Dependency theories which characterize causal relations with respect to statistical, logical, or counterfactual dependency relations, 2) Process theories which characterize causal relations with respect to the notions transmission and force, and 3) Perceptual cue theories which characterize causal relations with respect to spatial and temporal perceptual cues. The results reported in this paper might be viewed as problematic for all of these theories, because these theories define causation with respect to only one process. On the other hand, the results from this paper might be viewed as an opportunity. It may be that the different processes implied in this paper point to the need for multiple theories of causation. Perceptual cue theories might be well suited for explain intuitive processing, whereas as suggested by

Wolff and Shepard (2013), process theories might be well suited for reflective processes used in the identification of a mechanism that allows for the transmission of energy or force. An examination of the time-course of the processing of dependency relations and of forces may provide some resolution to the feasibility of a pluralistic theory of causation.

One difference between the current account and existing accounts of causation is that most existing accounts are normative. Both Bayesian network accounts (Gopnik et al, 2004; Glymour, 2003; Pearl, 2009) and probablistic dependency accounts (Cheng & Novick, 1992; Cheng, 1997) are computational accounts of how an ideal reasoner would behave. Causal illusions present a case – rare in the causal reasoning literature – where many people reason in a non-normative way. The major claim of the dual-process hypothesis is that such departures from normative reasoning can provide insight into the normal functioning of the causal reasoning system. Just as visual illusions can provide insight into the way the visual system normally works, so too we argue that causal illusions may provide insight into how the causal reasoning system normally works.

These results also have implications for dual process theories of cognition. As mentioned in the introduction, a current debate concerns whether the deliberative process should be further partitioned into a conflict detection process ("reflective mind") and a rule-based reasoning process ("algorithmic mind") (Stanovich, 2011). Part of this debate hinges on the source of individual differences in rational responding. If individual differences are driven by working memory or fluid intelligence, this suggests that rational responding involves the algorithmic mind. If, however, individual differences are driven by thinking styles such as cognitive reflectiveness, this suggests that rational responding also involves the reflective mind. In Experiment 3, we found that individual differences in the Cognitive Reflection Test predicted resistance to causal illusions. While it is difficult to know whether the CRT measures thinking styles alone, to the extent to which the CRT is a measure of thinking styles (Sloman, 2015), our data may point to involvement of the reflective rather than algorithmic mind in causal illusions.

The study of non-normative causal reasoning may connect basic research on causal reasoning to a number of interesting phenomena. Gamblers' belief that self-chosen lottery numbers increase odds of winning (Orgaz, Estevez, & Matute, 2013), sports fans' superstitious rituals, and behavioral compulsions in obsessive-compulsive disorder are all examples of illusory causal beliefs. Such illusory beliefs are not always accompanied by a belief in causal mechanism: common rituals and superstitions are usually rated as no more effective than other superstitions by the people that use them (Bleak & Frederick, 1988; Rudski & Edwards, 2007). Nevertheless, there are often strong perceptual cues in superstitious rituals: the rituals adopted are often those incidentally performed immediately prior to a rewarding event (Ono, 1987; Skinner, 1948). Such belief in causation absent mechanism may be well-explained by a dual-process account, where a strong response from the intuitive system may create an impression of causation absent a plausible causal mechanism. The study of non-normative causation may therefore help explain why illusory causal beliefs develop, as well as how illusory causal beliefs can be reduced.

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Tables and Figures

Figure 1: An example causal illusion. A man appears to open elevator doors using only his hands.

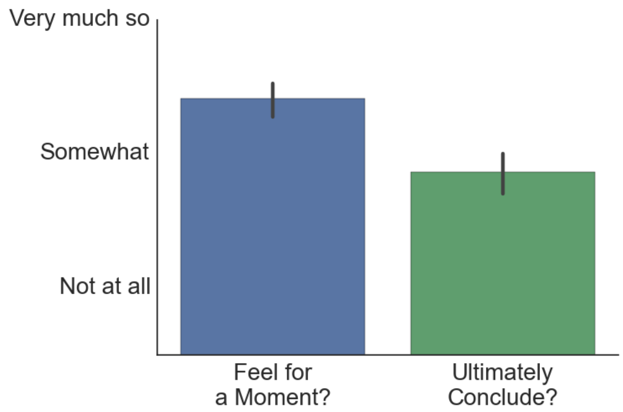

Figure 2: Causation ratings in Experiment 1. Participants rated a stronger initial than ultimate impression of causation. Error bars +/- 1 SEM.

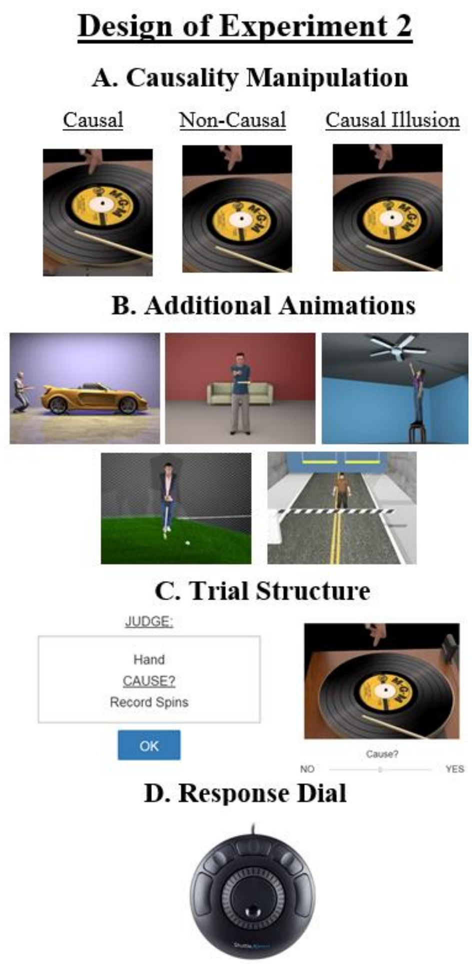

Figure 3: Experimental design for Experiment 2.

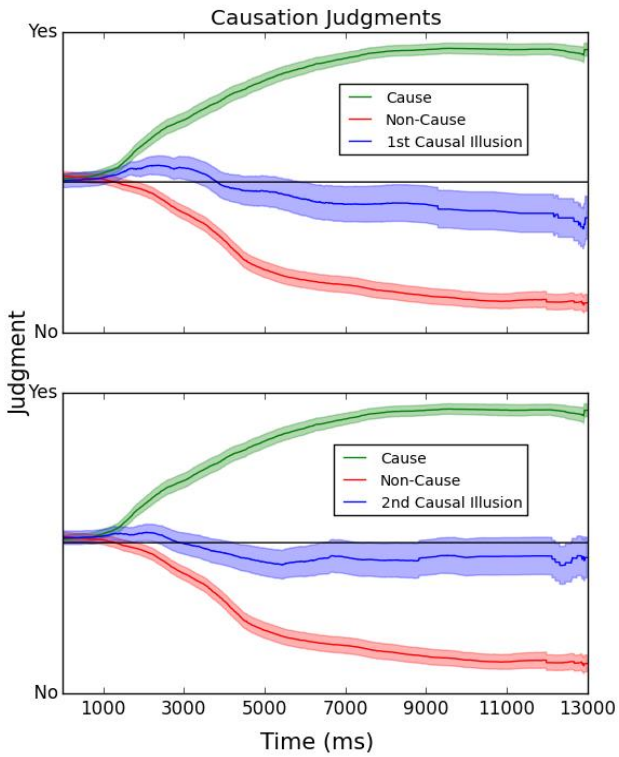

Figure 4: The average decision function for causal, non-causal, and causal illusion animations (shading +/- 1 SEM). Causal illusions are plotted separately for the 1st and 2nd causal illusions in Figure 7A and 7B, respectively.

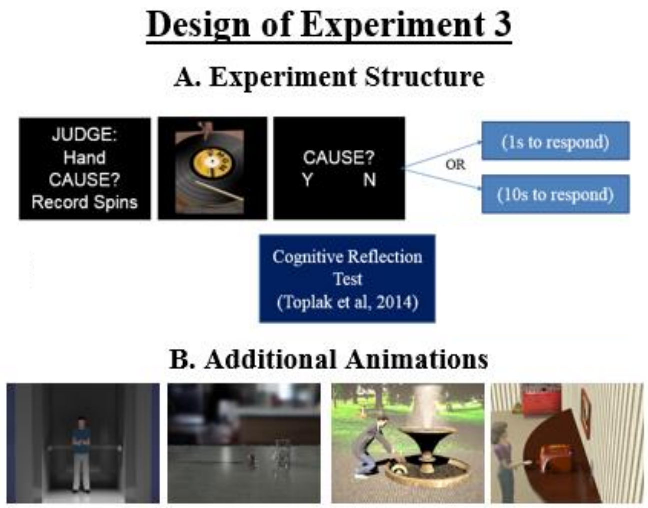

Figure 5: (A) The deadline procedure and thinking styles inventory used in Experiment 3. (B) Additional animations created for Experiment 3.

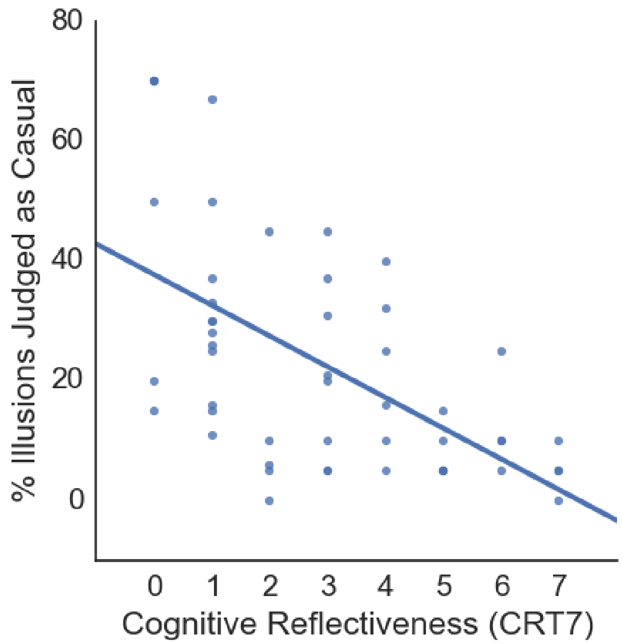

Figure 6: Causal illusion judgments and cognitive reflectiveness in Experiment 3. Participants high in cognitive reflectiveness were more likely to endorse causal illusions as causal.