UNIVERSITAT DE BARCELONA

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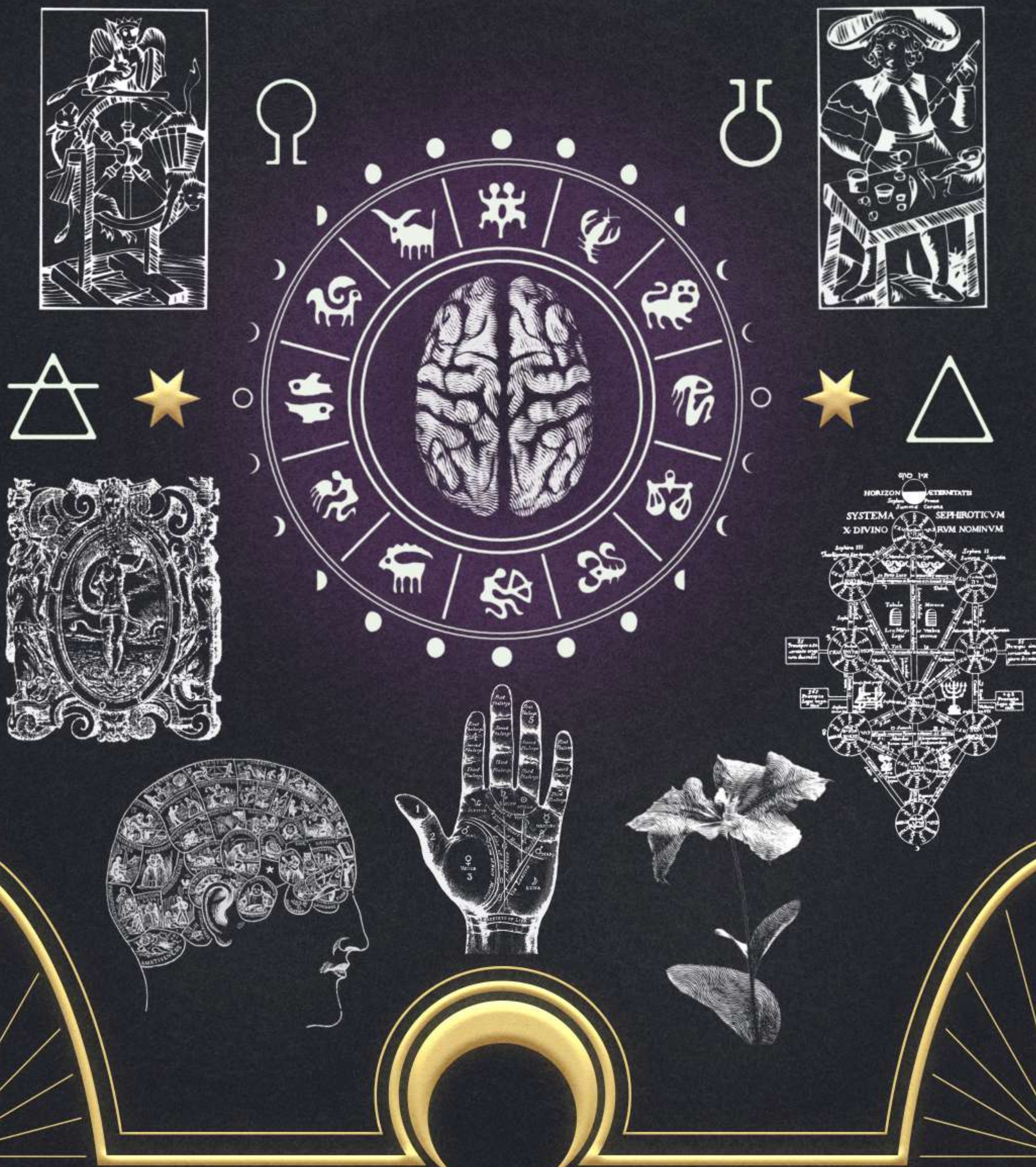

Causal illusion as a cognitive basis of pseudoscientific beliefs

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Declaration and certification

I hereby declare that, to the best of my knowledge, the content of this thesis is my own work and has not been submitted for any other degree or professional qualification. I confirm that the work presented is entirely my own, except where I have incorporated material from jointly-authored publications. The contributions of both myself and the other authors to this work have been clearly specified. I also confirm that proper credit has been given to the work of others wherever it is referenced in this thesis.

Marta Natalia Torres Domínguez

This is to certify that the work presented in this Ph.D. thesis, titled "*Causal illusion as a cognitive basis of pseudoscientific beliefs*", submitted by Marta Natalia Torres Domínguez, represents original research conducted by the student. We further certify that this work has not been submitted, in whole or in part, to any other university or institution for the award of any degree or diploma. Any research materials obtained from external sources and used in this thesis have been properly acknowledged.

Javier Rodríguez Ferreiro   Itxaso Barberia Fernández

Agraïments

Arribats a aquest punt, és difícil posar un límit de persones que m'han possibilitat i facilitat el camí fins arribar a l'acabament del doctorat. En primer lloc, de forma més directa, voldria donar les gràcies als meus tutors Javier Rodríguez Ferreiro i Itxaso Barberia Fernández, els quals m'han animat, m'han recolzat i m'han acompanyat aquests anys perquè aquesta tesi sigui una realitat. A pesar de haber tenido experiencias en el ámbito de la investigación previas al inicio del programa de doctorado, me habéis enseñado toda una nueva metodología, que puedo sentirme cómoda con nuevos ámbitos de investigación y que soy capaz de adaptarme a los retos del mundo académico.

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Moltes gràcies per fer-me costat.

Summary

The prevalence of pseudoscientific beliefs in society has notable repercussions on critical domains such as health and education. Causal illusions have been proposed as a potential cognitive bias underlying the formation and perpetuation of such beliefs. This doctoral thesis aims to delve into the relationship between causal illusion and the endorsement of pseudoscientific beliefs, through different studies. The first one focuses on the development of a tool to measure pseudoscience belief endorsement (Pseudoscience Endorsement Scale, PES) and testing its possible association with causal judgment scores obtained in a passive (*i.e.*, null) contingency detection task, in which participants observed a series of medical records indicating whether or not the patient took a certain infusion and whether or not he or she was subsequently cured of a headache. The results showed that participants who scored higher on the PES exhibited stronger causal illusions on the contingency detection task. In a second study, volunteers engaged in active contingency learning tasks in which they could manipulate the presence or absence of a potential cause to explore its impact on the outcome, thus reflecting not only information interpretation, but also search strategies. The findings consistently demonstrated that individuals with stronger pseudoscientific beliefs exhibited heightened causal illusions, irrespective of differential search strategies. Finally, a third study was conducted in order to explore other cognitive and sociodemographic correlates of pseudoscientific beliefs. The results indicated that the level of endorsement of pseudoscience showed positive correlations with other unwarranted beliefs, such as paranormal and conspiracist beliefs and science denialism, and negative correlations with scientific knowledge, cognitive reflection scores, and *bullshit* sensitivity, a measure that represents the ability to differentiate between legitimate motivational statements and profound-sounding but devoid of meaning sentences.

Taken together, these results suggest a robust link between pseudoscientific beliefs and the development of causal illusions, which arises regardless of whether those with higher pseudoscientific beliefs employ different information search strategies. Therefore, our research emphasizes the complex interaction between cognitive biases and belief systems, offering insights into possible approaches aimed at reducing the impact of pseudoscientific beliefs within society.

Resumen

La prevalencia de creencias pseudocientíficas en la sociedad tiene repercusiones notables en ámbitos críticos como la salud y la educación. Las ilusiones causales se han propuesto como un posible sesgo cognitivo subyacente en la formación y perpetuación de tales creencias. Esta tesis doctoral tiene como objetivo adentrarse en la relación entre la ilusión causal y el respaldo de creencias pseudocientíficas, a través de diferentes estudios. El primero se centra en el desarrollo de una herramienta para medir el nivel de apoyo hacia las creencias pseudocientíficas (Escala de Apoyo a las Pseudociencias, EAP) y probar su posible asociación con las puntuaciones de juicio causal obtenidas en una tarea pasiva de detección de contingencias (nulas), en la cual los participantes observaron una serie de historias clínicas que indicaban si el paciente había tomado o no cierta infusión y si, posteriormente, se había curado o no de un dolor de cabeza. Los resultados mostraron que los participantes que obtuvieron puntuaciones más altas en la EAP exhibieron ilusiones causales más potentes en la tarea de contingencias. En un segundo estudio, los voluntarios pasaron por una tarea de contingencias activa, en la cual podían manipular la presencia o ausencia de una posible causa para explorar su impacto en los resultados, reflejando no solo sus estrategias de interpretación de la información, sino también sus estrategias de búsqueda. Los hallazgos demostraron que las personas con creencias pseudocientíficas más fuertes mostraban ilusiones causales más intensas, con independencia de las diferentes estrategias de búsqueda de información que estuvieran aplicando. Finalmente, se llevó a cabo un tercer estudio con el objetivo de explorar otros correlatos cognitivos y sociodemográficos de las creencias pseudocientíficas. Los resultados indicaron que el nivel de apoyo a las pseudociencias correlacionaba positivamente con otras creencias injustificadas, como las paranormales y conspirativas y la negación de la ciencia; y correlacionaban negativamente con el conocimiento científico, la reflexión cognitiva y la sensibilidad a las patrañas, una medida que representa la capacidad para diferenciar entre frases motivacionales legítimas y frases que suenan profundas pero que carecen de significado.

En conjunto, estos resultados sugieren un vínculo sólido entre las creencias pseudocientíficas y el desarrollo de ilusiones causales, que surge independientemente de si aquellos con creencias pseudocientíficas más elevadas emplean diferentes estrategias de búsqueda de información. Por lo tanto, nuestra investigación enfatiza la compleja interacción entre los sesgos cognitivos y los sistemas de creencias, ofreciendo perspectivas sobre posibles enfoques dirigidos a reducir el impacto de las creencias pseudocientíficas en la sociedad.

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GENERAL INTRODUCTION

1. General introduction

1.1. Contingency detection in humans

Living beings commonly rely on predictable environments to survive because it enables them to anticipate events and facilitates awareness of the relationships that are established between different factors. Contingency, which refers to the "covariation between two or more binary variables" (Pineño & Miller, 2007), is essential for recognizing patterns in the environment. In this sense, contingency learning becomes crucial for both human and non-human animals to obtain resources necessary for survival and to anticipate future events. An example of the importance of contingency detection in animals can be observed in the foraging behaviour of honeybees. Contingency learning is essential for them to associate certain environmental cues with the availability of rewarding resources. Considering the dynamic nature of the environment, flowers change their colour as they are depleted of nectar, or their structure when new ones are blooming. Contingency detection allows honeybees to adapt their foraging strategies in response to these changes. This ability enhances their foraging efficiency and contributes to the overall success of the colony in collecting essential resources. Regarding humans, consider the scenario where a farmer is faced with a decision during a period of drought, having to decide whether to allocate the limited water resources towards irrigating fruit trees or wheat fields. In this situation, it becomes essential to gather information about the specific circumstances, such as the time of year and weather indicators, to determine the likelihood of rainfall in the near future. Additionally, understanding the potential consequences of water scarcity on each crop becomes crucial for making an informed decision.

To determine the extent to which human and non-human animals are good at detecting environmental relationships, it is necessary to have a normative approach that describes these relationships. To illustrate, going back to the previous example of the farmer, the target events would be, first, the presence of appropriate weather conditions, such as nimbostratus clouds (*i.e.*, the potential cause, C) and second, the occurrence of a rainfall (*i.e.*, the outcome, O). Therefore, there are four possible combinations between the potential cause and the outcome, since each of them can be either present or absent. As can be seen on Table 1, the organization of these four combinations lead to four types of cells in a contingency table, where cell "*a*" describes occasions in which the potential cause and outcome both occur (*i.e.*, rainfall occurrence in the presence of nimbostratus clouds); cell "*b*" showings cases in which the potential cause occurs in the absence of the outcome (*i.e.*, absence of rain with nimbostratus clouds present); cell "*c*", where the outcome occurs in the absence of the cause (*i.e.*, the rainfall occurs in the absence of nimbostratus); and cell "*d*" meaning that neither the cause nor the outcome occurs (*i.e.*, with no rain and no nimbostratus present).

Table 1. Distribution of the cell types in a contingency table.

	Outcome (O)	**No outcome (¬O)**
Potential cause (C)	*a*	*b*
No potential cause (¬C)	*c*	*d*

Contingency tables act as summarized representations from which it can be determined whether the contingency between the two events is positive or negative, or whether they are totally non-contingent. In other words, it can be evaluated whether or not the cause and the outcome are related upon each other, and to what degree. This is possible by applying the ΔP index (Allan, 1980), a normatively appropriate measure of the relationship between two events. This index is expressed as follows:

$$\Delta\mathrm{P} = P(O \mid C) - P(O \mid \neg C) = \frac{a}{a+b} - \frac{c}{c+d}$$

Where P(O|C) is the probability of occurrence of the outcome, O, in the presence of the potential cause, C (*i.e.*, probability of a rainfall with nimbostratus), and P(O|¬C) is the probability of the outcome in the absence of the cause (*i.e.*, probability of a rainfall without nimbostratus). ΔP can take values from -1 to +1, with positive ones indicating that the occurrence of the outcome is more likely in the presence than in the absence of the potential cause. In this case, the cue predicts the outcome. Negative values imply that the outcome is more likely when the potential cause is absent than when it is present. In this case, the cue predicts the absence of the outcome. Finally, a value of zero indicates that the potential cause predicts neither the presence nor the absence of the outcome, this is, the contingency is null or non-existent.

Initial investigations provided evidence of the sensitivity to different contingencies in non-human (*e.g.*, Rescorla, 1968) and human animals (*e.g.*, Shanks & Dickinson, 1987; Wasserman, 1990; Wasserman *et al.*, 1993; see Matute *et al.*, 2019, for a review). Regarding human sensitivity to contingencies, it is worth further explaining the Wasserman's (1990) study as one of the pioneers in the application of a medical cover story to contingency learning, nowadays known as "allergy task". One benefit of this method is that it helps sustain participants' interest in understanding the real connection between a potential cause and its outcome. Unlike previous studies where participants had to relate actions like pressing a button to whether a signal lights up (*e.g.*, Jenkins & Ward, 1965; Alloy & Abramson, 1979; Shanks & Dickinson, 1987), this approach involves identifying the component responsible for triggering an allergic reaction. Thus, the participants were asked to play the role of an allergist to identify the cause of a food allergy reaction. In his experimental design, volunteers had to observe, in each trial, a medical record informing about the potential allergens that the patient consumed and the outcome (*i.e.*, whether an allergic reaction developed or not). The experimental conditions involved five different levels of contingency between the potential allergens and the outcome: ΔP = 0, .25, .50, .75, and 1. After observing all the trials, participants were asked to specify their diagnosis of the allergic reaction by selecting the corresponding number on a rating scale ranging from 0 to 8. This scale included verbal descriptions at certain intervals: "(0) definitely not, (4) possibly, and (8) definitely the cause of the allergic reaction" (Wasserman, 1990, p. 299). Wasserman found that participants perceived higher causal connection between the potential allergens and the allergic reaction as the actual contingency increased.

Shortly after, Wasserman *et al*. (1993, Experiment 1) performed a study in which participants were presented with 25 different contingency learning problems, 60 seconds long each, created by combining five levels of conditional probabilities for an outcome occurring with the potential cause present, $P(O|C)$, and absent, $P(O|\neg C)$: 0, .25, .50, .75, and 1. In turn, the combination of the different values of conditional probabilities led to 9 different levels of contingency, $\Delta P = P(O|C) - P(O|\neg C)$: 1, .75, .50, .25, 0, -.25, -.50, -.75, and -1. Individuals were asked to determine whether pressing a telegraph key influenced the occurrence of a white light. At any moment, they could decide whether to press the key or refrain from doing so. Following each problem, participants were instructed to select a number on a scale ranging from -100 ("Prevents light from occurring") to 0 ("Has no effect on light") to 100 ("Causes light to occur") that most accurately described the impact of their telegraph key responses. Participants were informed that each rating should be made without consideration of their judgments from previous problems. The results indicated that all positive contingencies received positive ratings, negative contingencies were rated negatively, and zero contingencies were rated accordingly. Moreover, as it can be observed in Figure 1, the increment of $P(O|C)$ resulted in higher causal ratings, whereas greater $P(O|\neg C)$ led to lower scores on causal judgement.

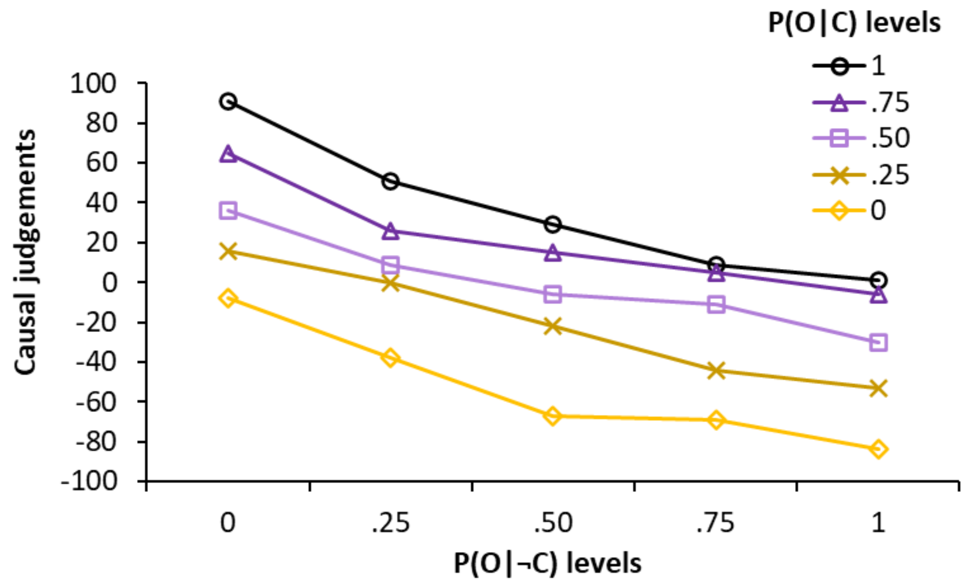

Figure 1. Mean scores of causal judgement obtained at the end of each problem on Wasserman *et al*.'s (1993) Experiment 1.

These results demonstrated that individuals can accurately perceive different levels of contingency between events (as in their previous study, Wasserman, 1990), in addition to the fact that increasing P(O|C) leads to higher positive causal judgments, while increasing P(O|¬C) leads to an increment of negative causal judgments.

However, other early studies also emerged whose results showed that causal judgments did not always adequately match the actual contingency established (*e.g.*, Jenkins & Ward, 1965; Alloy & Abramson, 1979; Allan & Jenkins, 1980). In their study, Alloy and Abramson (1979) focused on examining how individuals, particularly those who were depressed, perceived and judged the relationship between their actions and subsequent outcomes. In their Experiment 2, participants were presented with a contingency learning task where they had control over the presence of the potential cause (*i.e.*, pressing or not pressing a button) to produce an outcome (*i.e.*, the illumination or not of a green light). The volunteers were assigned to one of the following conditions: a non-contingent task in which the probability of the outcome was low, P(O) = .25, and another non-contingent task, but with a high probability of the outcome, P(O) = .75. After the presentation of all the trials, individuals were instructed to mark an "X" on a scale split into intervals of 5, in a range between 0, labelled as “No Control”, and 100, labelled as “Complete Control”. The intermediate part of the scale, value of 50, was labelled as “Intermediate Control”. Participants' judgments were examined in relation to their depressive symptoms, providing insights into how depression might influence the way individuals process and interpret contingencies. The results indicated that non-depressed volunteers overestimated their control in the High P(O) condition, but not in the Low P(O) one, whereas depressed participants provided relatively accurate scores of judgement of control in both conditions. In short, depressed individuals tended to perceive less contingency between their actions and outcomes, being more accurate in their judgements compared to non-depressed individuals, in the absence of contingency. Apart from the implications that this study had in the field of depressive realism (see Alloy & Abramson, 1988, for a review), the important result for the topic we are dealing with is that non-depressed individuals perceived positive contingency between the events when it was actually null. Moreover, participants showed higher scores of judgement of control as the frequency of the outcome increased (see Jenkins & Ward, 1965; and Allan and Jenkins, 1980, for similar results).

Previous research have demonstrated that individuals are sensitive to contingencies (*e.g.*, Shanks & Dickinson, 1987; Wasserman, 1990; Wasserman *et al*., 1993; López *et al*., 1999). However, other studies have also showed that individuals' judgments may also depart from the normative response (*e.g*., Jenkins & Ward, 1965; Alloy & Abramson, 1979; Allan & Jenkins, 1980, 1983; Dickinson *et al*., 1984). One of the most common errors is to attribute a causal relationship between the potential cause and the outcome when the contingency is actually null, a phenomenon known as causal illusion, or illusion of causality (see Matute *et al*., 2015, for a review). This term refers to the cognitive bias or perceptual distortion in which individuals mistakenly perceive a causal relationship between two events when there is no actual contingency between them. This phenomenon, which constitutes the central topic of this thesis, often occurs when people attribute a cause-and-effect relationship to events that co-occur by chance, leading to a false sense of causality (Matute *et al*., 2015, 2019; Blanco & Matute, 2019; Chow *et al*., 2019).

1.2. Causal illusion in passive contingency learning tasks: biases in the interpretation of information

With the aim to induce a causal illusion, researchers have to design non-contingent learning tasks (*i.e*., ΔP index = 0), meaning that the probability of the outcome is the same in the presence as in the absence of the potential cause. In order to assess participants' ability to discern causal relationships between two events, researchers typically rely on the participants' perceived level of causality, evaluated through the scores given in a causal judgment question. The discrepancy between the programmed contingency of zero and these scores will determine the level of bias about the causal relation of the two events (*i.e*., causal illusion) developed by the participants (*e.g*., Blanco *et al*., 2013; Vadillo *et al*., 2016; Matute *et al*., 2019; Barberia *et al*., 2019).

In addition, contingency learning tasks can be categorized into two groups according to the role played by the participant: passive and active. In passive tasks (*e.g*., Wasserman, 1990; Blanco *et al*., 2013; Blanco & Matute, 2019; Barberia *et al*., 2021), in each trial, volunteers are presented with different combinations of the presence or absence of the potential cause and the outcome (see Table 1). In contrast, active contingency learning tasks are characterized by the possibility for the participant to decide, on each trial, whether the potential cause will be present or not (the latter will be described in the following section). To illustrate a typical passive contingency learning task, as in the case of the farmer in the example at the beginning of the dissertation, who gained insights from the weather conditions to assess the likelihood of rain, I will explain one of the most standardized procedures (*e.g*., Matute *et al*., 2011; Blanco *et al*., 2013; Barberia *et al*., 2019, 2021; Moreno-Fernández *et al*., 2021), originally adapted from the "allergy task" formulated by Wasserman (1990). In this kind of procedure, participants are asked to determine the effectiveness of a given substance in curing a given disease. On each trial, participants observe a medical record illustrating a patient suffering an episode of, for example, a headache, and whether or not the patient was administered with a medicine. Then, with the aim to maintain their attention, volunteers are asked if they thought the patient would subsequently recover from the headache, with the answer options of "yes" or "no". Following this, participants are informed about the outcome (*i.e*., the patient's recovery, or not). After a predetermined number of trials, volunteers are presented with the causal judgement question (*e.g*., "To what extent do you think the medicine is effective against the headache? You must provide a score between 0, totally ineffective, and 100, totally effective"; Blanco *et al*., 2011, 2013), to determine their level of causal illusion developed. This response is assumed to reflect the way in which volunteers interpret the information gathered.

It is worth pointing that, as we could observe, the traditional design approach to contingency learning tasks involves presenting to participants a training phase where they sequentially observe various cue-outcome combinations trial by trial, ultimately leading to their causal judgments. In contrast, other less widespread designs of contingency learning experiments would involve, for example, displaying contingency tables to participants, prompting them to base their judgments on this statistical information (*e.g*., Jenkins & Ward, 1965; Kao & Wasserman, 1993). One reason for embracing the trial-by-trial approach in structuring contingency learning tasks in this dissertation is the observation that the causal illusion appears to manifest more prominently when information is presented sequentially on a trial-by-trial basis, as opposed to when it is displayed in contingency tables (Ward & Jenkins, 1965; Kao & Wasserman, 1993). We are interested in participants developing a strong causal illusion, as the objectives of this dissertation, subsequently described in the corresponding section, focus on the exploration of causal illusions in relation to pseudoscientific beliefs.

Two of the most prominent factors influencing the development of causal illusions when exploring the relationship between two events, in a passive contingency learning task, are the outcome-density and cause-density effects. Causal illusions can arise in the absence of an actual causal relationship between a potential cause and an outcome, when there are high levels of the probability of the outcome, P(O). In reference to the cells of the contingency table (see Table 1), the calculations will be as follows: P(O) = (*a+c*)/(*a+b+c+d*). Previous studies on human contingency learning have consistently demonstrated that participants tend to overestimate the causal association between the two events when there is a non-contingent relationship and the probability of the outcome is increased (*e.g.*, Allan & Jenkins, 1983; Dickinson *et al*., 1984; Wasserman *et al*., 1996; Buehner *et al*., 2003; Allan *et al*., 2005; Musca *et al*., 2010; Blanco *et al*., 2013; Moreno-Fernández *et al*., 2017). In a similar way, the cause-density (or cue-density) effect arises when, in a contingency learning task, the density of the potential cause, P(C) = (*a+b*)/(*a+b+c+d*), is increased while maintaining a contingency of 0 between the two events (*e.g.*, Allan & Jenkins, 1983; Wasserman *et al*., 1996; Perales *et al*., 2005; Matute *et al*., 2011; Vadillo *et al*., 2011; Blanco *et al*., 2013).

One of the studies that best illustrates these two factors affecting causal ratings in passive contingency learning tasks is the one carried out by Blanco *et al*., (2013, Experiment 1). In their study, volunteers had to put themselves in the shoes of a researcher testing the effectiveness of a fictitious medicine, “Batatrim”, in recovering from a fictitious disease, the “Lindsay syndrome”. Volunteers had to observe, over 100 trials, a series of medical records specifying if the patient was administered Batatrim or not during a Lindsay syndrome episode. At this point, participants had to predict if the patient would recover or not, choosing between the options “yes” or “no”. They were then informed about the patient’s recovery or not. Participants were split into four experimental conditions, as indicated in Table 2. The distribution of the trials according to each condition lead to two different probabilities of the outcome, P(O), and two probabilities of the potential cause, P(C), thus resulting in .2 for low density conditions and .8 for high density conditions. The level of contingency between the potential cause and the outcome always remained at 0, since the probability of recovery in the presence of Batatrim, P(O|C) = *a*/(*a*+*b*), was the same than the probability of recovery in its absence, P(O|¬C) = *c*/(*c*+*d*), in all conditions.

Table 2. Distribution of the trials in the four experimental conditions in Blanco *et al*.'s (2013) study.

Low cause (0.2) and low outcome (0.2) densities

	Recovery (O)	No Recovery (¬O)
Batatrim (C)	4	16
No Batatrim (¬C)	16	64

Low cause (0.2) and high outcome (0.8) densities

	Recovery (O)	No Recovery (¬O)
Batatrim (C)	16	4
No Batatrim (¬C)	64	16

High cause (0.8) and low outcome (0.2) densities

	Recovery (O)	No Recovery (¬O)
Batatrim (C)	16	64
No Batatrim (¬C)	4	16

High cause (0.8) and high outcome (0.8) densities

	Recovery (O)	No Recovery (¬O)
Batatrim (C)	64	16
No Batatrim (¬C)	16	4

After the training phase, the participants were asked about their causal judgement ("To what extent do you think that the medicine Batatrim has been effective in healing the crises of the patients you have just seen?"), which they had to rate on a scale ranging from 0 ("It was not effective at all") to 100 ("It was perfectly effective").

The results demonstrated the influence of both enhancing cause density and outcome density on the increase of causal illusion. Furthermore, Blanco *et al*. (2013) found an interaction between both outcome-density and cause-density effects, indicating that the overestimation of a null contingency is amplified when both the cue and the outcome are presented with high frequency. The outcome-density bias was detected across both high and low levels of P(C). However, the cue-density bias was observable only under High P(O), but not in Low P(O) conditions. In other words, their findings offer evidence supporting the notion that the causal illusion could be diminished in situations where the cue or the outcome occur infrequently.

Once we have stated that the manipulation of the P(O) and the P(C) influence the development of the causal illusion, it is interesting to understand how human contingency learning models explain these phenomena (see Perales & Shanks, 2007, for a review on the different types of contingency learning models). In order to explain the emergence of causal illusion, the associative or learning-based models propose that cues acquire associative strength over all the trials in which they are present in the learning phase, and the subsequent judgments reflect this acquired strength. Rescorla and Wagner's (1972) model, which is one of the most representative associative models, posits that information regarding the relationship between various events in the environment is stored as associations, and the strength of these associations is continually updated as new evidence is encountered. In causal learning situations, following with the medical cover story, the model assumes that when we observe a patient who takes a medicine and recovers from a disease, the connection between our mental representations of these two events (*i.e.*, the medicine intake and the recovery) becomes stronger. Conversely, when we are presented with a patient who takes the medicine but does not recover, the association between these events becomes weaker. In addition, in contingency learning situations, the model posits the presence of a constant contextual cue, across all trials, that is in competition with the target cue for associating with the outcome. Thus, as we accumulate enough information, the strength of the association between potential causes and effects would converge toward the true degree of correlation between them. In other words, through extensive training, the strength of these association would eventually reach an asymptotic value of zero when the contingency is null. From this perspective, causal illusions would arise when the learning experience is incomplete or has not yet reached a stable, asymptotic state (Chapman & Robbins, 1990; Wasserman *et al*., 1993; Matute *et al*., 2019; Barberia *et al*., 2019; Moreno-Fernández *et al*., 2021).

Furthermore, before reaching this learning asymptote, the Rescorla-Wagner model also predicts the cue and outcome-density biases (Vadillo & Barberia, 2018; Barberia *et al*., 2019). To illustrate this prediction, Figure 1 shows the results of a simulation with the Rescorla-Wagner model with High P(O) and Low P(O) conditions, top panel, and High P(C) and Low P(C) conditions, bottom panel (see Matute *et al*., 2019, for a similar simulation using the distribution of trials of the four different groups specified in the Blanco *et al*.'s (2013) study. The simulation was performed using Rescorla & Wagner Simulator+ (version 5; Chung *et al*., 2018). Following the original equation from the Rescorla-Wager model:

$$\Delta V_{\mathrm{A}}^{\mathrm{n}} = \alpha \cdot \beta \,(\lambda - V_{\mathrm{A}}^{\mathrm{n-1}})$$

Where α and β represent the salience of the CS and the US (*i.e*., the potential cause and the outcome, in contingency learning situations), respectively, and λ is the total amount of associative strength that can be reached at that specific trial; I stated the learning rate parameters for the potential cause (*i.e.*, parameter α_{cue}), the context (*i.e.*, parameter $\alpha_{context}$), and the outcome (*i.e.*, parameter β) at .4, .2, and .6, respectively (the same parameters used by Barberia *et al.*, 2019, in their analogous simulations). The value of λ was 1 for trials where the outcome occurred and 0 for trials where the outcome did not occur.

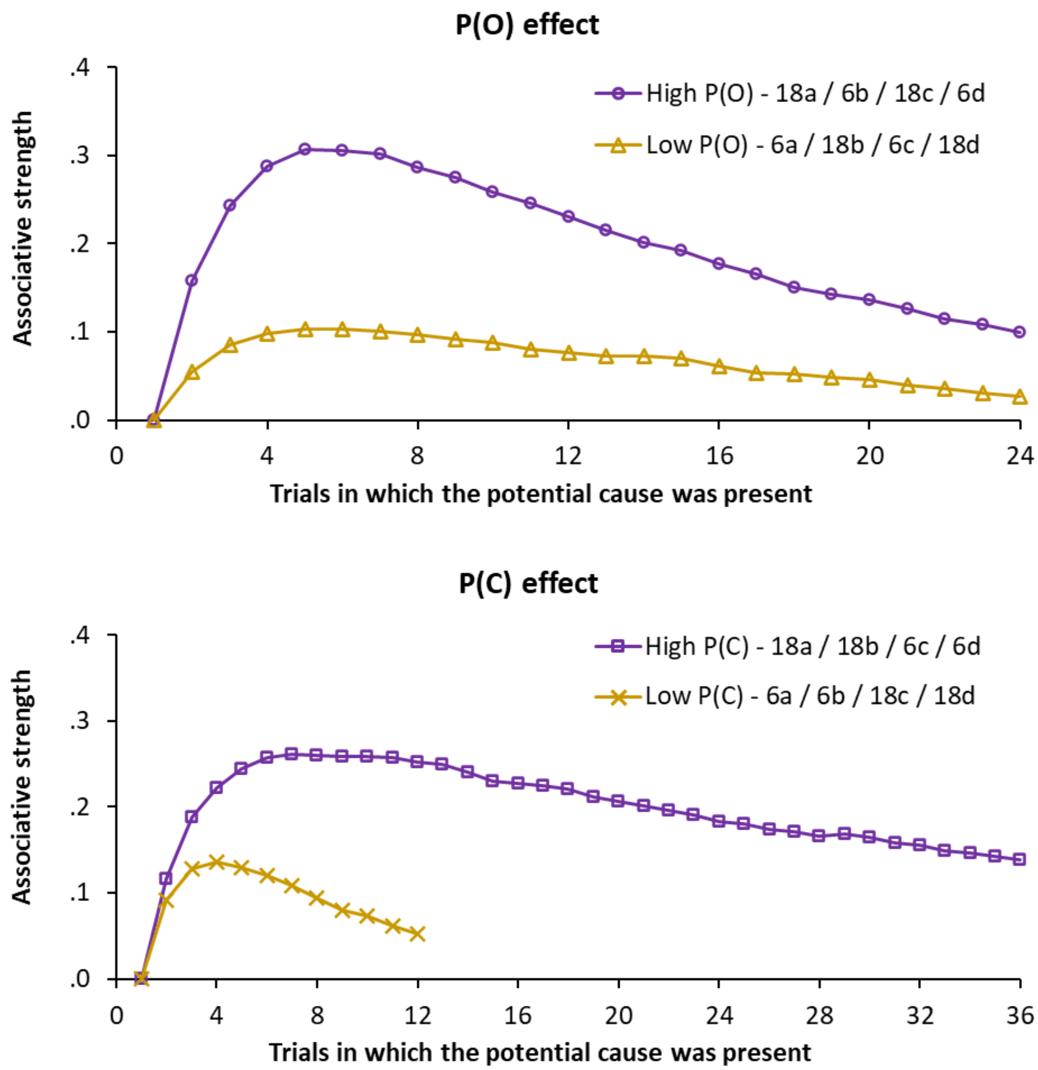

Figure 2. Simulation (mean results from 2,000 iterations with randomized trial sequence) of the Rescorla-Wagner model for the configuration of trials specified in each group (*i.e.*, the number of cells of each type of trial). High P(O) group values: 18a, 6b, 18c, and 6d. Low P(O) group values: 6a, 18b, 6c, and 18d. High P(C) group values: 18a, 18b, 6c, and 6d. Low P(C) group values: 6a, 6b, 18c, and 18d.

The results of the simulation are shown in Figure 2. On one hand, at the top panel we can observe the P(O) effect, since in the High P(O) group the candidate cause is expected to develop a higher associative strength compared to the Low P(O) group. On the other hand, the bottom panel shows the P(C) effect, given that the High P(C) group is showing higher associative strength than the Low P(C) group.

It is convenient to clarify, as illustrated in Figure 2, that the P(O) and P(C) effects are transient according to the Rescorla-Wagner model, as it predicts that with prolonged training the associative strength will tend to diminish towards zero in all four groups. However, recent empirical studies have cast doubt on the notion that increasing the duration of training significantly diminishes the strength of causal illusions, as predicted by Rescorla-Wagner model (*e.g.*, Blanco *et al*., 2011; Barberia *et al*., 2019). To illustrate, Barberia *et al*. (2019) conducted a contingency learning experiment employing a set number of trials, comparing a brief training phase with an unusually extended one. In contrast with the predictions posed by the Rescorla-Wager model, their findings revealed that causal illusions remained even when the training was extended from 48 to 288 trials. In fact, their results provided substantial evidence opposing the idea that elongating the training phase might reduce causal illusions, thus suggesting that these illusions may not arise from incomplete learning processes.

In contrast, as an alternative to the previous associative models, some statistical models of human contingency learning, such as the weighted ΔP model (see Perales & Shanks, 2007) and the Evidence Integration (EI) rule (Perales & Shanks, 2007) predict consistent outcomes across varying number of trials, indicating that they do not expect alterations in the average causal judgement score as the length of training increases. In line with these models, causal illusion can be attributed to the unequal prioritization of each type of evidence. Thus, individuals could be assigning unequal significance or importance to the available information, thereby influencing their assessments of the contingency between events. For example, the weighted ΔP model, the weighted version of the ΔP index (Perales & Shanks, 2007), states that individuals calculate the two conditional probabilities associated with ΔP, P(O|C) and P(O|¬C), but attribute to each of them a specific weighting parameter (w). Following Perales and Shanks (2007), the most suitable fit is achieved when P(O|C) is given greater consideration compared to P(O|¬C):

$$\Delta P_{weighted} = w_1 \mathrm{P(O|C)} - w_2 \mathrm{P(O|\neg C)}$$

Applying the values given by these authors, $w_1 = 1$ and $w_2 = 0.81$, to the same frequency data from Figure 2, we can observe (see Figure 3) the emergence the P(O) effect, since the model predicts a greater value for High P(O) group than for the Low P(O) group:

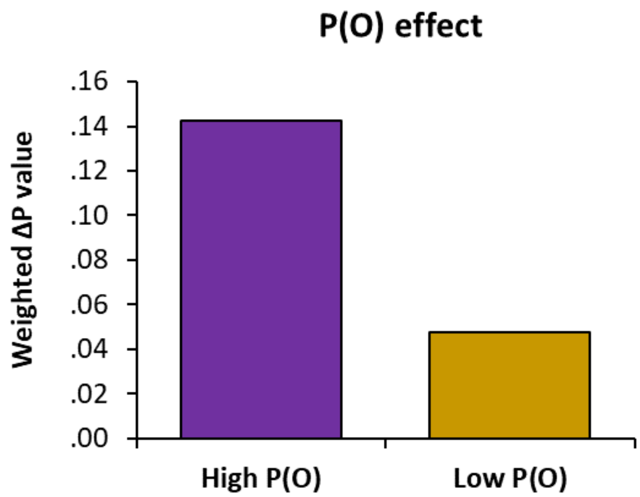

Figure 3. Graphical representation of the outcome-density effect, according to the weighted ΔP model. High P(O) group values: 18a, 6b, 18c, and 6d. Low P(O) group values: 6a, 18b, 6c, and 18d. High P(C) group values: 18a, 18b, 6c, and 6d. Low P(C) group values: 6a, 6b, 18c, and 18d.

The weighted ΔP model could not account for the P(C) effect, since the weights are assumed to be given to the conditional probabilities of the outcome in presence and in absence of the potential cause, resulting in the same values for the High P(C) and Low P(C) groups. In this sense, other statistical models assuming that individuals attribute different relevance to each of category of evidence (*i.e.*, cells *a*, *b*, *c*, and *d*, in Table 1) could explain both P(O) and P(C) effects. Indeed, Perales and Shanks (2007) indicated that events classified as type *a* carry a greater weight compared to other events, with the ranking of their weight as follows: *a* > *b* > *c* > *d*. According to their EI rule, these authors suggested that causal ratings arise from comparing confirmatory information from type *a* and *d* trials, with the disconfirmatory information provided by type *b* and *c* trials; taking into account the assignation of different weights to the four cells of the contingency table, in accordance with the mentioned hierarchy:

$$\mathrm{EI} = \frac{w_a\, a + w_d d}{w_a a + w_b b + w_c c + w_d d} - \frac{w_b b + w_c c}{w_a a + w_b b + w_c c + w_d d}$$

In their meta-analysis, Perales and Shanks (2007) also offered the most suitable values for each cell, through a cross-validation model-fitting method: w_a = 0.84, w_b = 0.58, w_c = 0.39, and w_d = 0.33. Hence, the P(O) and P(C) effects would be reflected as follows (see Figure 4), applying these weight values and the cell frequency data from Figure 2:

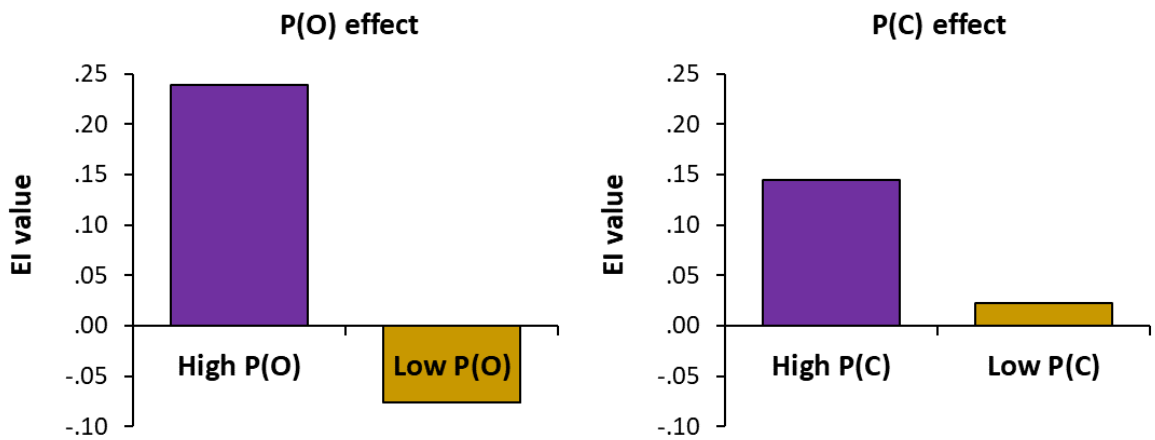

Figure 4. Graphical representation of the outcome-density (left panel) and cause-density (right panel) effects, according to the Evidence Integration rule. High P(O) group values: 18a, 6b, 18c, and 6d. Low P(O) group values: 6a, 18b, 6c, and 18d. High P(C) group values: 18a, 18b, 6c, and 6d. Low P(C) group values: 6a, 6b, 18c, and 18d.

As we can see, there are multiple ways to explain the development of causal illusion. I have showed a few of them without attempting to establish any kind of hierarchy between their level of suitability, as each of them has its own advantages and limitations.

1.3. Causal illusion in active contingency learning tasks: biases in the search of information

In the previous section, I presented passive tasks that help us to understand how gathered information is interpreted in causal inference situations. Nevertheless, in our daily experiences, we also come across situations where we have the choice to introduce the candidate cause or not. In the case of the example mentioned at the beginning of this dissertation, the farmer could notice a decline in crop yield due to the water scarcity. Aware of the correlation between water scarcity and reduced productivity, the farmer must decide whether to invest in irrigation systems or water-saving technologies, which require significant resources. By observing the effects of these measures on crop yield, the farmer could understand the relationship between water management practices and productivity. Implementing these measures and seeing improved yield would reinforce the belief in their effectiveness, likewise a continued decline in yield without implementation would strengthen the causal link between water scarcity and productivity.

Returning to controlled laboratory studies, the procedure used in active contingency learning tasks is the same than in the passive ones, with the exception of volunteers being able to manipulate the presence or absence of the potential cause (*e.g.*, Jenkins & Ward, 1965; Alloy & Abramson, 1979; Allan & Jenkins, 1980; Blanco *et al*., 2011, 2015), so the predictive question is not presented. When the potentially causal event involves the participant's actions, individuals tend to assign responsibility to their own conduct for the happening of an uncontrollable result. This is known as illusion of control (Langer, 1975; Langer & Roth, 1975) which is also considered a causal illusion (Blanco, 2017), so I will refer to both with the term "causal illusion". Moreover, since the individuals have the chance to control the occurrence of the potential cause, responses in this type of task reflect not only their information interpretation strategy, but also their strategy in gathering this information. Thus, in active tasks, the scores on causal judgement may also be influenced by how they have searched for information and, consequently, which cells of the contingency table they have been most exposed to. The information search strategy is reflected in the volunteers' probability of response, P(R) = (a+b)/(a+b+c+d), this is, the proportion of times in which they decide to introduce the potential cause. In fact, prior studies have shown that participants develop stronger causal illusions when they decide to expose themselves to more cause-present trials than cause-absent trials (*e.g*., Blanco *et al*., 2011; Barberia *et al*., 2013). It is noteworthy that the P(R) in active tasks can be considered equivalent to the P(C) in passive tasks, with the difference that, in this case, the participants determine their own P(R), since they have the ability to decide the presence or absence of the potential cause. Thus, the probability of response, P(R), will also determine the cause density, P(C), in active contingency learning tasks.

A clear example of this procedure can be found in the study by Blanco *et al*. (2011). These authors employed the same medical cover story about Batatrim and Lindsay syndrome, mentioned in the previous section, but in an active contingency learning task, with a null contingency between the potential cause and the outcome. Volunteers could decide on each trial if they wanted the potential cause to be present or not, that is, if they wanted to administer the Batatrim or not. Consequently, the cause density to which they were exposed depended on their own decisions. The results showed that participants overestimated the causal relation between the administration of Batatrim and the recovery from the Lindasy syndrome. This suggests that participants were inclined towards the belief that their actions could influence the outcome, implying the development of the mentioned illusion of control (Langer, 1975; Langer & Roth, 1975). Importantly, the greater the frequency with which volunteers decided to administer the medicine, the more intense their causal judgement, a phenomenon known as P(R) effect (see Blanco *et al*., 2009; Hannah & Beneteau, 2009, for similar results).

The tendency to administer the medicine in many trials, showed by the participants who developed stronger causal illusions, resembles the positive testing strategy (*e.g*., Klayman & Ha, 1989), which refers to a deeply rooted inclination to produce a positive outcome (in this case, the recovery of the patient) if the initial hypothesis (that the medicine is effective) were true. However, this behaviour may occur due to other factors, such as the willingness of the participants to achieve the outcome (recovery from the disease), which doesn't necessarily imply a hypothesis-testing strategy (Blanco *et al*., 2015). Another possible factor that could be influencing the development of the P(R) effect is the confirmation bias, which refers to the inclination to search for or interpret information in a manner that validates existing beliefs or hypotheses. This bias may result in favouring data that aligns with one's current viewpoint or decision, while minimizing or disregarding conflicting information (Nickerson, 1998). In sum, the standard procedure used in active contingency learning tasks does not allow to know whether participants deliberately use strategies that lead them to administer the medicine in most trials or not. However, for ease of reading, I will refer to this behaviour as confirmatory search strategy.

1.4. Causal illusion beyond the laboratory: erroneous causal beliefs in daily life

So far, I have examined the procedure and characteristics essential for the formation of the causal illusion in controlled laboratory environments. The aim of this thesis is to study whether this phenomenon could be responsible for the emergence of erroneous beliefs in our daily lives. The term epistemically unwarranted beliefs refers to those beliefs that are not founded on reliable reasoning or credible data (Lobato *et al*., 2014). Following Lobato *et al*. (2014), these beliefs might be classified as paranormal, conspiracy, pseudoscientific beliefs and science denialism. The term paranormal beliefs (which includes superstitious beliefs; Tobacyk, 2004; Griffiths *et al*., 2018) refers to those that in the case of being true, would contradict fundamental scientific principles (Broad, 1949). Conspiracy theories can be considered informal beliefs that assign the underlying cause of an event, or the act of keeping an event hidden from public knowledge, to a covert and malicious plot, orchestrated by multiple actors collaborating (Swami *et al*., 2010). Pseudoscientific beliefs are those concerning phenomena that, despite professing to be "scientific," are based on non-scientific evidentiary methods, such as authoritative assertions, anecdotes or vague explanations (Losh & Nzekwe, 2011). Finally, science denialism, which is classified by some authors as a form of pseudoscience (Lobato *et al*., 2014; Fasce & Picó, 2019), refers to the intentional refusal to accept well-established scientific theories, creating an artificial controversy among scientists (Fasce & Picó, 2019).

In the literature we can find some studies that have addressed the possible link between causal illusion and these unwarranted beliefs (*e.g*. Blanco *et al*., 2015; Griffiths *et al*., 2018). This is the case of the study of Blanco *et al*. (2015), who suggested a parallel between paranormal beliefs and causal illusions since these beliefs have been previously described as the result of a biased causal inference (Brugger & Graves, 1997). These authors stated that questionnaires measuring paranormal beliefs might reflect pre-existing illusions of causality developed through the mechanisms studied in contingency learning experiments. Consequently, individuals with a stronger tendency to endorse unwarranted beliefs, may not only have developed illusions in the past but could also exhibit a heightened vulnerability to laboratory-induced causal illusion compared to nonbelievers. Their study included the use of the Revised Paranormal Beliefs Scale (RPBS; Tobacyk, 2004), a questionnaire designed to measure this type of beliefs, in its Spanish version, the RPBS-Sp (Díaz-Vilela & Álvarez, 2004). They also designed an active contingency learning task, framed in the typical medical cover story. These authors granted participants the liberty to decide whether or not to administer the medicine. Blanco et al.’s results showed a correlation between participants' propensity to develop causal illusions in a contingency learning task and their degree of endorsement of paranormal beliefs. More precisely, participants who held stronger beliefs in the paranormal exhibited a higher level of causal illusion. Their results also revealed that volunteers administered the medicine in more than 50% of the trials, and that this confirmatory search strategy was mediating the connection between causal illusion and paranormal beliefs, leading them to propose that individuals who believe in the paranormal may exhibit biased information-gathering strategies, making them more susceptible to forming inaccurate causal judgments.

In a related research,, Griffiths *et al*. (2018) explored the connection between causal illusions and superstitious beliefs through the development and implementation of the Superstitious Beliefs Questionnaire (SBQ), and an active contingency learning task set in a non-medical context. In their contingency learning task, participants were asked to determine the relationship between pressing a switch and the illumination of a lightbulb. Notably, switch-pressing and illumination were unrelated, given that the lightbulb lit up in 60% of the trials, irrespective of whether the switch was activated. It's important to note that the researchers instructed participants to press the switch in approximately half of the trials to ensure a balance of cause-present and cause-absent trials, guiding the participants' information search strategy. Thus, I will focus on the results they found in relation to the participants' way of interpreting information, since the participants' information search strategies were controlled in order to ensure the emergence of the causal illusion without the possible influence of the confirmatory search strategy bias. Griffiths *et al*. (2018) found a positive correlation between the presence of superstitious beliefs (measured by the SBQ) and the extent of causal illusions shown in their contingency learning task. In light of these findings, their results suggest that not only the way individuals search for new information but also how they interpret existing information might play a role in the formation of unwarranted beliefs.

As far as I know, when I developed the studies that I will present in the dissertation, studies relating other kinds of epistemically unwarranted beliefs to the development of causal illusions had not yet been carried out. Nevertheless, Matute *et al*. (2011) proposed that, since many purported pseudosciences, particularly those related to medical treatments, depend on causal relationships, and causal illusions naturally emerge from the cognitive system's normal functioning when connecting causes and effects, these illusions could serve as a fundamental cognitive mechanism underlying pseudoscientific beliefs. It is precisely in this gap where the main objective of this thesis was focused, as I will specify below.

1.5. Characterizing believers in pseudoscience

Nowadays, a significant and widespread form of unwarranted belief is represented by pseudoscience. As previously stated, the term pseudoscientific beliefs refer to those beliefs about certain disciplines claiming to be scientific but lacking scientific evidence. It is interesting to mention that, regarding their prevalence, we can observe that pseudoscientific beliefs seem to be the most commonly observed among the different types of unwarranted beliefs. In the case of paranormal beliefs, 36% and 33.3% of the United States and the United Kingdom population, respectively, believes in ghosts (Ipsos, 2021; BGM Research, 2017). Regarding conspiracy theories, 19% of the United States population believe that the government is using chemicals to control the population (YouGov, 2019); 18.1% of people in Germany believe that the COVID-19 is a bioweapon intentionally designed to harm humans (Friedrich-Ebert-Stiftung, 2023); and 4% of citizens in United Kingdom believes that vaccinations have harmful effects which are not being fully disclosed to the public (Armstrong, 2019). Meanwhile, 39% and 66% of the United Kingdom citizens believe in the effectiveness of pseudoscientific therapies, such homeopathy and acupuncture, respectively, at treating illness (YouGov, 2015a, 2015b). Moreover, placing trust in the efficacy of certain pseudosciences may pose health and economic risks. For instance, individuals who opt for (ineffective) pseudoscientific treatments to address their illnesses or pathologies may experience increased susceptibility to morbidity and, in some cases, result in death (Lim *et al*., 2011; Johnson *et al*., 2018a, 2018b). Consequently, accurately gauging the prevalence of these beliefs and comprehending the cognitive factors that contribute to their emergence is crucial, as this understanding would facilitate the development of strategies aimed at reducing their detrimental impact.

At this point, it is of interest to explore the cognitive and sociodemographic factors that might contribute to the emergence and prevalence of these beliefs. Table 3 shows a summary of previous findings regarding the cognitive and sociodemographic correlates of pseudoscientific beliefs. As we can see, there is a general consensus regarding the positive correlation between the different unwarranted beliefs (*i.e*., endorsement of pseudoscience correlates positively with paranormal and conspiracy beliefs).

Table 3. Summary of the cognitive and sociodemographic correlates of pseudoscientific beliefs found in the literature.

Cognitive or sociodemographic correlate	Correlation direction	References
Paranormal beliefs	Positive	Lobato *et al*. (2014); Majima (2015); Fasce & Picó (2019); Huete-Pérez *et al*. (2022)
Conspiracy beliefs	Positive	Lobato *et al*. (2014); Fasce & Picó (2019); Huete-Pérez *et al*. (2022)
Faith in intuitive thinking	No correlation	Majima (2015)
Faith in intuitive thinking	Positive	Fasce & Picó (2019)
Need for cognition	No correlation	Lobato *et al*. (2014)
Need for cognition	Positive	Majima (2015)
Need for cognition	Negative	Fasce & Picó (2019)
Cognitive reflection	Negative	Fasce & Picó (2019); Majima *et al*. (2022)
Bullshit receptivity	Positive	Pennycook *et al*. (2015)
Formal education	Positive	Astin (1998); Barnes *et al*. (2008); CIS (2018)
Scientific knowledge	Negative	Fasce & Picó (2019)
Scientific knowledge	No correlation	Majima (2015)
Sex	Women > men	Lobato *et al*. (2014); Majima (2015); Huete-Pérez *et al*. (2022)
Socioeconomic status	Positive	Eisenberg *et al*. (1993); CIS (2018)

Two of the most controversial factors found, specifically in relation to pseudoscientific beliefs, are the faith in intuition, which refers to how much an individual relies on intuitive thinking, and the need for cognition, the degree to which individuals find enjoyment and engage in rational, logical, and analytic thinking, both measured through the Rational-Experiential Information Styles self-report questionnaire (Epstein *et al*., 1996). The fact of finding so much discrepancy in the results obtained suggests that a self-report may be biasing reality, so some authors have opted to employ the Cognitive Reflection Test (CRT; Frederick, 2005) to confirm or refute their results in relation to intuitive and reflective thinking. In this sense, Fasce and Picó (2019) and Majima *et al*., (2022) found that cognitive reflection was negatively correlated with the pseudoscientific beliefs.

There is another variable that might be influencing the development of pseudoscientific and other unwarranted beliefs: gullibility (*i.e.*, the inclination to embrace an incorrect assumption when confronted with cues indicating untrustworthiness; Teunisse *et al*., 2020). In this sense, Pennycook *et al*. (2015) designed a questionnaire to evaluate the individuals' tendency to attribute exaggerated judgments to statements devoid of meaning, the *Bullshit* Receptivity Scale (BSR). This scale included three main variables: *bullshit* receptivity (*i.e*., scores given to pseudo-profound and meaningless sentences), motivational quotations (*i.e*., scores given to legitimate motivational quotes), and *bullshit* sensitivity (*i.e*., the scores resulting by deducting the *bullshit* receptivity from the motivational quotation means). Their results supported the existence of a broad gullibility factor that might explain why certain participants were prone to accepting epistemically unwarranted beliefs. Although they did not address pseudoscientific beliefs directly, their measure of *bullshit* receptivity correlated positively with believe in the efficacy of complementary and alternative medicines (including certain pseudo-remedies, such as homeopathy), and with other unwarranted beliefs, such as paranormal beliefs and religions; and negatively correlated with cognitive reflection and *bullshit* sensitivity.

With regard to sociodemographic features, one of the main variables influencing the level of endorsement of these beliefs is the formal education. In this sense, some studies found a negative association between education level and paranormal beliefs (Aarnio & Lindeman, 2005; Majima, 2015). Conversely, in the case of belief in pseudoscience, it is suggested that this variable may show resilience to formal education, given that there is evidence suggesting that a positive correlation exists between this variable and the duration of education (Astin, 1998; Barnes *et al*., 2008; CIS, 2018). While higher education does not seem to be adequate in preventing the endorsement of pseudoscientific beliefs, the results derived from Fasce and Picó's (2019) study indicate that receiving specialized scientific education may encourage the rejection of pseudoscience, since these authors observed a negative correlation between this kind of unwarranted beliefs and scientific knowledge. However, the fact that Majima (2015) failed to find this correlation highlights that more research would be needed to clarify whether or not these variables actually correlate negatively.

Regarding other sociodemographic factors, the prevalence of pseudoscientific beliefs exhibits variations across them. One of the most notable variables is sex, since different studies have shown a higher prevalence of unjustified beliefs among women, specifically paranormal and pseudoscientific beliefs (*e.g*., Lobato *et al*., 2014; Majima, 2015; Huete-Pérez *et al*., 2022). Furthermore, pseudoscientific beliefs have been identified as more common among individuals with higher socioeconomic status (Eisenberg *et al*., 1993; CIS, 2018).

OBJECTIVES

2. Objectives

The objectives of the present doctoral thesis are as follows:

- **Objective 1:** To investigate the relationship between causal illusion and pseudoscientific beliefs (Study 1). The main hypothesis in the first study is that individuals who score higher on a scale assessing pseudoscientific beliefs will exhibit more pronounced causal illusions, in a passive contingency learning task. Additionally, it is expected that the level of endorsement of pseudoscience will show a positive correlation with other scales gauging beliefs in the paranormal and superstitions.
- **Objective 2:** To disentangle the influence of information interpretation and information search strategies in the association between causal illusion and pseudoscientific beliefs (Study 2). My hypothesis in that the strength of causal illusions, developed in an active contingency learning task, will be positively correlated with the pseudoscientific beliefs' scores. Moreover, it is anticipated an information search effect, meaning that this association will disappear when controlling for the way in which participants search for information, paralleling previous results found by Blanco *et al*. (2015) with paranormal beliefs.
- **Objective 3:** To further investigate other possible cognitive contributors to pseudoscientific belief endorsement (Study 3). It is to be expected that the endorsement of pseudoscientific beliefs will be positively correlated with other unwarranted beliefs as well as gullibility. Conversely, I expect negative correlations with analytic thinking (*i.e*., reflective rather than intuitive) and scientific knowledge. Regarding sociodemographic characteristics, aligning with prior findings, I predict a higher endorsement of pseudoscientific beliefs among women compared to men. Additionally, I anticipate greater endorsement among individuals with higher levels of education and socioeconomic status.

The three studies presented below are faithful reproductions of the published scientific articles, the only difference being that they have been aesthetically adapted, and formatted in APA style (7th Edition), to give uniformity to the format of this doctoral thesis. The front-page of each article can be found in the Annex section, at the end of this dissertation.

STUDY I

3. Study 1: Causal illusion as a cognitive basis of pseudoscientific beliefs

[1]Torres, M. N., Barberia, I., & Rodríguez-Ferreiro, J. (2020). Causal illusion as a cognitive basis of pseudoscientific beliefs. British Journal of Psychology, *11*(4), 840–852. https://doi.org/10.1111/bjop.12441

3.1. Abstract

Causal illusion has been proposed as a cognitive mediator of pseudoscientific beliefs. However, previous studies have only tested the association between this cognitive bias and a closely related but different type of unwarranted beliefs, those related to superstition and paranormal phenomena. Participants (n = 225) responded to a novel questionnaire of pseudoscientific beliefs designed for this study. They also completed a contingency learning task in which a possible cause, infusion intake, and a desired effect, headache remission, were actually non-contingent. Volunteers with higher scores on the questionnaire also presented stronger causal illusion effects. These results support the hypothesis that causal illusions might play a fundamental role in the endorsement of pseudoscientific beliefs.

[1] **Acknowledgements:** This study was supported by the grants PSI2016-75776-R (AEI/FEDER, UE) to IB and PSI2016-80061-R, (AEI/FEDER, UE) to JRF, both from the Agencia Estatal de Investigación of the Spanish Government and from the European Regional Development Fund, as well as grant 2017SGR387 (AGAUR) from the Catalan Government to JRF.

3.2. Introduction

Previous studies have aimed to identify the mechanisms underlying unwarranted beliefs related to paranormal phenomena (Blackmore & Trościanko, 1985; Brugger *et al*., 1990; Van Prooijen *et al*., 2018; Wiseman & Watt, 2006). In this study, we focus on a different, though closely related, domain of unwarranted beliefs: those related to pseudoscience. According to the demarcation criteria adopted by Fasce and Picó (2019, p. 618), for something to be considered a pseudoscience, it needs to be "presented as scientific knowledge" (A) and also meet at least one of the following three conditions: "refers to entities and/or processes outside the domain of science" (B), and/or "makes use of a deficient methodology" (C), and/or "is not supported by evidence" (D). As noted by these authors, the difference between pseudoscientific and paranormal beliefs lies in the fact that although the latter still refers to aspects outside the domain of science (it fulfils B), it is not presented as scientific knowledge (does not fulfil A). While paranormal and pseudoscientific beliefs tend to positively correlate (Fasce & Picó, 2019; Lindeman, 2011; Majima, 2015), they present different prevalence rates in the population. For instance, according to a national survey on social perception of science conducted in Spain (FECYT, 2017), whereas only 22.4% and 27.5% of the population, respectively, believe in paranormal phenomena and superstitions (*i.e*., lucky charms or numbers), when asked regarding the effectiveness of pseudoscientific treatments, the percentages rise to 52.7% for homeopathy and 59.9% for acupuncture.

Understanding the cognitive mechanisms supporting pseudoscientific beliefs is especially relevant because, unlike what happens in relation to paranormal beliefs, which are negatively related to education level (Aarnio & Lindeman, 2005), they have been shown to be more present in individuals with higher education levels (NCCIH-NIH, 2008), and endorsement of these kinds of claims is noteworthy even among educated professionals such as physicians (Posadzki *et al*., 2012) or teachers (Ferrero *et al*., 2016).

Given that much putative pseudoscience (for instance, that related to medical treatments) relies on causal relations, it has been proposed that causal illusions might be a fundamental cognitive basis of pseudoscientific beliefs (Matute *et al*., 2011). The terms causal illusion or illusion of causality refer to a cognitive bias leading one to perceive a causal connection between two events which are actually non-contingent (Matute *et al*., 2015).

To our knowledge, there have been two recent attempts to explore the relationship between the scores obtained in questionnaires measuring unwarranted beliefs and the intensity of the causal illusions generated in null contingency learning tasks. First, Blanco *et al*. (2015) found that individual differences in the number of paranormal beliefs held by a group of participants, as measured by the Revised Paranormal Beliefs Scale (RPBS, Tobacyk, 2004) in its Spanish version (RPBS-Sp, Díaz-Vilela & Álvarez, 2004), predicted differential propensity to develop causal illusions. Blanco *et al*. (2015) presented their participants with the records of several fictitious patients who allegedly suffered from the same disease. The volunteers could then decide whether to administer each patient a given drug or not. Immediately afterwards, they were told whether the patient healed or not. Note that, in this task, the two binary variables for which the contingency is being assessed are conceived as events (taking the drug; recovering from the disease) *vs*. non-events (no drug; no recovery), and, therefore, it can be considered an asymmetric contingency learning task (Allan, 1993). After the volunteers had gone through all the patients, they evaluated the effectiveness of the drug on a numerical scale from 0 (the drug was ineffective) to 100 (the drug was perfectly effective). The chances of recovery were set at 75% irrespective of the administration of the drug and, therefore, the drug did not increase the probability that a patient would show recovery (here we are focusing on their non-contingent condition, but the authors also included a contingent condition in their design). Given this null contingency between drug administration and recovery, higher ratings in the numerical effectiveness scale were treated as indicative of a greater causal illusion developed by the participants. In Blanco *et al*.'s results, the relation between paranormal beliefs and causal illusion was mediated by the proportion of patients to which each participant decided to administer the drug, leading the authors to conclude that the way in which individuals expose themselves to available information might play a crucial role in the relation between paranormal beliefs and causal illusion.

The other noteworthy work regarding the relationship between causal illusions and misbeliefs is a recent study by Griffiths *et al*. (2018). In their study, Griffiths *et al*. (2018) asked their participants to discover the extent to which pressing a button controlled the illumination of a light. Again, the task involved a null contingency between the button press and the illumination of the light, that is, the light illuminated about 60% of the time independent of the participant pressing or not pressing the button. Similar to the procedure used by Blanco *et al*., after completing the task the participants were asked to evaluate the extent to which the action of button-pressing controlled the illumination of the light, on a numerical scale ranging from 0 (meaning no control) to 100 (meaning total control).

These authors showed that differential scores in superstitious beliefs, as measured by the Superstitious Beliefs Questionnaire (SBQ, developed ad hoc for their study), were positively correlated with the intensity of the causal illusions developed in their contingency learning task. Griffiths *et al*. instructed their participants to press the button on about half the occasions and not to press it on the other half. Interestingly, even when controlling for spontaneous individual differences in the behavioural component by instructing participants about how to behave during the task, these authors still found a positive correlation between the intensity of the causal illusions developed by the participants and their scores on the SBQ. Griffiths *et al*. concluded that their findings were complementary to those of Blanco *et al*. (2015) by showing that the differences between superstitious and non-superstitious individuals relied on the way they interpreted the experienced cause–effect contingencies.

Note that the questionnaires employed by each of the preceding studies differed. Blanco *et al*. (2015) opted for the RPBS-Sp, which includes items distributed across eight dimensions: witchcraft, psi, traditional religious beliefs, spiritualism, extraterrestrial life and actual visits, pre-cognition, superstition, and extraordinary life forms (Díaz-Vilela & Álvarez, 2004). Griffiths *et al*. instead developed a new questionnaire because they argued that the RPBS and other measures “contained statements that have not yet or cannot be verified, but which may be rational beliefs (“There is life on other planets”) or items that have little bearing on daily life (“The abominable snowman of Tibet exists”)” (Griffiths *et al*., 2018, pp. 504–505). In its place, they developed items “to reflect beliefs held in the community, which address implausible causal relationships, and for which evidence (either for or against the belief) is likely to be encountered in ordinary life” (Griffiths *et al*., 2018, p. 505). When going through the items chosen by Griffiths *et al*. (2018, see their Appendix B), we can find statements related to subscales already present in the RPBS-Sp, such as items related to superstition (“If I passed a ladder I would walk around it rather than underneath it”) or religion [“I believe in the existence of a higher being (such as a Christian God, Allah, Shiva, Waheguru, or Satan)”], but also items related to pseudoscientific disciplines such as homeopathy [“’Alternative’ therapies (such as homeopathic remedies, aromatherapy, reflexology, chiropractic manipulation, or therapy based on the body’s energy fields) can be an effective way of treating illnesses and ailments”] or graphology (“It is possible to gain information about a person’s personality by analysing their handwriting”).

Along with the theoretical basis outlined above, the fact that Griffiths *et al*. (2018) observed a significant correlation between the intensity of causal illusions and scores on a questionnaire partially consisting of items related to pseudoscientific beliefs inspired us to assess the specific relation between causal illusions developed in the laboratory and misbeliefs specifically related to pseudoscience. To do this, we measured our participants' pseudoscientific beliefs and presented them with a contingency learning task. In order to mirror a situation specifically related to pseudoscience, the contingency learning task used a pseudomedicine-related scenario in which participants were asked to decide whether a given infusion was effective in reducing headache. In contrast to the procedure used by Blanco *et al*. (2015), in which volunteers decided whether or not to administer the drug to the patients, our participants were passively presented with the information regarding whether the patients used the infusion and whether they recovered from the headache. In this sense, our task is more similar to the one used by Griffiths *et al*. (2018), who controlled for the rate of cause administration by asking their participants to keep a constant rate of cause administration. However, instead of presenting participants with balanced samples of patients taking and not taking the infusion, we presented them with a majority of patients taking the infusion. Specifically, 75% of patients took the infusion, whereas only 25% did not take it (75% of patients recovered irrespective of the intake of the infusion, see Barberia *et al*., 2019, for another study using the same frequencies). These frequencies were used in order to maximize the causal illusion effect in our participants, as previous studies have shown that passive contingency learning tasks in which the potential cause is frequently present yield stronger illusion effects, especially when the outcome also occurs with a high frequency (*e.g*., Blanco *et al*., 2013). Taking this into account, our hypothesis is that individuals with higher scores in a scale measuring pseudoscientific beliefs will rate the infusion as more effective, thus displaying stronger causal illusions than those with lower scores. Given the passive nature of our task, this result would be indicative of a bias in the interpretation of available contingency information. Finally, in order to replicate the results obtained in previous studies, we also included a measure of superstitious beliefs Griffiths *et al*. (2018) in our experimental design.

3.3. Method

3.3.1. Participants

A total of 225 psychology students from the University of Barcelona (44 males and 181 females) participated in this study. Ages ranged from 20 to 64, with a mean of 22.79 years old (*SD* = 6.05). The study protocols were approved by the ethics committee of the university (Institutional Review Board IRB00003099, Comissió de Bioètica de la Universitat de Barcelona). Participants provided informed consent before their participation.

3.3.2. Materials

Contingency learning task

The task was an adaptation of the standard task employed in the literature on causal illusions (*e.g.*, Blanco *et al*., 2013). Participants were asked to judge the ability of an infusion of an herb brought from the Amazon to heal headache (the Amazônia task). The participants viewed, on a computer screen, a series of medical records (one per trial) describing patients suffering a headache. In each trial, the participants were shown whether a given patient received the infusion or not, and they were asked (yes/no question) whether they thought the patient would heal in the subsequent two hours. Then, the participants received feedback indicating whether the patient was healed. After observing all patients, the volunteers were presented with an effectiveness question (*i.e.*, "To what extent do you think the herb infusion is effective as a cure for headache? Provide a number between 0 and 100 where 0 means not effective at all and 100 means totally effective"; original question in Spanish: "¿Hasta qué punto crees que la infusión de hierbas es efectiva contra el dolor de cabeza? Introduce un número entre 0 y 100. Un valor de 0 significa que no es nada efectiva y un valor de 100 que es totalmente efectiva"). The infusion was completely ineffective, as healing rates were non-contingent on the administration of the infusion: P(Healing|Infusion) = P(Healing|¬Infusion) = 0.75, making the contingency 0. Specifically, participants observed a total of 48 patients. The infusion was administered to 36 of them, from which the headache disappeared in 27 cases and persisted in 9. The infusion was not administered to the remaining 12 patients, from which the headache disappeared in 9 cases and persisted in 3. The different trial types were presented in a separate random order for each participant.

For exploratory reasons, we also measured participants' recall of the frequencies of the four different trial types experienced during the task (*e.g.*, "In how many patients who took the infusion did the headache disappear?"). About half of the participants responded to these questions before the effectiveness one. The other half responded to the frequency questions after the effectiveness question.

Pseudoscience Endorsement Scale

We designed the Pseudoscience Endorsement Scale (PES) to be used in our study. All instructions and items for the PES are listed in Appendix A. The scale consists of 20 items referring to popular pseudoscientific myths (*e.g.*, the preventive impact of a positive attitude over cancer, stress being the primary cause for ulcers, the use of polygraph as a lie detection mechanism..., see Lilienfeld *et al*., 2010) and disciplines (*e.g.*, homeopathy, Reiki, Bach flowers, graphology, neuro-linguistic programming). Three of the items (items 1, 15, and 20) were adapted from the Belief in the non-Paranormal Pseudoscience Scale by Majima (2015). Each item consisted of a statement that the participants had to rate on a scale from 1 (*i.e*., "Strongly disagree") to 7 (*i.e*., "Strongly agree"). Note that, according to Fasce and Picó (2019), a claim can be considered pseudoscience if it is presented as scientific knowledge but is not supported by evidence. Therefore, the pseudoscientific status of a myth or discipline is not necessarily immutable and can change in the light of new evidence. Moreover, the fact that a topic is considered pseudoscientific does not imply that studies investigating the topic are themselves pseudoscientific.

In order to verify the reliability of the PES, a total of 143 psychology students from the University of Barcelona (122 females, 19 males, and 2 participants who did not disclose their gender), different from those who took part in the experiment, completed this scale. Ages ranged from 21 to 54, with a mean of 22.89 years old (SD = 3.89). A reliability analysis on the PES data (*mean* = 3.47, SD = 0.83) performed with IBM SPSS Statistics (version 23.0.0.2) showed high internal consistency of item scores, Cronbach's $\alpha = 0.89$. Hotelling's T^2 index of equality was $T^2 = 897.28$, $F(19,124) = 41.24$, $p < .001$, and Tukey's test of non-additivity was $F(1,2698) = 1.02$, $p = .312$. Thus, all the items were interrelated and additive. Then, we tested the suitability of our data for the principal components analysis (PCA). The Kaiser–Meyer–Olkin (KMO) test showed a high measure of sampling adequacy, $KMO = 0.87$, and Bartlett's test of sphericity was significant, $\chi^2(190) = 930.21$, $p < .001$, showing high correlation between items. The PCA showed five components with eigenvalues over 1.0, which explained 32.48%, 7.61%, 6.13%, 5.84%, and 5.11% of the variance. According to the PCA, most items had a higher load in component 1 and the variance percentages explained by the other four components were very low. A parallel analysis was conducted, which extracted only one component. Given these results, it seems legitimate to accept the parallel analysis solution, based on only one component (general pseudoscientific beliefs).

A total of 141 of these participants also responded to the RPBS-Sp (Díaz-Vilela & Álvarez, 2004). Following Barberia *et al*. (2018), we slightly reworded item 20 and did not consider scores corresponding to item 23 to calculate the global score. Mean global scores for this scale were 1.92 (SD = 0.70). The Shapiro–Wilk test for normality showed that the mean scores on RPBS-Sp did not follow a normal distribution, $W(141) = 0.92$, $p < .001$. Thus, we conducted the non-parametrical Kendall's tau test to analyse the correlation between scores on the RPBS-Sp and the PES, which returned a positive correlation, $r_\tau = 0.34$, $p < .001$.

It should be noted that another interesting scale for measuring pseudoscientific beliefs has been published since we designed the PES and gathered these initial data for testing its reliability. This is the Pseudoscientific Beliefs Scale by Fasce and Picó (2019). However, we believe that our scale might be more adequate for our purposes here because it specifically focuses on pseudoscience, whereas that of Fasce and Picó (2019) includes both items related to pseudoscience as well as to science denialism, a close but conceptually different subcategory of unwarranted beliefs. In any case, Fasce and Picó's (2019) scale constitutes an alternative for measuring pseudoscientific beliefs that might also be employed in future studies on causal illusions.

Superstitious Beliefs Questionnaire

We translated the English SBQ (Griffiths *et al*., 2018) into Spanish following common translation and back-translation procedures (Sierro *et al*., 2016). Thus, a Spanish speaker of advanced English proficiency translated the English version into Spanish. Then, an English-native bilingual translator back-translated the Spanish version. The minor differences revealed by comparing the two versions were discussed by the two translators until agreement was reached. Our participants completed this Spanish version of the SBQ. The statements were rated by the participants on a scale from 0 (*i.e*., "Strongly disagree") to 4 (*i.e*., "Strongly agree").

3.3.3. Procedure

The participants completed first the Amazônia computerized contingency learning task followed by the PES, designed for the present study, and the SBQ (Griffiths *et al*., 2018), in that order.

3.4. Results

The data set can be found at https://osf.io/w29cs/. Data were analysed with JASP (version 0.9.2.0). We performed Bayesian *t*-tests using JASP's default Cauchy prior width, r = .707. We interpreted Bayes factors (*BF*) following Table 1 in Wagenmakers *et al*. (2018). Given that the Shapiro–Wilk test showed that the mean scores on the contingency task, $W(225) = 0.87$, $p < .001$, and the mean scores on the SBQ, $W(225) = 0.92$, $p < .001$, did not follow a normal distribution, we opted to conduct Kendall's tau for testing all correlations.

Regarding the contingency task, the mean of effectiveness judgements (*i.e*., casual illusion) was significantly higher than zero, *mean* = 63.22, *SD* = 21.07, $t(224) = 45.00$, $p < .001$, $BF_{10} = 1.995^{110}$. These results suggest that the participants perceived the task as contingent, developing, at least to some extent, a causal illusion.

Per-participant subjective probability contrasts [P(Healing|Infusion) - P(Healing|¬Infusion)], calculated from their responses to the exploratory frequency recall questions, significantly correlated with the causal illusion, r = .543, $p < .001$, $BF_{10} = 3.653^{15}$. This result suggests that the relative recall of different trial types by the participants could be, somehow, related to their perception of a causal relation between the infusion and the disappearance of the headache. Given that question presentation order did not affect the causal illusion ($F < 1$), we ignore these exploratory questions in the following.

Both the reliability of the PES and the SBQ were high for the experimental sample, $\alpha = 0.91$ and $\alpha = 0.93$, respectively. In general, scores on the PES, *mean* = 3.30 (on a 1 to 7 scale), *SD* = 1.02, appeared to be relatively higher than those corresponding to the SBQ, *mean* = 0.87 (on a 0 – 4 scale), *SD* = 0.69. Crucially, a Kendall correlation analysis between causal illusion scores on the contingency task and scores on the PES showed that they were positively correlated, $r_\tau = 0.13$, $p = .007$, $BF_{10} = 4.76$ (see Figure 5, left panel). The PES and the SBQ were significantly correlated, $r_\tau = 0.47$, $p < .001$, $BF_{10} = 1.939^{22}$. Nevertheless, in contrast to the results obtained by Griffiths *et al*. (2018), we observed no significant correlation between the causal judgements and the SBQ scores, $r_\tau = 0.09$, $p = .068$, BF_{10} =

0.55 (see Figure 5, right panel). For the sake of comparison with previous studies (Blanco *et al.*, 2015; Griffiths *et al.*, 2018), we also performed Pearson correlations, which showed that scores on the PES were positively correlated with both causal illusion, $r = 0.22$, $p < .001$, $BF_{10} = 23.96$, and scores on the SBQ, $r = 0.63$, $p < .001$, $BF_{10} = 1.597^{23}$. According to this analysis, the correlation between scores on the SBQ and the intensity of the causal illusion was, again, not significant, $r = 0.11$, $p = .105$, $BF_{10} = 0.31$.

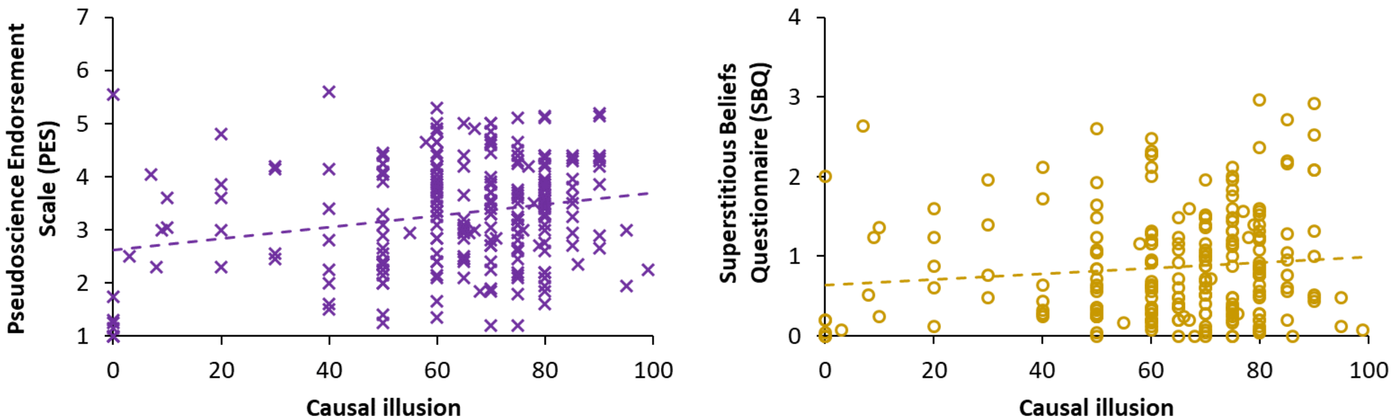

Figure 5. Association between the intensity of the causal illusion and the scores in the PES (left pannel) and SBQ (right pannel) questionnaires.

All in all, attending to the results of the previous Bayesian analyses, our data provide moderate-to-strong evidence favouring the existence of a positive association between scores on the PES and causal illusion. In contrast, our results offer anecdotal-to-moderate evidence against the association between causal illusion and scores on the SBQ.

3.5. Discussion

In this research, we aimed to assess the relation between causal illusion and belief in pseudoscience. Our data show that participants with higher scores on a novel scale specifically designed to measure pseudoscientific beliefs also developed stronger causal illusions in a contingency learning task with zero contingency. Although the rate of headache remission in the experimental task was independent of the patients taking or not taking the infusion, most of the participants perceived some degree of causal relation between infusion intake and healing. Crucially, volunteers with higher pseudoscientific beliefs rated the causal relation as stronger than those with low pseudoscientific beliefs.

Our study elaborated on previous research by Blanco *et al*. (2015); Griffiths *et al*. (2018), who observed that volunteers with higher levels of, respectively, paranormal and superstitious beliefs also tended to develop stronger causal illusions during contingency learning tasks. We extended these findings to the field of pseudoscience, which is closely related to paranormal beliefs, but presents its own characteristics (Fasce & Picó, 2019). Our data, nevertheless, did not replicate the association between superstitious beliefs, as measured by the SBQ, and causal illusion, as we failed to observe a significant correlation between these two variables. We consider that the lack of significant effects in this regard could have been due to a floor effect as evidenced by the extremely low scores obtained by our participants on the superstitious beliefs scale. In our view, this null effect, in fact, stresses the relevance of this study, indicating that, whereas superstition might not be that relevant in our context, pseudoscientific beliefs appear to be more widespread.

As noted by the reviewers of an early version of this article, an alternative explanation for the discrepancy between our results and those of Griffiths *et al*. (2018) is that our contingency learning task was framed in terms of a natural remedy, an herb from the Amazon, a scenario that might parallel that of pseudomedicines. In contrast, Griffiths *et al*. (2018) used a more neutral scenario referring to discovering the connection between pressing a button and the illumination of a light. In this sense, it is possible that those participants who endorsed more pseudoscientific beliefs were, from the start, more inclined to believe in the natural remedy, independent of the contingency information observed during our task. Note, besides, that differences in the cover story used could also be responsible for the lack of replication of the significant correlation between superstitious beliefs and causal illusion observed by these authors. In our view, employing contingency learning tasks with content-relevant cover stories might more accurately mimic the conditions in which those beliefs develop in real life. Nevertheless, future research should explore whether the correlation we observed between causal illusions and pseudoscientific beliefs also appears when the contingency learning task refers to a more neutral scenario, such as that used by Griffiths *et al*. (2018).

Regarding the specific cognitive mechanisms supporting the observed effect, in the study by Blanco *et al*. (2015) the association between belief in the paranormal and causal illusion had been shown to be mediated by the volunteers' tendency to administer the drug to the patients, leading the authors to conclude that the individuals' information search strategies played a crucial role in their observed effect. In our study, the fact that participants were passively presented with the information (*i.e*., they could not manipulate the administration of the infusion during the task), indicates that the association between pseudoscientific beliefs and causal illusion also relies on the way individuals interpret given information. In this sense, our results are analogous to those obtained by Griffiths *et al*. (2018) although, in our case, the association is specifically drawn between causal illusion and pseudoscientific beliefs. From their perspective, the key aspect to understand the association between unwarranted beliefs and causal illusion could be a biased interpretation of the cooccurrences of events so that believers underestimate the likelihood of these coincidences (in our asymmetrical contingency learning task the events being having the infusion and recovering from the headache) and, hence, overestimate their relevance when taking them into account during the causal judgement. This hypothesis is rooted in previous evidence associating the random number generation bias (*i.e*., the tendency to avoid number repetition when trying to produce sequences of random numbers) to paranormal beliefs (Brugger *et al*., 1990). The general claim is that believers overestimate the relevance of coincidences because they misunderstand the probability of these coincidences occurring by chance due to an inaccurate representation of randomness.

Alternatively, it could be the case that believers generally present a stronger propensity to connect separate events (Bressan, 2002), in line with the results of studies showing that those who believe in the paranormal tend to perceive more meaningful patterns in random visual noise than non-believers (Brugger *et al*., 1993). From this perspective, individuals would vary in the amount of evidence they require to accept or reject a given hypothesis, with believers being more inclined to accept causal explanations for coincidences in general (Brugger & Graves, 1997).

Although our results indicate the existence of a relevant relation between endorsement of pseudoscientific beliefs and a tendency to develop causal illusions, we emphasize that the correlational nature of our study does not allow the establishment of a causal relation between these two variables. Nor does it allow one to ascertain the direction of a putative causal relation. Through this paper, we outline the possibility that a cognitive bias leading to the development of causal illusions could be responsible for the endorsement of pseudoscientific beliefs. Nevertheless, it could also be the case that some individuals tend to develop causal illusions in our task because they hold prior pseudoscientific beliefs. Moreover, both causal illusion and pseudoscientific beliefs could stem from a different mechanism not contemplated in our research.

All in all, our results show a reliable association between pseudoscientific beliefs and causal illusion. In our view, this observation could indicate that believers in pseudoscience might present a bias in the interpretation of a given piece of contingency information, leading to stronger perception of a causal relation between non-contingent events, at least when the task is framed in pseudoscientific terms. We extend previous observations regarding individuals who believe in the paranormal to a set of unwarranted beliefs which appear to be more relevant and present in our daily lives.

STUDY II

4. Study 2: Causal illusion in the core of pseudoscientific beliefs: The role of information interpretation and search strategies

[2]Torres, M. N., Barberia, I., & Rodríguez-Ferreiro, J. (2022). Causal illusion in the core of pseudoscientific beliefs: The role of information interpretation and search strategies. *PloS ONE*, *17*(9), e0272201. https://doi.org/10.1371/journal.pone.0272201

4.1. Abstract

The prevalence of pseudoscientific beliefs in our societies negatively influences relevant areas such as health or education. Causal illusions have been proposed as a possible cognitive basis for the development of such beliefs. The aim of our study was to further investigate the specific nature of the association between causal illusion and endorsement of pseudoscientific beliefs through an active contingency detection task. In this task, volunteers are given the opportunity to manipulate the presence or absence of a potential cause in order to explore its possible influence over the outcome. Responses provided are assumed to reflect both the participants' information interpretation strategies as well as their information search strategies. Following a previous study investigating the association between causal illusion and the presence of paranormal beliefs, we expected that the association between causal illusion and pseudoscientific beliefs would disappear when controlling for the information search strategy (*i.e.*, the proportion of trials in which the participants decided to present the potential cause). Volunteers with higher pseudoscientific beliefs also developed stronger causal illusions in active contingency detection tasks. This association appeared irrespective of the participants with more pseudoscientific beliefs showing (Experiment 2) or not (Experiment 1) differential search strategies. Our results suggest that both information interpretation and search strategies could be significantly associated to the development of pseudoscientific (and paranormal) beliefs.

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4.2. Introduction

The term "epistemically unwarranted beliefs" (Lobato *et al.*, 2014) refers to beliefs endorsed in the absence of substantial evidence supporting them (*e.g.*, believing in ghosts or astral journeys, in the therapeutic benefits of Bach flowers, or that "chemtrails" contain biological agents sprayed to psychologically control the population). Although they lack adequate scientific support, these kinds of beliefs are relatively common in western society: 40% of the European population believes in lucky numbers (European Commission, 2010), and 37% of the U.S. population considers astrology to be scientific (National Science Board, 2018). Several studies have investigated the conditions favouring the presence of unwarranted beliefs, mostly focusing on those related to the paranormal (Blackmore & Trościanko, 1985; Brugger *et al.*, 1990; Van Prooijen *et al.*, 2018; Wiseman & Watt, 2006; Rodríguez-Ferreiro *et al.*, 2021). Nevertheless, their possible cognitive basis is still unclear.

Causal illusion has been proposed as one possible cognitive phenomenon underlying unwarranted beliefs. The term causal illusion refers to the erroneous impression of a causal relationship between two unrelated events (Matute *et al.*, 2015). This cognitive bias can be induced experimentally in the context of a contingency detection task (*e.g.*, Barberia *et al.*, 2019). One way of doing this is by asking the volunteers to judge the extent to which two events, a candidate cause and an outcome, are related (*e.g.*, drug intake and healing from a health condition). In an active version of this experimental task (*e.g.*, Blanco *et al.*, 2011), in each trial, participants are allowed to decide whether or not to introduce the potential cause (*e.g.*, administer the drug to a patient). Immediately afterwards, they are informed whether the outcome appears (*e.g.*, whether the patient has recovered) or not. After a pre-specified number of trials, volunteers are asked about the causal relationship between the events (causal rating). For instance, they are asked to indicate the level of effectiveness of the medicine, which they should typically rate on a scale from 0 (ineffective) to 100 (totally effective). This measure is taken as an indicator of the degree of perceived causal relationship and has been extensively used in previous studies (*e.g.*, Blanco *et al.*, 2011; Blanco *et al.*, 2013; Yarritu *et al.*, 2015; Barberia *et al.*, 2019; Moreno-Fernández *et al.*, 2021). The relative densities of the different combinations of events will indicate the level of contingency between medicine administration and cure. In causal illusion tasks, these densities are manipulated so that the cure is not contingent on the administration of the medicine [*i.e.*, the probability of recovery is equal whether the medicine is present or absent, P(Cure|Medicine) = P(Cure|¬Medicine)].

Therefore, the higher the causal ratings, the stronger the developed causal illusion is considered to be.

Importantly, since participants in active contingency detection tasks are given the opportunity to manipulate the presence or absence of the potential cause in order to explore its possible influence over the outcome, responses provided in this kind of task are assumed to reflect the participants' information search strategies, *i.e.*, how they look for new information in order to generate a causal impression; as well as their information interpretation strategies, *i.e.*, how they integrate given information to generate a causal impression (Griffiths *et al*., 2018). In this sense, as suggested by Griffiths *et al*. (2018), superstitious individuals might be characterized by a general bias leading them to overweight conjunctive events, that is, cases in which cause and outcome (*e.g.*, drug intake and healing) occur together, relative to disjunctive events, that is, when cause and outcome do not co-occur. This general bias could be expressed either in a tendency to actively search for conjunctive events (*e.g.*, frequently administering the drug) or in a tendency to overestimate the relevance of conjunctive events (*e.g.*, cases in which the drug is administered and healing occurs) when inferring the strength of the causal connection, or both. Nevertheless, so far, it remains unclear to what extent information search and information interpretation strategies have a role in the association between causal illusion and unwarranted beliefs.

To our knowledge, three studies have investigated the relationship between causal illusion and endorsement of these kinds of beliefs. First, Blanco *et al*. (2015) investigated the relationship between causal illusions and the development of paranormal beliefs. These authors presented participants with an active contingency learning task framed in a medical scenario in which they had to decide whether or not to administer a fictitious drug to patients suffering a fictional disease. In reality the drug was ineffective, as the probability of healing remained at 0.75 whether the drug was administered or not (their design also included a contingent task, but we will focus on the non-contingent one for our purposes here). After the volunteers provided their causal rating, they were asked to complete a questionnaire measuring several paranormal beliefs. Blanco *et al*. (2015) observed a significant positive correlation between endorsement of paranormal beliefs and causal ratings provided in the contingency learning task. They also found that the amount of trials in which the participants administered the drug was positively associated both with causal ratings and with the score on the paranormal beliefs scale. Crucially, this search tendency fully mediated the correlation between causal ratings and paranormal beliefs. This observation led them to suggest that believers in the paranormal might be characterized by biased information-sampling strategies, which would make them more susceptible to develop erroneous causal impressions.

Blanco *et al*.'s (2015) results contrast with those obtained by Griffiths *et al*. (2018), who investigated the association between causal illusions and superstitious beliefs by means of an active contingency learning task framed in a non-medical scenario. These authors asked their volunteers to determine the extent to which the illumination of a lightbulb depended on pressing a switch. Switch-pressing and illumination were non-contingent, as the lightbulb illuminated about 60% of the time regardless of whether or not the switch was pressed. Once the participants provided their causal rating at the end of the task, they were asked to respond to a questionnaire measuring superstitious beliefs. Griffiths *et al*. (2018) showed that the presence of superstitious beliefs correlated positively with the level of causal illusions developed in their contingency learning task. Importantly, although the task used by Griffiths *et al*. (2018) was designed as an active contingency learning task, the interpretability of their results in relation to the impact of information search strategies over the development of unwarranted beliefs is limited because the authors instructed their participants to press the switch in about half of the trials. This was done in an attempt to control, to a certain extent, the times that participants exposed themselves to the potential cause (*i.e*., pressing the switch) with the aim of ensuring that the volunteers experienced enough cause-present and cause-absent trials. While this manipulation made sense for their study, it also implies that although the volunteers were, in principle, free to press the switch or not, their information search behaviour was constrained by the instructions. In this context, Griffiths *et al*.'s (2018) results suggest that variability in the way one interprets given information, and not just the way we look for new information, could also be playing a role in the development of unwarranted beliefs.

Both Blanco *et al*.'s (2015) and Griffiths *et al*.'s (2018) studies were aimed at investigating the possible association between causal illusion and paranormal/superstitious beliefs. More recently, a third study has tried to extend those results to the directly related, but conceptually distinct, field of (also unwarranted) pseudoscientific beliefs. The term pseudoscience refers to disciplines which are presented as scientific knowledge but do not qualify as such (Fasce & Picó, 2019), while paranormal and superstitious beliefs refer to phenomena that would contradict basic principles of science if they were true (Broad, 1949). In addition, paranormal and pseudoscientific beliefs differ in their prevalence. For instance, while 22.7% of the Spanish population believes in paranormal phenomena, the percentages increase for pseudoscientific treatments such as homeopathy, 52.7%, and acupuncture, 59.9% (FECYT, 2017). Regarding pseudoscientific beliefs, Torres *et al*. (2020) used a passive contingency detection task framed in terms of a natural remedy. In this kind of task, volunteers are passively presented with different combinations of presence or absence of the cue and outcome events (*e.g*., remedy and relief). Torres *et al*. (2020) observed a positive correlation between causal ratings given on the contingency learning task and scores on a scale designed ad hoc to measure the presence of pseudoscientific beliefs. Their results indicate an association between endorsement of pseudoscientific beliefs and causal illusion. Nevertheless, given that information sampling was not allowed by their design, their results are not informative with respect to the influence of information search strategies in that association.

In the present study, we aim to extend Torres *et al*.'s (2020) results by further investigating the nature of the association between causal illusion and unwarranted beliefs. To this end, we presented participants with a measure of pseudoscientific beliefs and asked them to complete a contingency learning task in which they were free to decide whether to introduce the potential cause or not (*i.e*., an active task). A limitation of Torres *et al*.'s study was that they framed the task in the context of testing the efficacy of a natural remedy. Given the possible consideration of this remedy as a pseudotherapy, it could have been the case that volunteers with higher levels of pseudoscientific beliefs might have been more inclined to believe in the natural remedy irrespective of the contingency observed during the task. Taking this into account, we decided to use a neutral (*i.e*., non-pseudoscientific) scenario (the light bulb illumination scenario used by Griffiths *et al*. (2018) to frame our experiment. In line with Torres *et al*. (2020), our hypothesis is that the strength of causal illusion will be associated with endorsement of pseudoscientific beliefs. Moreover, and in consonance with Blanco *et al*.'s (2015) observations, we expect that this association will vanish when considering individual differences in the participants' search strategy in situations in which they are free to decide how to look for causal information.

4.3. Experiment 1

4.3.1. Method

4.3.1.1. Participants

A total of 112 psychology students from the University of Barcelona participated in this experiment. Ninety-six were women and 16 were men, with ages ranging from 20 to 57, and a mean of 22.29 years old (*SD* = 4.25). The study protocols were approved by the ethics committee of the University of Barcelona (Institutional Review Board IRB00003099, Comissió de Bioètica de la Universitat de Barcelona). The study was performed in a regular class of the Psychology degree. The students could decide, at the end of each task, if they wanted to consent for their data to be used anonymously for research purposes or not. We obtained the participants' written consent as follows: They were presented with the consent statement on the screen and they had to tick a box if they agreed. Only the data from students who gave consent are presented. Due to the COVID-19 global pandemic, we were forced to stop on-campus testing for this experiment. After adapting the task into an on-line version, we kept on testing participants. The results corresponding to the full (on-line and on-campus) sample, which are consistent with those obtained with the on-campus sample, are presented as Appendix B.

4.3.1.2. Materials

Contingency learning task

Our contingency learning task, based on that designed by Griffiths *et al*. (2018), was framed in a neutral scenario. The volunteers were required to judge the control that a switch (*i.e*., cause) had over the illumination of a light bulb (*i.e*., outcome). Specifically, initial instructions stated that their task was to find out whether a switch controlled the illumination of a light bulb. They were told that the electrical installation was old and very complicated, and that the switch and the bulb were separated from each other, so they had to test the switch and then go see if the bulb had turned on or not. They were also informed that there may have been other switches in other parts of the building that controlled the same bulb. Finally, they were further informed that the light bulb had a timer and turned off some time after it had been turned on, and that, once turned off, the switch could be tested again.

The participants had a total of 48 trials to explore the relation between these two events. In each trial, on a computer screen, they had the image of an unlit light bulb and a switch, and they were asked whether they wanted to press the switch. The participants had to click on a tick or a cross, depending on their decision. Then, the feedback appeared on the screen with either the light bulb on and the sentence "The light bulb has gone on!" or the bulb off and the sentence "The bulb is still off". The outcome (*i.e*., light bulb illumination) occurred following two randomized sequences, one for each decision. Specifically, it happened 6 out of every 8 trials, both among trials in which participants decided to press the switch and among those in which they chose not to. Therefore, the switch did not control the illumination of the light bulb, as illumination rates were non-contingent on the decision to press the switch, *i.e.*, P(Outcome|Cause) = P(Outcome|¬Cause) = 0.75. After completing all 48 trials, the participants were required to provide a causal rating (*i.e.*, "To what extent do you think the switch controls the bulb? Please use the sliding scale to respond. You can click inside the scale as many times as you wish until you mark the value you deem most appropriate. Any value between 0 and 100 is valid"). The value of zero was labelled as "No control", and the value of 100 was labelled as "Total control".

Pseudoscience Endorsement Scale

We gathered responses to the Pseudoscience Endorsement Scale (PES, Torres *et al*., 2020) from 97 participants (81 women and 16 men, mean age 22.30, *SD* = 4.48). The scale comprises 20 items referring to popular pseudoscientific myths and disciplines. Participants' responses to each item were provided on a Likert-like scale ranging from 1 (*i.e.*, "Totally disagree") to 7 (*i.e.*, "Totally agree"). Higher scores on this measure mean that the participants show greater endorsement of pseudoscientific beliefs.

Superstitious Beliefs Questionnaire

Following Griffiths *et al*. (2018), we also included the Spanish version of their Superstitious Beliefs Questionnaire (SBQ), a translated version of the original English questionnaire by Griffiths *et al*. (2018), as a complementary measure to the PES. We gathered responses to this questionnaire from 106 participants (93 women and 13 men, mean age 22.34, *SD* = 4.35). The volunteers had to rate 25 statements on a scale from 0 (*i.e.*, "Strongly disagree") to 4 (*i.e.*, "Strongly agree"). Higher scores on this questionnaire indicate that the participant presents a higher level of superstitious beliefs.

4.3.1.3. Procedure

The participants first completed the computerized contingency learning task followed by the PES (Torres *et al*., 2020) and the SBQ (Griffiths *et al*., 2018), in that order. The two questionnaires were presented through Qualtrics (http://www.qualtrics.com).

4.3.2. Results

The dataset employed in the analysis is available at https://osf.io/f4jcx/?view_only=afb95c269c00499b96b6cdf3423b95e4. We used JASP (version

0.16.0.0) to carry out all data analysis. The Bayesian *t*-tests were conducted using JASP's default Cauchy prior width, r = 0.707. The Bayes factors (*BF*) were interpreted following Table 1 in Wagenmakers *et al*. (2018), according to which values above 1, 3 and 10 indicate, respectively, anecdotal, moderate and strong evidence favouring the alternative (BF_{10}) or the null (BF_{01}) hypothesis.

Concerning the contingency task, since we let each participant decide how many times they pressed the switch or not, there was the possibility that some of them experienced a contingency slightly different from zero. Thus, we calculated the individual contingency (experienced ΔP) between switch pressing and bulb illumination experienced by each participant. In order to ensure that only data from participants who experienced a contingency close to 0 entered the analysis, we identified outliers (*i.e*., three *SD* above or below the mean) on the experienced ΔP, leading to the removal of one case. In addition, we also removed participants who always or never introduced the potential cause (11 participants) because such approach does not allow them to determine whether cause and outcome are related or not (*i.e*., if participants were only exposed to the probability of the outcome with or without the potential cause, the experienced contingency is not computable). The resulting sample consisted of 100 participants (87 women and 13 men, *mean age* = 22.30, *SD* = 4.44).

In relation to the questionnaires, both the PES and the SBQ showed high reliability, α = 0.91 and α = 0.92, respectively. The scores obtained on the PES, *mean* = 3.32 (in a 1 to 7 scale), *SD* = 0.96, were higher than those obtained on the SBQ, *mean* = 1.08 (in a 0 to 4 scale), *SD* = 0.68. We tested the correlations by means of Kendall's tau, since the Shapiro-Wilk test showed that neither the causal ratings, $W(99) = 0.94$, $p < .001$, or the scores on the SBQ,$W(94) = 0.97$, $p = .025$, followed a normal distribution. Scores on both questionnaires were positively correlated, $r_\tau = 0.49$, $p < .001$, $BF_{10} = 1.150^8$.

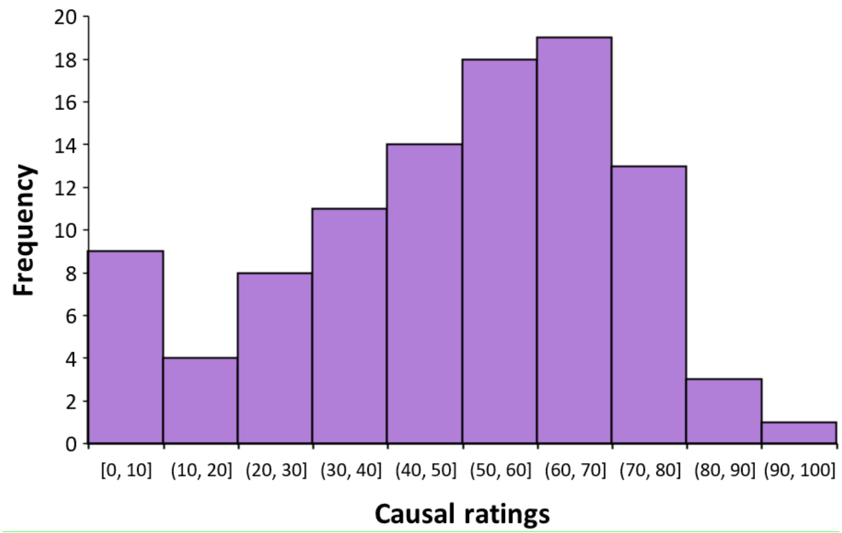

Figure 6. Distribution of causal ratings in Experiment 1.

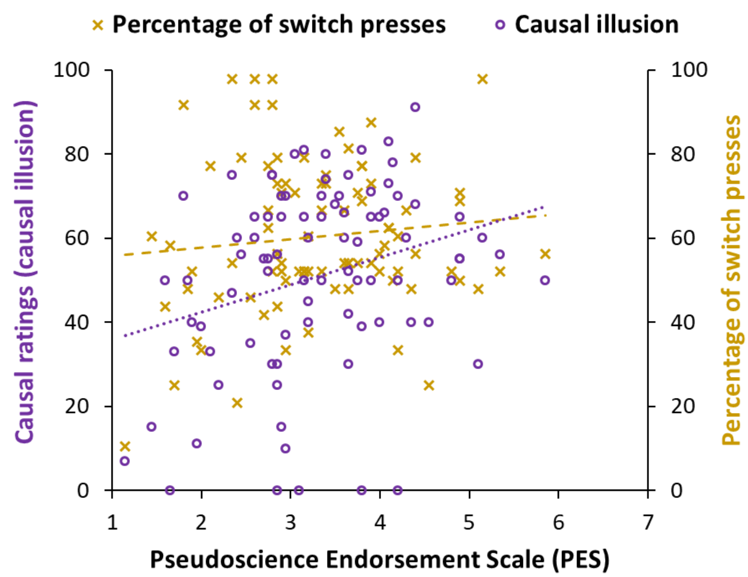

Figure 7. Scatterplot showing the associations between the main variables in Experiment 1.

Figure 6 shows the distribution of causal ratings in the contingency learning task (*mean* = 50.35, *SD* = 22.64). Figure 7 shows the association between mean scores on the PES and both the causal ratings (*i.e.*, causal illusion) and the percentage of switch presses (*mean* = 0.60, *SD* = 0.18). We observed a positive correlation between percentage of switch presses and causal ratings, r_τ = 0.41, p < .001, BF_{10} = 7.095[6], between causal ratings and scores on the PES, r_τ = 0.17, p = .021, BF_{10} = 2.17, and between causal ratings and scores on the SBQ, r_τ = 0.24, p < .001, BF_{10} = 48.25. In contrast, we observed no significant correlations between percentage of switch presses and scores on the PES, r_τ = 0.04, p = .625, and scores on the SBQ, r_τ = 0.14, p = .059. The Bayesian analogue analyses showed moderate, BF_{01} = 6.32, and anecdotal, BF_{01} = 1.16, evidence favouring the null hypothesis, for the correlations of switch presses with the PES and the SBQ, respectively. Next, we repeated some of the previous correlational analyses, while controlling for the individually experienced contingency (partial correlations) on the contingency learning task, in order to control for subtle deviations from zero in the experienced contingency that could explain the observed associations between causal ratings in the contingency learning task and the rest of the variables. The previous conclusions were corroborated as, even when controlling for the experienced ΔP, causal ratings remained significantly associated with scores in PES, r_τ = 0.17, p = .019, SBQ, r_τ = 0.24, p < .001, and the percentage of switch presses, r_τ = 0.40, p < .001.

Previous studies have shown that the percentage of cases in which the potential cause is present affects the intensity of causal illusions: the higher the percentage of cause-present trial the stronger the causal illusion developed (Blanco *et al*., 2011a). Thus, we conducted a partial correlation between causal ratings and scores on the PES, controlling both for the experienced contingency and for the percentage of switch presses, which was statistically significant, r_τ = 0.17, p = .021. An analogous partial correlation between causal ratings and the scores on the SBQ, again controlling for both the experienced contingency and the percentage of switch presses, also reached significance, r_τ = 0.21, p = .004. These results suggest that the correlation between causal ratings and mean scores on both questionnaires is robust enough to remain even when the percentage of switch presses is controlled.

Analyses carried out without eliminating any participant led us to the same conclusions as those presented above, with only one exception: The correlation analysis between causal ratings and mean scores on PES approached, but did not reach, significance, r_τ = 0.123, p = .080, BF_{01} = 1.554.

4.3.3. Discussion

The results of Experiment 1 confirmed the association between endorsement of pseudoscientific (and superstitious) beliefs and the tendency to develop causal illusions observed in previous studies (Griffiths *et al*., 2018; Torres *et al*., 2020). This effect appeared even though the causal illusion task was framed in a neutral (non-pseudoscientific) scenario and the participants were free to decide whether or not to introduce the cause throughout the task. In relation to this, and in conflict with results by Blanco *et al*. (2015), the volunteers' information search strategy was not associated with the presence of unwarranted beliefs. Hence, the association between causal illusion and belief endorsement did not disappear when controlling for cause introduction rate.

When trying to reconcile the results of Experiment 1 and previous data by Blanco *et al*. (2015) we came up with two possible explanations. One possibility is that information search strategies are differentially associated with different types of unwarranted beliefs. In their study, Blanco *et al*. (2015) applied the Revised Paranormal Beliefs Scale (RPBS) by Tobacyk (2004), which is one of the most common scales used to measure endorsement of paranormal beliefs. In contrast, we used the PES, aimed at measuring endorsement of pseudoscientific beliefs, and the SBQ, aimed at measuring superstitious beliefs (usually considered a subtype of paranormal beliefs). Note, however, that a close inspection of this last scale reveals that it includes both items related to paranormal beliefs (*e.g.*, "I am interested in learning more about paranormal activity or psychic phenomena"), but also to pseudoscientific beliefs [*e.g.*, "It is possible to gain information about a person's personality by analysing their handwriting", or "'Alternative' therapies (such as homeopathic remedies, aromatherapy, reflexology, chiropractic manipulation, or therapy based on the body's energy fields) can be an effective way of treating illnesses and ailments."]. Thus, it could be the case that the data gathered in our experiment did not adequately reflect endorsement of paranormal beliefs, and, hence, the lack of influence of information search strategies is specific to the association between causal illusion and pseudoscientific beliefs.

A second possibility is related to the framing of the tasks used by Blanco *et al*. (2015) and in our Experiment 1. Blanco *et al*. (2015) framed their task as a medical scenario, in which the participants had to ascertain whether a given treatment was effective as a cure for a medical condition, as opposed to the more neutral (light bulb illumination) scenario used in our case. Previous studies have shown that causal illusions are facilitated by certain information search strategies (Barberia *et al*., 2013, 2018). Specifically, participants develop stronger causal illusions when applying a confirmatory search strategy, consisting of a spontaneous tendency to test the relationship between the two events mainly observing cases in which the potential cause is present (Blanco *et al*., 2011b). In this sense, it could be the case that the medical and neutral scenarios differentially led the volunteers to get involved in active confirmation of the tested hypothesis (*i.e*., the medicine heals the condition vs. the switch controls the light bulb).

With these two hypotheses in mind, we conducted a second experiment in which we attempted to replicate Blanco *et al*.'s (2015) experiment including both the RPBS and the PES as measures of paranormal and pseudoscientific beliefs respectively. Following Blanco *et al*., the scenario we employed for the contingency learning task was medical. However, note that, while they presented a scenario in which a fictitious drug was to be tested as a remedy against a fictitious disease, in our case the drug was presented as a potential remedy for headaches. If search strategy is differentially associated with paranormal and pseudoscientific beliefs, then we could expect that the relation between causal illusion and paranormal beliefs might disappear when controlling for the tendency to introduce the candidate cause during the task. In contrast, the association between causal illusion and pseudoscientific beliefs would remain even when controlling for this factor. On the other hand, if the lack of effect of information search strategies in our previous experiment was due to the use of a more neutral scenario, then we could expect the search strategy to impact the association between causal illusion and endorsement of both paranormal and pseudoscientific beliefs.

Furthermore, the second experiment also incorporated two additional measures, *i.e*., an intelligence test and a question regarding the education level of the participants. We included them in order to evaluate if any of these potentially confounding factors could explain the previously found association between causal illusions and unwarranted beliefs.

4.4. Experiment 2

4.4.1. Method

4.4.1.1. Participants

A total of 190 participants were recruited through the on-line experimentation platform Prolific (https://www.prolific.co/) for this study. Half of the volunteers were women and the other half were men. Their mean age was 31.53 years old (*SD* = 11.02), ranging from 18 to 82. The study protocols were approved by the ethics committee of the University of Barcelona (Institutional Review Board IRB00003099, Comissió de Bioètica de la Universitat de Barcelona). The volunteers were presented with the consent statement on the screen at the beginning of the experiment and they agreed to participate in the study by entering their Prolific ID.

4.4.1.2. Materials

Contingency learning task

The volunteers were asked to determine the extent to which an experimental medicine (*i.e*., cause) was effective as a treatment for headache (*i.e*., outcome). Specifically, instructions indicated that they had to imagine that they were studying the extent to which an experimental medicine was effective as a treatment for headache, and that they would be shown several medical records of patients suffering a headache episode.

Over 40 trials, for each patient, their task was to decide whether or not to administer the medicine during the headache episode. In each trial, they had three seconds to decide whether they wanted to administer the medicine, in which case they had to click on the image of a pill, or not to administer it, in which case they just had to wait for the three seconds to pass without doing anything. Then, they received feedback about whether or not the patient overcame the headache within two hours and they were moved on to the next record. The medicine was not effective against the headache, as the rates remained non-contingent also for this experiment: $P(Outcome|Cause) = P(Outcome|\neg Cause) = 0.75$, following the same sequences as in Experiment 1 (*i.e*., 6 out of every 8 trials the patient recovers from the headache, both when the medicine was administered and when it was not). After the 40 trials, the volunteers were asked to give a causal rating (*i.e*., "To what extent do you think the experimental medicine is effective as a cure for headache? Answer using the following scale, where the numbers are interpreted as follows: 0: Not effective at all; 100: Totally effective").

Pseudoscience Endorsement Scale

The same scale measuring endorsement of pseudoscience used in Experiment 1 (PES; Torres *et al*., 2020) was also introduced in this experiment.

Revised Paranormal Beliefs Scale

We used the Revised Paranormal Beliefs Scale (RPBS; Tobacyk, 2004) to measure the level of endorsement of paranormal beliefs. Participants were presented with 26 statements that they had to rate on a Likert-like scale ranging from 1 ("Strongly disagree") to 7 ("Strongly agree"). The level of endorsement of paranormal beliefs is the mean of the responses to each item, with higher scores indicating stronger paranormal beliefs.

Given the presumably greater heterogeneity of the sample recruited for Experiment 2 (general population through an online recruitment platform) compared with Experiment 1 (psychology students), we also included additional measures aimed to assess two variables which have been previously associated with variability in unwarranted belief endorsement: intelligence and level of education (Dean *et al*., 2022).

Raven's Advanced Progressive Matrices

Volunteers were presented with Raven's Advanced Progressive Matrices (APM-I; Raven & Raven, 2003), a twelve-item scale designed to measure general intelligence. Each item consists of a drawing matrix, presented in black ink on a white background, which is missing a part. The participants had to choose one of eight given options to complete the matrix, and the complexity of the matrices increased as the items passed through. The score on the questionnaire was calculated as the sum of correct responses, with higher values indicating higher general intelligence.

Education level

In order to get a measure of the education level of the participants, we introduced a question asking them to state how many years they had been in formal education, with indications ranging from "Primary or Elementary education: total of approximately 6 years" to "PhD: total of approximately 22 years". The three questionnaires were presented through Qualtrics (http://www.qualtrics.com).

4.4.1.3. Procedure

The participants first completed the contingency learning task. Then, they responded to the PES (Torres *et al*., 2020) and the RPBS (Tobacyk, 2004) in random order. Finally, they completed the APM-I (Raven & Raven, 2003) and indicated their years of schooling.

4.4.2. Results

The dataset is available at https://osf.io/f4jcx/?view_only=afb95c269c00499b96b6cdf3423b95e4. Data analysis was analogous to that of Experiment 1.

An outlier analysis regarding the experienced ΔP resulted in the exclusion of four cases. Participants who always administered or never administered the medicine were also removed. Finally, the sample consisted of 181 participants (89 women and 92 men, *mean age* = 31.48; *SD* = 10.84). The same conclusions can be drawn from the analysis carried out without the elimination of any participant.

In relation to the unwarranted beliefs questionnaires, both the PES (α = 0.93) and the RPBS (α = 0.95) showed excellent internal consistency. In general, the mean scores on the PES (*mean* = 3.85, *SD* = 1.12) were higher than those gathered on the RPBS (*mean* = 3.32, *SD* = 1.34), both in a 0 to 7 scale, $t(180) = 8.07$, $p < .001$, $d = 0.60$, $BF_{10} = 6.585^{10}$. Moreover, scores obtained on both scales were positively correlated, $r_\tau = 0.56$, $p < .001$, $BF_{10} = 8.408^{25}$.

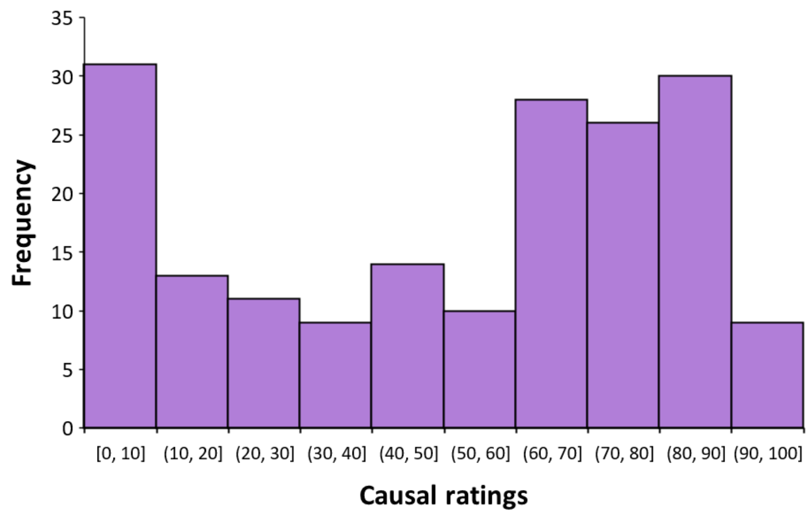

Figure 8. Distribution of causal ratings in Experiment 2.

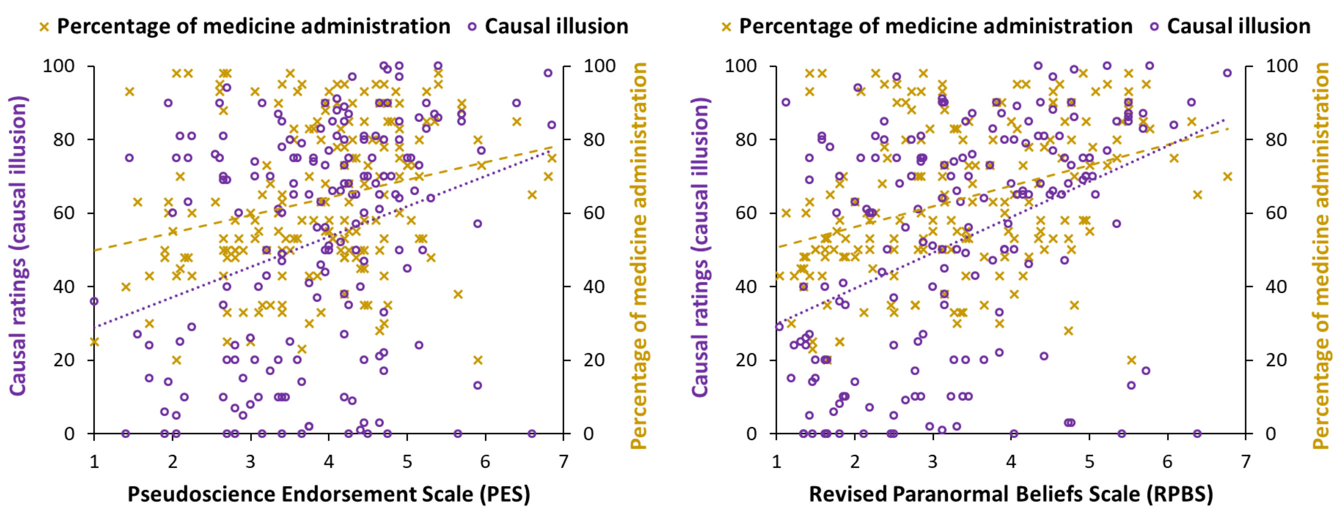

Figure 9. Scatterplots showing the association between the main variables in Experiment 2. Left pannel: Pseudoscience Endorsement Scale (PES); right pannel: Revised Paranormal Beliefs Scale (RPBS).

Figure 8 shows the distribution of causal ratings for Experiment 2 (*mean* = 52.39, *SD* = 31.07). Figure 9 shows the association between mean scores on the PES and mean scores on the RPBS, and both the causal ratings (*i.e*., causal illusion) and the percentage of medicine administration (*mean* = 0.64, *SD* = 0.21). All of them were positively correlated with each other: percentage of medicine administration and causal ratings, $r_\tau = 0.46$, $p < .001$, $BF_{10} = 1.201^{17}$; causal ratings and mean scores on the PES, $r_\tau = 0.21$, $p < .001$, $BF_{10} = 637.44$; causal ratings and mean scores on the RPBS, $r_\tau = 0.31$, $p < .001$, $BF_{10} = 1.478^{7}$; percentage of medicine administration and mean scores on the PES, $r_\tau = 0.19$, $p < .001$, $BF_{10} = 96.34$; and percentage of medicine administration and mean scores on the RPBS, $r_\tau = 0.26$, $p < .001$, $BF_{10} = 84190.90$.

Next, and similar to Experiment 1, we replicated those previous correlational analyses that included causal ratings, while controlling for the individually experienced contingency (partial correlations). We also included other potential confounding factors that were measured in this experiment, *i.e*., the score of the participants in the Raven test (*mean* = 8.11, *SD* = 2.93) and the years of schooling (*mean* = 16.82, *SD* = 3.28). Causal ratings remained significantly associated with PES, $r_\tau = 0.15$, $p = .003$, RBPS, $r_\tau = 0.25$, $p < .001$, and percentage of medicine administration, $r_\tau = 0.42$, $p < .001$, even when controlling for all these factors. Percentage of medicine administration also remained significantly associated both with PES, $r_\tau = 0.14$, $p = .007$, and RPBS, $r_\tau = 0.21$, $p < .001$.

Finally, and following the same assumption as in the previous experiment (*i.e*., the presence of pseudoscientific beliefs might be associated with both information interpretation strategies and information search strategies), we conducted a partial correlation between causal ratings and scores on the PES, controlling not only for the experienced contingency but, crucially, for the percentage of medicine administration, which returned a significant positive correlation, $r_\tau = 0.15$, $p = .003$. The analogous analysis with the mean scores on the RPBS also showed a positive correlation, $r_\tau = 0.23$, $p < .001$. Again, these results suggest that the correlation between causal ratings and mean scores on both questionnaires related to unwarranted beliefs (*i.e*., the PES and the RPBS) cannot simply be due to differences in the percentage of medicine administration.

4.4.3. General discussion

Throughout this study, we examined the relationship between causal illusions and endorsement of unwarranted beliefs. In two experiments, our results revealed that volunteers with higher scores on different scales assessing pseudoscientific and paranormal beliefs tended to develop stronger causal illusions in a contingency learning task.

These results extend those reported by Blanco *et al*. (2015), Griffiths *et al*. (2018) and Torres *et al*. (2020). First, we replicated the association between endorsement of pseudoscientific beliefs and causal illusions generated in a contingency detection task, now framed in a neutral, non-pseudoscientific scenario. This observation suggests that the effect observed by Torres *et al*. (2020) was not dependent on the use of a pseudoscientific cover and, hence, reinforces the hypothesis of the existence of a significant association between the tendency to develop causal illusions in simple contingency learning tasks and the endorsement of pseudoscientific beliefs. Moreover, we also observed an association between causal illusions and superstitious (SBQ) and paranormal (RPBS) beliefs, a result that is consistent with previous observations by Griffiths *et al*. (2018) and Blanco *et al*. (2015), respectively.

Torres *et al*. and Griffiths *et al*., respectively used a passive contingency learning task and an active task in which participants were instructed regarding how frequently they should introduce the potential cause. In contrast, volunteers in the present study were able to decide freely when to respond. This allowed us to investigate the role of spontaneous search strategies activated by the participants. As found in previous studies (*e.g.*, Blanco *et al*., 2011; Barberia *et al*., 2018), the participants' tendency to introduce the potential cause in more trials was associated with the development of stronger causal illusions at the end of the task both in Experiments 1 and 2. Regarding the role of these search strategies in the association between causal illusions and unwarranted beliefs, our conclusions differ from those previously noted by Blanco *et al*. (2015). The association between causal illusions and unwarranted beliefs was meaningful even after controlling for the participants' information search strategies. Specifically, in Experiment 1 we found no evidence of an association between the tendency to introduce the potential cause in the contingency learning task and the endorsement of neither pseudoscientific nor superstitious beliefs. In contrast, in Experiment 2 we did observe a positive correlation between the tendency to introduce the potential cause and the endorsement of pseudoscientific and paranormal beliefs, a result suggesting that individuals holding more unwarranted beliefs tend to search for causal information by more frequently introducing the potential cause. Noteworthily and differing from the results by Blanco *et al*. (2015), the association between causal ratings in the contingency learning task and the scores in questionnaires measuring paranormal and pseudoscientific beliefs remained significant even when controlling for this behavioural component. This result suggests that believers might differ from nonbelievers, not only in their search strategies, but also in the way in which they interpret causal information.

Finally, although, as previously stated, paranormal and pseudoscientific beliefs differ both conceptually and in terms of prevalence (Broad, 1949; FECYT, 2017; Fasce & Picó, 2019), both types of beliefs positively correlated in our study, a result that is consistent with previous observations (Lobato *et al*., 2014; Majima, 2015; Fasce & Picó, 2019; Torres *et al*., 2020). Furthermore, our data suggest that they might both share a common cognitive tendency to develop causal illusions, since both types of unwarranted beliefs produced the same associations with causal illusions.

The divergent results between the two experiments regarding the association between search strategies and unwarranted beliefs might be due to differences in the procedures applied in the contingency learning tasks of each of them. A significant source of divergence stems from the use of different cover stories. Whereas Experiment 1 asked participants to determine to what extent a switch controlled the illumination of a lightbulb, Experiment 2 was framed in a medical scenario where participants had to determine if an experimental drug was effective against headaches. As noted by a reviewer of a previous version of this manuscript, the medical scenario employed in the contingency task of Experiment 2 better aligns with the items included in the Pseudoscience Endorsement Scale (PES), some of which refer to remedies against medical conditions (*e.g*., "Homeopathic remedies are effective as complements in the treatment of some diseases"). In this sense, it might be the case that the association between search strategy and unwarranted beliefs is restricted to situations involving health-related issues. However, this account does not explain parallel results found regarding the Revised Paranormal Beliefs Scale (RPBS), where the items are not focused on medical treatments (*e.g*., "A person's thoughts can influence the movement of a physical object").

Differences in the description of each task could also be responsible for the discrepancies between the results of the two studies. In Experiment 1 the cover story explicitly stated that the outcome (*i.e*., lightbulb illumination) might be produced not only by the candidate cause (*i.e*., the specific switch under study) but also by other alternative causes (*i.e*., "[. . .] there may be other switches in other parts of the building that control the same bulb"). In contrast, in Experiment 2 the instructions did not mention any other tentative causes of the outcome (*i.e*., recovery from headache) apart from the candidate cause (*i.e*., the experimental drug). The fact that other possible causes were mentioned in the instructions of Experiment 1 might have reduced the strength of the general bias towards overweighting conjunctive events (for instance, by activating a secondary hypothesis regarding the possible connection between alternative causes and lightbulb illumination the participants would have tried to test by not pressing the switch), therefore, making the task less sensitive to detecting individual differences among search strategies. Indeed, although differences between cause administration rates of Experiments 1 (*mean* = 0.60) and 2 (*mean* = 0.64) did not reach significance, $t(279) = -1.666$, $p = .097$, $d = -0.21$, $BF_{01} = 1.97$, variance among them was larger in Experiment 2 ($SD = 0.21$) than in Experiment 1 ($SD = 0.18$) as a Levene's test indicated, $F(1,279) = 5.65$, $p = .018$. It might have been the case that slight differences in the task instructions have led participants to engage in active search of the cause-outcome connection to a different extent. Increased variance between participants might have favoured the identification of a significant correlation between search strategy and unwarranted beliefs in Experiment 2. In any case, this explanation is merely tentative, and further studies should be conducted to ascertain whether explicit mention of alternative hypotheses influences the participants' testing strategy.

This study is not without limitations. Following Griffiths *et al*. (2018) we could hypothesize that the general bias leading individuals to overweight conjunctive events when assessing causal relations could be a facilitator for the acquisition and perseverance of unwarranted beliefs. This would explain that the same individuals showing high scores on questionnaires measuring previously acquired unwarranted beliefs also develop stronger causal illusions in our laboratory tasks. Nevertheless, our research is correlational and, hence, it does not allow extracting conclusions regarding the directionality of the association between sensitivity to causal illusions and proneness to holding unwarranted beliefs. Moreover, it could also be the case that third variables not included in our study are responsible for the observed association. In this sense, even though in Experiment 2 we controlled for some potential confounding variables, we cannot rule out this possibility, as a myriad of non-contemplated alternative variables might explain such correlation.

Another limitation refers to the scale used to measure the development of causal illusion in our contingency learning tasks. Although many previous studies have regularly relied on this type of causal or effectiveness rating (Blanco *et al*., 2011, 2013; Yarritu *et al*., 2015; Barberia *et al*., 2019; Moreno-Fernández *et al*., 2021), this measure is not without problems. In this sense, absolute scores on this scale are difficult to interpret, as it is not clear whether the participants are actually expressing the strength of the causal relation or if these ratings are influenced by other aspects, such as their confidence in the judgement (Perales *et al*., 2017). Considering this, further studies should try to replicate our results including more directly interpretable dependent variables such as choice-related measures (see Aarnio & Lindeman, 2005).

Finally, the use of the term "causal illusion" in our study might be subject to discussion. Tasks investigating causal illusions have typically relied on contingency (Allan, 1980) as the normative statistic to which to compare causal impressions, and the terms "causal illusion" or "illusion of causality" have become the norm to denote the phenomenon of medium to high causal ratings in zero contingency contexts (*e.g*., Matute *et al*., 2011; Griffiths *et al*., 2018; Chow *et al*., 2019). Nevertheless, some authors have suggested that ratings that deviate from the programmed contingency should not necessarily be interpreted as errors or illusions, and have offered a rational explanation for the special importance given to conjunctive trials. McKenzie and Mikkelsen (2007) argued that, given certain assumptions, such as the rarity of the candidate cause and outcome events, it would be adequate from a Bayesian inference approach to consider conjunctive trials particularly informative. As noted by these authors, the assumption that the occurrence of each event is rare, that is, that their absence is more common than their presence, would not be restricted to the probabilities experienced in the contingency learning task, but might be the consequence of prior beliefs that participants carry to the lab.

In any case, even though the tendency to overweight conjunctive events when establishing causal relationships might be, to some extent, adaptive, our study suggests that it might also involve certain drawbacks, as indicated by the association between higher causal ratings in zero-contingency tasks and endorsement of paranormal and pseudoscientific beliefs in our life.

STUDY III

5. Study 3: A validation of the Pseudoscience Endorsement Scale and assessment of the cognitive correlates of pseudoscientific beliefs

[3]Torres, M. N., Barberia, I., & Rodríguez-Ferreiro, J. (2023). A validation of the Pseudoscience Endorsement Scale and assessment of the cognitive correlates of pseudoscientific beliefs. Humanities and Social Sciences Communications, 10(1), 1–8. https://doi.org/10.1057/s41599-023-01681-3

5.1. Abstract

Pseudoscientific beliefs are widespread and have potentially harmful consequences. Being able to identify their presence and recognize the factors characterizing their endorsement is crucial to understanding their prevalence. In this preregistered study, we validated the English version of the Pseudoscience Endorsement Scale and investigated its correlates. A group of volunteers (n = 510), representative of the U.S. population, responded to this scale and to questionnaires measuring the presence of paranormal, denialist, and conspiracist beliefs. The validation resulted in a shorter version of the scale, the sPES. Participants also completed a scientific literacy questionnaire as well as *bullshit* detection and cognitive reflection tests. Scores obtained on the questionnaires corresponding to different unwarranted beliefs correlated with each other, suggesting a possible common basis. Scientific knowledge, cognitive reflection scores, and *bullshit* sensitivity were negatively associated with scores on the pseudoscience scale. Of note, *bullshit* receptivity was the main contributor in a model predicting pseudoscience endorsement.

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5.2. Introduction

Different types of epistemically unwarranted beliefs, that is, beliefs lacking substantial evidence to justify them (Lobato *et al*., 2014) are present in our societies. Common subcategories are belief in paranormal phenomena, *i.e*. those that, if genuine, would be in conflict with basic principles of science (Broad, 1949); conspiracy theories: “lay beliefs that attribute the ultimate cause of an event, or the concealment of an event from public knowledge, to a secret, unlawful, and malevolent plot by multiple actors working together” (Swami *et al*., 2010, p. 749); pseudoscientific beliefs, defined by Losh and Nzekwe (2011, p. 579) as “cognitions about material phenomena that, although they lay claim to be ‘science’, use non-scientific evidentiary processes including authoritative assertion, anecdotes, or unelaborated ‘natural’ causes”; and science denialism, which refers to a “motivated rejection […] of well-established scientific theories, simulating from a pseudoskeptical standpoint a false controversy among scientists” (Fasce & Picó, 2019, p. 619), and is considered by some authors to be a subtype of pseudoscience (Lobato *et al*., 2014; Fasce & Picó, 2019).

In the present study, we revised and translated into English the Pseudoscience Endorsement Scale (PES), originally created by Torres *et al*. (2020) in Spanish. Unlike other questionnaires, which intermingle different types of unjustified beliefs (Lobato *et al*., 2014; Majima, 2015; Fasce & Picó, 2019; Huete-Pérez *et al*., 2022), include assessments of scientific knowledge (Johnson & Pigliucci, 2004; Losh & Nzekwe, 2011), or are exclusively addressed to evaluate the use of complementary and alternative medicine (Astin, 1998; Lindeman, 2011), the PES focuses only on the endorsement of pseudoscientific beliefs, thus avoiding other possible confounding variables, but encompasses the variety of pseudoscientific myths and beliefs about pseudotherapies that proliferate in nowadays society.

Our first goal was to validate this scale and to study the relationship between the presence of pseudoscientific beliefs and of other unwarranted beliefs. Following previous studies (Lobato *et al*., 2014; Fasce & Picó, 2019; Majima, 2015; Torres *et al*., 2020; Huete-Pérez *et al*., 2022), our hypothesis is that, despite possible conceptual and distributional differences (see below), endorsement of pseudoscientific beliefs positively correlates with the presence of other types of unwarranted beliefs *(i.e*., paranormal beliefs, science denialism and conspiracist beliefs).

Pseudoscientific beliefs are particularly interesting because they seem to be more widespread than other types of unwarranted beliefs. For instance, 59% and 68.6% of the Spanish population believe in the effectiveness of pseudoscientific therapies, such as homoeopathy and acupuncture, respectively; while only 22.7% and 27.9% believe in paranormal phenomena and superstitions, respectively (FECYT, 2017). Furthermore, believing in the effectiveness of certain pseudosciences may carry associated risks to people's health and economy. For example, if they decide to deal with their illnesses or pathologies with (non-effective) pseudoscientific therapies they might face increased morbidity and even fatal consequences (Lim *et al*., 2011; Johnson *et al*., 2018a, 2018b). Hence, being able to adequately measure the presence of these beliefs and understanding the cognitive factors influencing their appearance is important because it would allow the design of strategies aimed to diminish their harmful influence.

Taking this into account, as a second goal, we aimed to study the endorsement of pseudoscientific beliefs in relation to possible cognitive correlates and key sociodemographic variables. An interesting aspect of pseudoscientific beliefs is their relation to formal education. Paranormal beliefs are known to be negatively related to education level (Majima, 2015; Aarnio & Lindeman, 2005), which suggests that formal education is an effective tool against the spreading of this kind of belief. In contrast, some data indicate that there could even be a positive relation between the length of education and endorsement of pseudoscientific belief (Astin, 1998; Barnes *et al*., 2008; CIS, 2018), suggesting that these beliefs might be resistant to formal education. In fact, pseudoscientific beliefs have been observed to be widespread among professionals with higher education, such as physicians (Posadzki *et al*., 2012) and teachers (Ferrero *et al*., 2016).

Even though achieving higher education, in general, appears not to be sufficient to prevent the endorsement of pseudoscientific beliefs, it could be the case that receiving specific scientific instruction does promote the rejection of pseudoscience. In this sense, Fasce and Picó (2019) observed a negative association between scientific knowledge and endorsement of pseudoscientific beliefs (note, however, that Majima, 2015, failed to observe this association). A positive relation between scientific knowledge and reduced pseudoscientific beliefs offers an encouraging possibility. Nevertheless, the predisposition to acquire scientific knowledge itself could be modulated by cognitive and meta-cognitive factors related to reasoning styles and analytic thinking. In relation to this, Fasce and Picó (2019) observed that the presence of pseudoscientific beliefs correlated with scores on the Rational-Experiential Information Styles self-report questionnaire (Epstein *et al*., 1996; see also Majima *et al*., 2022, for similar results with an abbreviated version of the scale). Specifically, endorsement of pseudoscience among Fasce and Picó's participants was positively correlated with scores on the faith in intuition subscale (*i.e.*, the extent to which and individual relies on intuitive thinking), and negatively associated with scores on the need for cognition subscale (*i.e.*, the individuals' level of enjoyment and engagement of rational, logical, and analytic thinking). However, in a previous study, Lobato *et al*. (2014) observed no correlation between the need for cognition and the endorsement of pseudoscientific beliefs. Also in conflict with the results by Fasce and Picó (2019), Majima (2015), who applied a Japanese-adapted version of the same test (Information-Processing Style Inventory Short Form; Naito *et al*., 2004, study 2), observed a positive association between the scores in their non-paranormal pseudoscience scale and results obtained on the need for cognition-equivalent dimension, as well as a null association with results of the faith in intuition-equivalent scale.

Among other factors, discrepancies between the results of these studies might be related to the use of self-report measures, which might not be the best tool to adequately capture reasoning strategies. In this sense, Fasce and Picó (2019; see also Majima *et al*., 2022) confirmed their results with regard to analytical thinking by means of the Cognitive Reflection Test (CRT; Frederick, 2005). Correct responses in this questionnaire have been assumed to indicate the ability to resist reporting intuitive answers ("System 1"-based responses in terms of Stanovich & West, 2000), and engage in reflective, effortful reasoning ("System 2"-based processes). Note, however, that recent studies indicate that many correct responses to the test are, in fact, obtained intuitively. Taking this into account, CRT scores could be reflecting, not the ability to correct intuitive responses by means of deliberation, but the capacity to detect potential conflicts between heuristic and logical intuitions (Bago & De Neys, 2019; Šrol & De Neys, 2021).

Another variable, which could be playing a role in the development and maintenance of pseudoscientific beliefs could be gullibility, which has been defined as "an individual's propensity to accept a false premise in the presence of untrustworthiness cues" (Teunisse *et al*., 2020, p. 2). Forer (1949) studied gullibility in his classic demonstration of the Barnum effect: the tendency to rate universally valid personality descriptions as highly accurate assessments of our own personality. Forer himself linked this effect to epistemically unwarranted beliefs such as those related to crystal-gazing, astrology or graphology. More recently, in their study of receptivity to pseudo-profound *bullshit* (*i.e.*, apparently impressive statements which are presented as meaningful but are essentially vacuous), Pennycook *et al*. (2015) suggested that a general gullibility factor could be responsible for the tendency of some of their volunteers to accept both their stimuli and epistemically unwarranted beliefs. In this sense, some individuals might have an "uncritical open mind" (Pennycook *et al*., 2015, p. 559) leading them toward accepting statements as true, which could influence their endorsement of epistemically unwarranted beliefs, including those related to pseudoscience.

Finally, endorsement of pseudoscientific beliefs has been observed to differ with regard to several sociodemographic characteristics. For instance, some studies indicate that they are more prevalent among women (Lobato *et al*., 2014; Majima, 2015; Huete-Pérez *et al*., 2022). These differences might be related with the predominant role of women in community health, as they are the ones who usually assume the role of caregivers. Indeed, women are known to be more prone to use alternative and complementary medicine (Bishop & Lewith, 2010; Klein *et al*., 2015; Peltzer & Pengpid, 2018), what could explain the differences with regard to pseudoscientific beliefs in general. Moreover, pseudoscientific beliefs have been shown to be more frequent among individuals with higher socioeconomic status (FECYT, 2017; CIS, 2018; Eisenberg *et al*., 1993) what has been attributed to ideas of sophistication and exclusivity often associated to these kinds of beliefs (Fasce & Picó, 2019).

All in all, following previous studies, we expect the presence of pseudoscientific beliefs to be positively predicted by gullibility, as measured by a *bullshit* detection questionnaire and negatively predicted by analytic thinking (*i.e*., reflective as opposed to intuitive) and scientific knowledge. In relation to sociodemographic characteristics, and following previous observations, we expect that endorsement of pseudoscientific beliefs will be greater for women than for men (Lobato *et al*., 2014; Majima, 2015; Huete-Pérez *et al*., 2022) and will be higher for individuals with higher education level (Astin, 1998; FECYT, 2017; CIS, 2018) and socioeconomic status (FECYT, 2017; CIS, 2018).

5.3. Method

Prior to data collection, our hypotheses and the corresponding analyses were pre-registered at AsPredicted.org: https://aspredicted.org/x7mx5.pdf.

5.3.1. Participants

A total of 510 volunteers, representative of the U.S. population and recruited through the online experiment platform Prolific (https://www.prolific.co/), participated in this study. Supplementary Table S1 (see Appendix C) displays the distribution of the participants according to their age, sex, and ethnicity. Half of the participants were women, and the other half were men. Their ages ranged from 18 to 80 (*mean* = 45.99, *SD* = 15.85).

The ethics committee of the university (Institutional Review Board IRB00003099, Universitat de Barcelona) approved the study protocols. All the volunteers provided informed consent prior to their participation. Each participant received £3.74 ($4.52) approximately (£13.61/h, with a median time of completion of 16.5 min) as compensation for their contribution to the study.

5.3.2. Materials

Pseudoscience Endorsement Scale

The main aim of the study was to validate an English version of the PES. We translated the Spanish Pseudoscience Endorsement Scale (Torres *et al*., 2020) into English following common translation and back-translation procedures (Sierro *et al*., 2016). The scale includes 20 items referring to popular pseudoscientific myths and disciplines. Each item consisted of a statement (*e.g*., "Radiation derived from the use of a mobile phone increases the risk of a brain tumour") that the participants had to rate on a scale from 1 ("Totally disagree") to 7 ("Totally agree"). The level of endorsement of pseudoscience is measured by averaging the responses to all the items. High scores on this scale indicate that the participants show great endorsement of pseudoscientific beliefs. Supplementary Table S2 includes the type of statement about pseudoscience (myths or disciplines), the topic referred by each item, and key references justifying their inclusion as examples of pseudoscience. The scale is available at https://osf.io/xbyz4 (and at Appendix A).

Revised Paranormal Beliefs Scale

The Revised Paranormal Beliefs Scale (RPBS; Tobacyk, 2004) is a twenty-six-item questionnaire with seven subscales assessing endorsement of paranormal beliefs (*e.g*., "Some people have an unexplained ability to predict the future"). The participants provided their responses on a Likertlike scale ranging from 1 ("Strongly disagree") to 7 ("Strongly agree"). The level of endorsement of paranormal beliefs is the mean of the responses to each item, with higher scores indicating stronger paranormal beliefs. The RPBS had an excellent internal consistency in our sample (ω = 0.94). We used global scores on the RPBS in our analyses because we did not have specific predictions for the different subscales. Nevertheless, results regarding the association between each of them and pseudoscientific beliefs are presented as supplementary materials.

Science denialism items—Pseudoscientific Beliefs Scale

Participants also responded to the Science Denialism items included in the Pseudoscientific Belief Scale (SD-PBS) by Fasce and Picó (2019), which are nine statements reflecting science denialism, this is, the rejection of sound and proven scientific theories on the basis of fake arguments (*e.g.*, “Vaccines are unsafe, some of them cause diseases such as autism”). Volunteers had to provide their responses by means of a Likert-like scale ranging from 1 (“Strong disagreement”) to 5 (“Strong agreement”). The SD-PBS measure showed poor internal consistency in our sample (ω = 0.63). According to the individual item reliability analysis, item 4 was negatively influencing the reliability of this scale, so we dropped it for the subsequent analysis. A new reliability analysis showed a McDonald’s ω of 0.64. Mean scores of the eight items were calculated for each participant, with higher scores reflecting more science denialism.

Generic Conspiracist Beliefs Scale

We used the Generic Conspiracist Beliefs Scale (GCB; Brotherton *et al*., 2013) to assess endorsement of conspiracist beliefs, that is, the tendency of participants to believe that an event is the result of a conspiracy when a plainer explanation is more likely. Volunteers were presented with 15 statements describing generic conspiracies (*e.g*., “Secret organizations communicate with extraterrestrials, but keep this fact from the public”). They provided their responses on a Likertlike scale ranging from 1 (“Definitely not true”) to 5 (“Definitely true”). The level of conspiracist beliefs is reflected in the average scores of all the items, with higher values reflecting stronger conspiracist beliefs. The GCB measure presented an excellent internal consistency in our sample (ω = 0.95).

***Bullshit* detection**

In order to assess the inclination to assign overstated judgments to meaningless statements, we followed Pennycook *et al*. (2015, study 4) and presented the volunteers with 10 motivational quotes (*e.g*., “Your teacher can open the door, but you must enter by yourself”) and 10 *bullshit* sentences. The *bullshit* items consist of seemingly impressive statements that are presented as true and significant but are actually meaningless and empty (*e.g*., “Hidden meaning transforms unparalleled abstract beauty”). Pennycook *et al*. (2015) originally gathered these items from two websites, which create sentences by pseudorandomly shuffling profound-sounding words: http://wisdomofchopra.com and http://sebpearce.com/bullshit/. Volunteers had to rate the profoundness (*i.e*., the level “of deep meaning; of great and broadly inclusive significance”) of each item on a five-point scale ranging from 1 ("Not at all profound") to 5 ("Very profound"). This scale showed very high internal consistency in our sample (ω = 0.92). Following Pennycook *et al*. (2015), different measures were calculated for this questionnaire: mean ratings for motivational quotes; mean ratings for *bullshit* sentences (*i.e*., *bullshit* receptivity); and mean *bullshit* sensitivity scores (*i.e*., profundity ratings for the motivational quotes minus profundity ratings for the *bullshit* items).

Science Literacy Knowledge Questionnaire

The Science Literacy Knowledge Questionnaire (SLKQ; Majima, 2015) is aimed to assess scientific knowledge. It consists of eleven statements about scientific topics. The participants had to judge whether they were true or false (*e.g*., "The continents on which we live have been moving their location for millions of years and will continue to move in the future"). The SLKQ showed poor internal consistency in our sample (ω = 0.58). According to the individual item reliability analysis, items 4 and 10 were negatively influencing the reliability of this scale, so we dropped them for the subsequent analysis. A subsequent reliability analysis showed a McDonald's ω of 0.62. The score on the questionnaire is calculated as the sum of correct responses, with higher values indicating higher scientific knowledge.

Cognitive Reflection Test

We gathered the participants' responses on the Cognitive Reflection Test (CRT; Sirota & Juanchich, 2018). This scale includes seven multiple choice questions, consisting of mathematical word problems, with four response options each, only one of them being correct (*e.g*., "A bat and a ball cost £1.10 in total. The bat costs £1.00 more than the ball. How much does the ball cost? 5 pence; 10 pence; 9 pence; 1 pence."). The CRT measure had acceptable internal consistency in our sample (ω = 0.71). The score for this test is calculated as the sum of correct responses.

5.3.3. Procedure

The entire study was conducted online. All the questionnaires were designed through the online survey platform Qualtrics (http://www.qualtrics.com) and presented through the online experiment platform Prolific (https://www.prolific.co/). The participants first responded to the PES. Then, the remaining questionnaires were presented in random order. Before finishing, volunteers indicated their sex, age, political ideology (in a 1–7 scale, where 1 was "very left-wing/liberal" and 7 was "very right-wing/conservative"), years of schooling, and socioeconomic status (in a scale from 1 being "the poorest people" in the country, to 10 being "the richest people" in the country). Finally, Prolific provided us with the ethnicity of the volunteers.

Design and analysis strategy

We first validated the English version of the PES and then we conducted a correlational study including this and other measures. We started analysing the psychometric properties and empirical structure of the English version of the PES with IMB SPSS Statistics (version 26.0.0.1). Then, we conducted frequentist and Bayesian correlational analyses with JASP (version 0.16.3.0) in which we included endorsement of pseudoscientific, paranormal, denialist and conspiracist beliefs as well as all the cognitive variables and sociodemographic data. These analyses were complemented with a comparison between scores obtained by men and women and specific correlations for each of them. Finally, as a complementary analysis, we constructed linear regression models aimed to compare the influence of the different predictors over the four types of unwarranted beliefs.

5.4. Results

The dataset that supports the findings of this study is available at https://osf.io/xbyz4.

Psychometric properties of the PES. A reliability analysis on the PES data (*mean* = 3.74, *SD* = 1.02) revealed very high internal consistency of item scores, McDonald's ω = 0.92. Hotelling's T^2 index of equality, T^2 = 2038.13, $F(19,491)$ = 103.48, p < 0.001, showed that all the items were interrelated, and Tukey's test of non-additivity, $F(1,9671)$ = 18.36, p < .001, indicated that they were not additive. We explored the individual item distributions to determine whether any particular item was affecting the additivity property. Kolmogorov–Smirnov (*K–S*) test showed that none of the items followed a normal distribution, all *K–S* values < 0.25, and all *p*s < .001. None of the items were excluded following kurtosis and skewness analyses (Kim, 2013). Item 10 (*i.e.*, "Nutritional supplements like vitamins or minerals can improve the state of one's health and prevent diseases") was the only item with extreme outliers. We performed a second reliability analysis without this item, which still showed an excellent internal consistency of the item scores, ω = 0.92. Hotelling's T^2 also remained significant, T^2 = 1596.26, $F(18,492)$ = 85.72, p < .001. Nevertheless, in this case, Tukey's test showed additivity, $F(1,9162)$ = 2.23, p = .135. It seems that the non-additivity of the scale was related to the distribution of the scores on this item.

Empirical structure of the PES. The suitability of our data for the principal components analysis (PCA) was appropriate, as the Kaiser–Meyer–Olkin (*KMO*) test showed a high measure of sampling adequacy, *KMO* = 0.94. Bartlett's test of sphericity was also significant, $\chi^2(190) = 4056.46$, $p < .001$, an indicator of a high correlation between items. When the PCA was performed, we observed three components with eigenvalues over 1.0, which explained 39.43%, 6.13%, and 5.50% of the total variance, respectively. Nevertheless, most items loaded higher in component 1, and the variance percentages explained by the other two components were very low. Then, we opted to conduct a parallel analysis (oblimin rotation), which extracted only one component. Given this pattern of results, we accepted the one-component solution, suggesting that the PES is providing a general measure of pseudoscientific beliefs. Finally, eight items (*i.e.*, items 1, 2, 3, 7, 10, 16, 18, and 20) showed weak loadings (*i.e.*, values below 0.6). We removed them from the subsequent analysis to make the scale more robust and reliable. The short version of the scale (henceforth, sPES) still showed very high internal consistency ($\omega = 0.90$).

Correlational analyses. In the following, we present the results of correlational analyses obtained with the sPES (results obtained with the full version were very similar and are included in Supplementary Tables S3–S6). We conducted Kendall's tau for testing all correlations since the Shapiro–Wilk test revealed that none of the variables followed a normal distribution, all Ws(510) > 0.86, and all ps < 0.023.

Table 4. Mean and SD of the participants' scores on the unwarranted beliefs questionnaires and their correlations with the scores on the sPES.

	Mean	***SD***	r_t	BF_{10}
Paranormal Beliefs (RPBS)	2.80	1.17	0.49***	5.301^{57}
Science Denialism (SD-PBS)	2.01	0.54	0.36***	1.141^{30}
Conspiracist Beliefs (GCBS)	2.32	0.98	0.37***	4.069^{31}

*** $p < .001$

Table 4 shows that the sPES (*mean* = 3.58, *SD* = 1.14) was positively correlated with the other three measures of unwarranted beliefs: RPBS, SD-PBS, and GCBS. As for the cognitive measures (see Table 5), sPES scores were positively correlated with profoundness ratings for both *bullshit* statements and motivational quotes, but negatively correlated with the *bullshit* sensitivity measure (*i.e.*, the higher endorsement of pseudoscientific beliefs, the lower the ability to realise that a statement is *bullshit* compared to the motivational ones), with the SLKQ (*i.e*., the higher the scores on the sPES, the lower the scientific knowledge), and with correct responses on the CRT. Pseudoscientific beliefs also correlated positively with age and political ideology (*i.e*., the higher the tendency to score right-wing/conservative, the higher mean scores on the sPES), and negatively with years of schooling. The socioeconomic status seemed not to influence the endorsement of pseudoscientific beliefs (p = .072).

Table 5. Mean and SD of the participants' scores on the cognitive questionnaires and sociodemographic characteristics, as well as their Kendall's τ correlations with scores on the sPES.

	Mean	*SD*	r_t	BF_{10}
***Bullshit* Detection:**				
***Bullshit* Receptivity**	2.11	0.87	0.33***	8.275^{25}
Motivational quotes	2.96	0.78	0.25***	9.498^{14}
***Bullshit* Sensitivity**	0.85	0.74	–0.10***	26.06
Science Literacy (SLKQ)	7.75	1.49	–0.27***	7.191^{16}
Cognitive Reflection (CRT)	3.73	2.25	–0.18***	2.623^{6}
Age	45.99	15.85	0.12***	300.37
Political ideology	3.13	1.64	0.14***	3142.08
Years of schooling	15.98	2.47	–0.08*	1.79
Socioeconomic status	5.23	1.65	0.06	2.52 (BF_{01})

* p < .05, *** p < .001

RPBS stands for Revised Paranormal Beliefs Scale. SD-PBS stands for the science denialism items of the Pseudoscientific Beliefs Scale. GCBS stands for General Conspiracist Beliefs Scale. SLKQ stands for Science Literacy Knowledge Questionnaire. CRT stands for Cognitive Reflection Test.

An independent samples t-test indicated that men (*mean* = 3.68, *SD* = 1.13) scored slightly higher than women (*mean* = 3.47, *SD* = 1.15) on the sPES, $t(508) = 2.02$, $p = .044$, $d = 0.18$. Note, however, that the Bayesian analysis indicated anecdotal evidence favouring the null hypothesis, $BF_{01} = 1.41$. When correlations were performed separately according to sex, women and men showed the same pattern of correlations as when the whole sample was considered, with only one exception. In men, the correlation between mean scores on the sPES and the *bullshit* sensitivity measure did not reach significance ($r_\tau = -0.05$, $p = 0.229$, $BF_{01} = 5.72$).

Regression analyses. Although it had not been originally planned in our preregistration, we ran four different forced entry regression models (see Table 6), respectively including scores reflecting pseudoscientific beliefs, paranormal beliefs, science denialism and conspiracist beliefs as dependent variables, and reflectiveness, *bullshit* receptivity, *bullshit* sensitivity, scientific knowledge, sex, age, years of schooling and socioeconomic status as predictors. Collinearity diagnostics discarded multicollinearity issues between the predictors (variance inflation factor < 1.63, tolerance > 0.62). Percentages of explained variance for the final models were 33% for pseudoscientific beliefs, 32% for paranormal beliefs, 23% for science denialism, and 19% for conspiracist beliefs.

Table 6. Summary of the regression models for each type of epistemically unwarranted belief.

	Pseudoscientific beliefs (sPES)		**Paranormal beliefs (RPBS)**		**Science denialism (SD-PBS)**		**Conspiracist beliefs (CGBS)**	
	β	***p***	***β***	***p***	***β***	***p***	***β***	***p***
(Intercept)		< .001		< .001		< .001		< .001
Cognitive Reflection (CRT)	-0.07	.096	-0.23	< .001	-0.18	< .001	-0.13	.005
***Bullshit* Receptivity**	0.47	< .001	0.43	< .001	0.13	.011	0.31	< .001
***Bullshit* Sensitivity**	0.13	.004	0.14	.001	-0.02	.733	0.10	.036
Science Literacy (SLKQ)	-0.18	< .001	-0.14	.002	-0.26	< .001	-0.12	.011
Sex	0.07	.062	0.06	.151	-0.03	.414	-0.08	.059
Age	0.19	< .001	0.07	.061	0.20	< .001	-0.10	.019
Years of schooling	-0.05	.207	-0.02	.677	-0.02	.677	-0.09	.032
Socioeconomic status	0.06	.156	-0.06	.110	-0.06	.184	-0.12	.004

sPES stands for the short Pseudoscience Endorsement Scale. RPBS stands for Revised Paranormal Beliefs Scale. SD-PBS stands for the science denialism items of the Pseudoscientific Beliefs Scale. GCBS stands for General Conspiracist Beliefs Scale. CRT stands for Cognitive Reflection Test. SLKQ stands for Science Literacy Knowledge Questionnaire.

Individuals with higher scientific literacy showed fewer epistemically unwarranted beliefs of the four types. So did participants less inclined to accept *bullshit* statements as profound. Correct scores on the CRT negatively predicted scores on the paranormal, denialist and conspiracist scales, but only approached significance in the case of pseudoscientific beliefs. Participants with more *bullshit* sensitivity showed more endorsement of pseudoscientific, paranormal, and conspiracist beliefs.

5.5. Discussion

In this study, we first validated an English version of the PES, and then we investigated the association between different types of epistemically unwarranted beliefs as well as possible cognitive factors and sociodemographic variables influencing them.

Regarding our validation, the English version of the PES showed very high internal consistency and a one-component solution appeared to be the most adequate. Nevertheless, eight of the items showed weak loadings, which led us to eliminate them, resulting in the short version of the scale, sPES.

With regards to the association between different kinds of epistemically unwarranted beliefs, as predicted, the presence of pseudoscientific beliefs in our participants was associated with endorsement of the other three belief categories. This result suggests that, despite conceptual divergences between them, different kinds of epistemically unwarranted beliefs might share an underlying basis (Lobato *et al*., 2014).

We were also interested in investigating possible cognitive correlates of pseudoscientific beliefs endorsement. First, we observed a significant positive association between the presence of pseudoscientific beliefs and gullibility. In our study, believers in pseudoscience tended to rate as more profound *bullshit* sentences in the *bullshit* detection scale. We thus replicate previous observations by Pennycook *et al*. (2015) who reported a significant correlation between receptivity to *bullshit* items and a measure of belief in the efficacy of different instances of complementary and alternative medicine, which partially overlaps with the content of our measure of pseudoscientific beliefs. In contrast with their results, we also observed a significant negative effect of *bullshit* sensitivity (*i.e.*, the difference between profundity ratings to motivational and *bullshit* items) over endorsement of pseudoscientific beliefs. Nevertheless, according to our regression analysis, the willingness to accept *bullshit* statements as profound is more relevant for endorsement of pseudoscientific beliefs than the ability to discriminate between doubtfully significant sentences.

Moreover, our study indicates that the same can be said about denialist, paranormal, and conspiracist beliefs.

Second, scientific knowledge appeared to have a protective role against pseudoscientific beliefs in our study. We, thus, replicate the negative association between scientific knowledge and endorsement of pseudoscientific beliefs observed by Fasce and Picó (2019; though see Majima, 2015). Furthermore, we extended this observation to both conspiracist, denialist and paranormal beliefs. Pseudoscience and science denialism are obviously associated with scientific topics, so it is reasonable to expect them to be negatively associated with scientific knowledge. As for conspiracist beliefs, scientists are considered as main actors in some of the most extended conspiracies (*e.g*., chemtrails, fake moon landing, HIV- and COVID19-related conspiracies, etc.) and, although the conspiracist beliefs scale used in our study (Brotherton *et al*., 2013) does not refer to specific conspiracies, it includes items such as "Groups of scientists manipulate, fabricate, or suppress evidence in order to deceive the public", which clearly refer to distrust in science. In this sense, an association between a lack of scientific knowledge and conspiracist beliefs is to be expected. In contrast, paranormal beliefs, although inherently lacking scientific support, are not as directly related to knowledge of scientific facts. Nevertheless, note that scientific knowledge is closely related with the concept of scientific (*i.e*., critical) thinking, and both concepts are considered constituents of the more complex construct of scientific literacy (Siarova *et al*., 2019). From this perspective, the association between paranormal beliefs and scientific literacy in our study (see also Majima, 2015), aligns with the results of previous studies showing a reduction of certain paranormal beliefs after educational interventions based on scientific thinking strategies (Barberia *et al*., 2018; Rodríguez-Ferreiro *et al*., 2021).

Finally, believers in pseudoscience presented lower scores on the CRT. Previous studies based on self-informed measures of thinking style (Lobato *et al*., 2014; Fasce & Picó, 2019; Majima, 2015) provided conflicting results regarding the role of reflectiveness (*i.e*., analytic style) over pseudoscience endorsement (for a similar lack of agreement between previous results with regards to paranormal beliefs see Majima, 2015; Lasikiewicz, 2016; Irwin, 2015; Genovese, 2005). Our data, based on a direct measure of thinking style, the Cognitive Reflection Test, are in line with those obtained by Fasce and Picó (2019) and Majima *et al*. (2022) in showing that believers in pseudoscience obtain higher scores on this test. Furthermore, our study goes beyond the specific dimension of pseudoscientific beliefs, and confirms that a similar pattern is observed in relation with denialist (see also Fasce & Picó, 2019), paranormal (see also Majima *et al*., 2022; Sirota & Juanchich, 2018; Rizeq *et al*., 2021; Ståhl & Van Prooijen, 2018) and conspiracist beliefs (see also Rizeq *et al*., 2021).

This result could be taken to indicate that sceptics are either more suited to suppress intuitive incorrect answers in favour of correct responses obtained through effortful deliberation (Stanovich & West, 2000) or that they present better abilities to detect potential conflicts between their heuristic and logical intuitions (Bago & De Neys, 2019; Raoelison *et al*., 2020; Šrol & De Neys, 2021). Nevertheless, when entered into a regression analysis with the other predictors, the effect of CRT over pseudoscientific beliefs was very weak, making its contribution not as relevant as those of other variables such as gullibility or scientific knowledge.

Regarding sociodemographic characteristics, our data did not show robust differences in the endorsement of pseudoscientific beliefs between men and women. This result contrasts with those observed in some previous studies (*e.g*., Lobato *et al*., 2014; Majima, 2015, Huete-Pérez *et al*., 2022; Majima *et al*., 2022), although other studies have failed to find sex differences (Fasce & Picó, 2019). Our hypotheses regarding the educational level and socioeconomic status were not confirmed either. On the one hand, although the effect was small and unreliable, participants indicating more years of schooling showed lower endorsement of pseudoscientific beliefs (note however, that this effect did not survive when included with other variables, such as scientific knowledge, in a regression model). On the other hand, our data provided evidence favouring a lack of association between socioeconomic status and pseudoscientific beliefs. These results contrast with previous observations of stronger endorsement of some particular pseudoscientific beliefs on people with higher educational and socioeconomic status. For example, Astin (1998) found that more educated individuals and those with higher income showed a stronger tendency to use alternative medicine (see Barbadoro *et al*., 2011; Thomas & Coleman, 2004, for similar results). The discrepancy with our results might stem from the fact that our scale is not restricted to pseudoscientific remedies and treatments but includes other relevant pseudoscientific domains, where these demographic variables might not operate in the same way. In fact, Fasce *et al*. (2020) recently observed that pseudoscientific beliefs, measured by their Pseudoscientific Belief Scale (Fasce & Picó, 2019), were more prevalent among people with pre-university studies than among people with university studies, a result in line with ours.

Regarding the two sociodemographic variables for which we had no a priori hypothesis, political ideology and age, we found that older participants and those self-identifying as right-wing/conservative were more prone to endorse pseudoscience. This result is, again, partially consistent with those of Fasce *et al*. (2020), who found a positive correlation between pseudoscientific endorsement and conservatism, but not age, and Majima *et al*. (2022), who also observed older participants present more pseudoscientific beliefs.

All in all, our results indicate that the four types of epistemically unwarranted beliefs could share a similar cognitive basis, characterized by gullibility and grounded in a lack of reflective thinking strategies (or conflict detection abilities). Moreover, scientific literacy also appears to have a protective role against these kinds of misbeliefs. Nevertheless, the correlational nature of our study prevents us from extracting strong conclusions regarding the direction of the associations observed in our results. Our hypothesis is that cognitive factors influence the development of epistemically unwarranted beliefs. However, it could also be the case that endorsement of unwarranted beliefs influences those factors, or that they all depend on a third mechanism not considered in our research. Future studies manipulating these variables should be conducted to confirm our hypothesis.

GENERAL DISCUSSION

6. General discussion of the dissertation

The main aim of this dissertation was to explore the relationship between causal illusion and belief in pseudoscience and examine whether pseudoscientific beliefs are related to other unwarranted beliefs, such as paranormal phenomena and superstitions. The results of both Studies 1 and 2, indicated that participants with higher scores on a scale measuring pseudoscientific beliefs constructed for these studies, the PES, also exhibited stronger causal illusions in the contingency learning tasks. In other words, in non-contingent tasks, individuals with stronger pseudoscientific beliefs rated the causal relation between the potential cause and the outcome more strongly than those with lower pseudoscientific beliefs.

Throughout the experiments of Studies 1 and 2, three different cover stories were used in the contingency learning tasks, with the aim to avoid the possibility that their framing could have influenced the participants' beliefs and interpretations. Thus, a scenario involving a natural remedy, which could be perceived as a pseudotherapy, was implemented in Study 1, while a cover story involving switch presses and lightbulbs (Experiment 1), and a medical scenario with drug intake and healing from headache (Experiment 2) were applied in Study 2. The aforementioned correlation between the development of causal illusion and the endorsement of pseudoscience was not compromised by the framing of the contingency detection task, supporting the idea of a robust link between the propensity to form causal illusions in basic learning tasks and the acceptance of pseudoscientific beliefs.

This research builds upon previous studies by Blanco *et al*. (2015) and Griffiths *et al*. (2018), which found similar associations between, respectively, paranormal and superstitious beliefs, and causal illusions. Studies 1 and 2 further extend these findings to the domain of pseudoscience, suggesting that a cognitive bias resulting in the formation of causal illusions might be also responsible for the acceptance of pseudoscientific beliefs. Although no significant correlation was found in our Study 1 between superstitious beliefs and causal illusions, a possible floor effect due to the particularly low scores on the superstitious beliefs scale might be interfering. In fact, this correlation was observed in Study 2 (Experiment 1), where the scores on superstition were apparently higher than the ones gathered in Study 1. As an alternative explanation, it is possible that the framing of the contingency learning task could have had a different influence on the different unwarranted beliefs. Indeed, a more recent study conducted by Vicente *et al*. (2023) observed that the correlation found between causal illusions and pseudoscientific beliefs was more pronounced when the contingency learning task was framed in a scenario with an alternative medicine than when it was framed in terms of a conventional medical substance. These variations in the narrative presented could also account for the failure to reproduce the correlation between superstitious beliefs and causal illusion observed by Griffiths *et al*. (2018), in the sense that the natural remedy cover story would be enhancing the correlation of causal illusion with pseudoscientific beliefs, but not with superstitions.

Concerning the particular cognitive factors underlying the association between causal illusion and unwarranted beliefs, in a previous study, Blanco *et al*. (2015) found that the link between belief in the paranormal and causal illusion was influenced by participants' search strategies. However, in our Study 1, participants were passive recipients of information, indicating that the association between pseudoscientific beliefs and causal illusion depends, at least to a certain degree, on individuals' interpretation of information. This aligns with findings from Griffiths *et al*. (2018), although our study specifically links causal illusion to pseudoscientific beliefs instead of to superstitious/paranormal beliefs. One hypothesis suggests that believers may overestimate the relevance of coincidences (*i.e*., trials in which both the potential cause and the outcome appear) because they misinterpret the probabilities of these coincidences based on chance. This misunderstanding may be due to a bias concerning the incorrect representation of chance, which has been previously related with belief in paranormal phenomena (Brugger *et al*., 1990). Alternatively, believers may have a stronger tendency to connect unrelated events (Bressan, 2002), leading them to accept causal explanations for coincidences more readily (Brugger & Graves, 1997). This is, believers would need less amount of evidence than non-believers to provide a causal judgement. Some recent research seems consistent with this alternative hypothesis, in the sense that the tendency to stop collecting information has been found to be related to the development of greater causal illusions (Moreno-Fernández *et al*., 2021). More research is needed to determine whether believers in pseudoscience would show a greater tendency to stop collecting evidence and to jump to conclusions (see also Rodríguez-Ferreiro & Barberia, 2021).

With the aim to conduct a deeper investigation into the impact of information interpretation and search strategies on the relationship between causal illusions and the endorsement of unwarranted beliefs, particularly focusing on pseudoscience, Study 2 (Experiments 1 and 2) involved active contingency learning tasks. Contrary to Study 1, in which a passive contingency learning task was presented, participants in Study 2 were given the freedom to choose when to respond (*i.e*., to manipulate the presence or absence of a potential cause), allowing for an assessment of their spontaneous search strategies. Consistent with prior findings (*e.g.*, Blanco *et al*., 2011; Barberia *et al*., 2018), participants who introduced the potential cause more frequently tended to develop stronger causal illusions, as found in both Experiments 1 and 2 of Study 2.

The main difference in the results obtained in both experiments of Study 2 is related to the presence or not of a positive correlation between the frequency of introduction of the potential cause and endorsement of pseudoscientific beliefs. This association was only found in Experiment 2 but not in Experiment 1. In any case, the association between causal illusions and unwarranted beliefs remained significant even after accounting for search strategies in both experiments, this is, when controlling for the proportion of trials in which de participants decided to introduce the potential cause. This reinforces the idea that believers may not only differ from nonbelievers in their search strategies but also in how they interpret causal information. These results do not match those found by Blanco *et al*. (2015), in the sense that they found that the search strategy adopted by the participant fully mediated the correlation between causal ratings and paranormal beliefs. In contrast, both Studies 1 and 2 indicate that believers in pseudoscience may not only differ from nonbelievers in their search strategies but also in how they interpret causal information.

The differing outcomes between the two experiments of the Study 2, regarding the link between search strategies and unwarranted beliefs may stem from variations in the procedures of the contingency learning tasks. A key factor contributing to this difference is the use of different cover stories. While Experiment 1 involved determining the control of a lightbulb's illumination by a switch, Experiment 2 focused on assessing the effectiveness of an experimental drug against headaches. It is possible that the medical scenario in Experiment 2 better aligns with items in the pseudoscience scale, PES, related to medical remedies (*e.g.*, “The manipulation of energies bringing hands close to the patient can cure physical and psychological maladies”). This raises the possibility that the association between search strategy and unwarranted beliefs may be confined to health-related scenarios. However, this explanation does not account for similar findings on the paranormal scale, RPBS, which does not focus on medical treatments (*e.g.*, “During altered states, such as sleep or trances, the spirit can leave the body”) but still yielded parallel results. Moreover, a study conducted by Saltor *et al*. (2023), in which an active contingency learning task framed in a medical scenario was presented, followed by a scale designed *ad hoc* to measure the ability to differentiate between fake and real news about COVID-19, showed that the rates of drug administration did not have any correlation with scores on the fake news discrimination scale. Therefore, the lack of such a correlation within a medical cover story for the contingency task suggests that the task's context might not account for the different results between Experiments 1 and 2.

The differences in how each task was described may also have contributed to the disparities in results between the two experiments. In Experiment 1, the cover story explicitly mentioned alternative causes for the outcome, the lightbulb illumination, besides the candidate cause, the specific switch being tested (*i.e.*, "[. . .] there may be other switches in other parts of the building that control the same bulb"). In contrast, in Experiment 2 there was not any mention to alternative causes besides the candidate cause (the experimental drug) for the outcome (recovery from headache). The inclusion of other possible causes in Experiment 1 may have weakened the tendency to overweight conjunctive events, making the task less sensitive to detecting individual differences in search strategies (all instructions for both experiments can be found at Appendix B, section "Instructions and cover stories for the experiments"). Additional research is needed to determine if explicitly mentioning alternative hypotheses affects participants' testing approach.

The Spanish version of the PES, employed in Studies 1 and 2, previously demonstrated to be a reliable tool for measuring pseudoscientific beliefs. Thus, by validating it in English and making it publicly available, its use by the research community would be encouraged and its broader application and comparison across different contexts would be facilitated. Therefore, in Study 3, the English version of the Pseudoscience Endorsement Scale (PES) was validated, followed by the exploration of its relationship with various types of epistemically unwarranted beliefs and with several cognitive and sociodemographic factors. The English version of the PES demonstrated high internal consistency, with a one-component solution being the most suitable. However, eight items exhibited weak loadings, leading us to their removal and resulting in a short version of the scale, named short-PES (sPES). The correlational analysis revealed that participants endorsing pseudoscientific beliefs also tended to endorse other categories of unwarranted beliefs, despite the conceptual and prevalence differences between them. This aligns with previous research in which endorsement of pseudoscience correlated positively with paranormal beliefs (*i.e.*, Lobato *et al*., 2014; Majima, 2015; Fasce & Picó, 2019; Huete-Pérez *et al*., 2022; Studies 1 and 2 of this dissertation), and conspiracist beliefs (*i.e.*, Lobato *et al*., 2014; Fasce & Picó, 2019; Huete-Pérez *et al*., 2022). This finding suggests a potential shared underlying basis among different types of epistemically unwarranted beliefs (Lobato *et al*., 2014), as also evidenced by their similar associations with causal illusions.

With regard to possible cognitive correlates, first, Study 3 found a positive correlation between the presence of pseudoscientific beliefs and gullibility. Participants endorsing pseudoscience tended to rate *bullshit* sentences as more profound on the Bullshit Detection Scale, replicating findings by Pennycook *et al*. (2015), who also observed a similar correlation with belief in complementary and alternative medicine. However, contrary to their results, we also found a negative effect of *bullshit* sensitivity on endorsement of pseudoscientific beliefs. Despite this, regression analysis suggested that the inclination to accept profound *bullshit* statements is more influential than the ability to differentiate between doubtfully significant sentences in endorsing pseudoscientific beliefs. Additionally, our study suggests similar relationships with denialist, paranormal, and conspiracist beliefs.

Moreover, possessing scientific knowledge acted as a defence against pseudoscientific beliefs, replicating findings from Fasce and Picó (2019). This link extended to conspiracist, denialist, and paranormal beliefs. Given that pseudoscience and science denialism are inherently linked to scientific topics, it's logical to expect a negative correlation with scientific knowledge. Conspiracist beliefs often involve distrust in science, making an association with lack of scientific knowledge logical. Paranormal beliefs lack scientific backing, but they are not directly tied to scientific facts, making sense of the negative correlation with scientific knowledge. This latter result is consistent with prior research indicating that paranormal beliefs decrease following educational interventions employing scientific thinking strategies, as demonstrated by Barberia *et al*. (2018) and Rodríguez-Ferreiro *et al*. (2021).

Lastly, Study 3 results, using a direct assessment of thinking style, the Cognitive Reflection Test (CRT), mirror the results of Fasce and Picó (2019) and Majima *et al*. (2022), *i.e*., individuals who endorse more pseudoscientific beliefs tend to achieve higher scores on the CRT. Additionally, this study extends beyond pseudoscientific beliefs, confirming that a comparable trend is evident in denialist, paranormal, and conspiracist beliefs. However, when included in a regression analysis alongside other predictors, the influence of the CRT on pseudoscientific beliefs was minimal, indicating its contribution is less significant compared to variables like gullibility or scientific knowledge. These results are consistent with those found in Study 2, Experiment 2, where intelligence was assessed through Raven's matrices (APM-I; Raven & Raven, 2003).

In relation to the sociodemographic variables, Study 3 found no significant differences in the endorsement of pseudoscientific beliefs between men and women, contrasting with some prior research (*e.g.*, Lobato *et al*., 2014; Majima, 2015, Huete-Pérez *et al*., 2022; Majima *et al*., 2022) in which women believed generally more than men. Results from Study 3 showed the same tendency, since women scored slightly above men, although it was not statistically significant. A possible explanation for this result is that differences between men and women are only significant through the use of scales measuring pseudoscientific beliefs combined with other unwarranted beliefs, as was the case in Lobato *et al*. (2014), Majima (2015), and Huete-Pérez *et al*. (2022). However, when addressing pseudoscience endorsement separately, the sex differences may be significantly diminished. Indeed, Fasce and Picó (2019) also found no differences between men and women using their pseudoscientific beliefs scale. Other sociodemographic variables could be influencing the discrepancy between these results, such as the nationality or the culture of the participants.

Similarly, our findings regarding educational level and socioeconomic status did not align with our hypotheses. While higher education level was weakly associated with lower endorsement of pseudoscientific beliefs, this effect diminished when considered alongside other factors like scientific knowledge. Moreover, socioeconomic status showed no clear link with pseudoscientific beliefs in our data. These results contradict previous studies suggesting a stronger tendency for pseudoscientific beliefs among those with higher education and socioeconomic status (Astin, 1998; Thomas & Coleman, 2004; Barbadoro *et al*., 2011). This discrepancy may arise from our scale's broader scope, encompassing various pseudoscientific domains beyond remedies and treatments. In fact, recent research aligns with our findings, indicating higher prevalence of pseudoscientific beliefs among those with pre-university education compared to university-educated individuals (Fasce *et al*., 2020). For the two demographic factors we have not initially considered, political ideology and age, we discovered that older individuals and those identifying as right-wing/conservative were more likely to support pseudoscience. This finding partially aligns with previous studies by Fasce *et al*. (2020), which found a link between endorsing pseudoscience and conservatism, and Majima *et al*. (2022), who also noted higher pseudoscientific beliefs among older participants.

In summary, the findings from the third study suggest that the different types of epistemically unwarranted beliefs may stem from similar cognitive traits like gullibility and a lack of reflective thinking skills. Additionally, scientific literacy appears to act as a protective factor against these beliefs. However, due to the correlational nature of our study, we cannot definitively determine the direction of these associations, as was the case in previous studies in this dissertation. While we hypothesize that cognitive factors influence the development of unwarranted beliefs, it is also possible that the endorsement of such beliefs influences these cognitive factors, or that they are both influenced by a third, unexplored factor/s. Further research manipulating these variables is needed to confirm these hypotheses.

6.1. Limitations

Although the studies presented in this dissertation have been carried out as rigorously as possible, they have certain constraints. One of the limitations resides in the scale utilized for measuring causal illusion in our contingency learning tasks. While this scale is commonly employed in previous research (*e.g.*, Blanco *et al.*, 2011; Blanco *et al.*, 2013; Yarritu *et al.*, 2015; Barberia *et al.*, 2019; Moreno-Fernández *et al.*, 2021), its interpretation may be challenging. Absolute scores on this scale may not accurately reflect the strength of the causal relation, as they could be influenced by factors such as participants' confidence in their judgments (Perales *et al.*, 2017). Moreover, the results from the study performed by Ng *et al.* (2023) suggest that while causal illusion is observable with both unidirectional (*e.g.*, scales with a range between 0 and 100) and bidirectional rating scales (*e.g.*, scales ranging from -100 to 100), its extent might be overestimated when using unidirectional scales. Therefore, future studies should attempt to replicate these findings using more directly interpretable dependent variables, such as choice-related measures (see Aarnio & Lindeman, 2005; Barberia *et al.*, 2021).

A further limitation is connected to the interpretation of the term "causal illusion" used in our studies. Typically, tasks exploring causal illusions compare results to contingency statistics, and terms like "causal illusion" or "illusion of causality" are used for medium to high causal ratings in zero contingency situations (*e.g.*, Matute *et al.*, 2011; Griffiths *et al.*, 2018; Chow *et al.*, 2019). However, some researchers argue that deviations from programmed contingency should not necessarily be seen as errors, suggesting that conjunctive trials could be particularly informative. According to McKenzie and Mikkelsen (2007), this perspective aligns with Bayesian inference, where the assumption that events are rare could influence participants' beliefs and perceptions during the task. Nevertheless, while prioritizing conjunctive events in establishing causal relationships may be somewhat adaptive, Studies 1 and 2 suggests it may also have disadvantages. This is evidenced by the correlation between higher causal ratings in zero-contingency tasks and the endorsement of paranormal and pseudoscientific beliefs in our lives.

To conclude, despite Studies 1 and 2 highlight a significant association between causal illusions and pseudoscientific beliefs, and Study 2 extends these results by suggesting the possibility that such a correlation is due to both the way we search for and interpret information, these results should be taken with caution. It is worth noting that the correlational nature of the research impedes establishing a causal relationship, nor determine the directionality of this association, as in the case of Study 3, when exploring the cognitive and sociodemographic correlates of the pseudoscience endorsement. Moreover, unexplored variables may influence the observed correlations, despite attempts to control for confounding factors in Study 2, Experiment 2 (*i.e.*, intelligence). Further studies are needed to explore the direction and underlying mechanisms of these associations.

6.2. Future research

An interesting line of research is related to disentangling the possible factors influencing causal illusion and/or pseudoscience endorsement. This issue could be addressed by means of experimental designs manipulating certain variables for which we have found a correlation with pseudoscientific belief endorsement, such as cognitive reflection. Thus, volunteers in future experiments could be divided into two experimental groups in which cognitive reflection is promoted or not. For instance, by means of explicit instructions emphasizing deliberation or introducing time constraints leading to intuitive responses (*e.g.*, Calvillo et al., 2022; Orona et al., 2024).

An analogous design could be performed with an intervention focused on scientific knowledge, since we have observed that the higher the science literacy (measured by the SLKQ), the lower the pseudoscience endorsement, as showed by previous research (*i.e*. Fasce & Picó, 2019; Study 3 in this dissertation). Note that Barberia *et al*. (2018) conducted a similar study in which the intervention consisting in training-in-bias and training-in-rules techniques aimed to promote scientific thinking was shown to reduce participants' causal illusion and paranormal beliefs. If training in scientific knowledge has a beneficial effect, it is expected that, with the proposed experimental design, the group receiving the intervention would exhibit a lower degree of causal illusion and a reduced level of pseudoscientific beliefs.

Finally, a third line of future research could focus on the relation between search strategy in active contingency learning tasks and the endorsement of pseudoscience. I previously discussed whether explicitly mentioning alternative hypotheses may have influenced participants' searching on both experiments of Study 2. In Experiment 1, the cover story explicitly referred to other possible causes for the outcome, while instructions in Experiment 2 did not mention any alternative causes. Thus, the design used in Experiment 1 could have reduced the tendency to overemphasize conjunctive events, making the task less effective in detecting individual differences in search strategies. I propose to create two different conditions in an active contingency learning task: one in which instructions explicitly mention alternative causes, in addition to the main potential cue; and another condition whose instructions refer only to the target potential cause. Volunteers would then be presented with the PES. If the association between search strategy and pseudoscientific beliefs is influenced by this experimental manipulation, this would suggest that the way instructions are given in the contingency task is affecting this relationship.

CONCLUSIONS

7. Conclusions

The present dissertation aimed to explore the relationship between causal illusions and pseudoscientific beliefs across a series of experiments, shedding light on the cognitive mechanisms underlying the endorsement of pseudoscience. The results derived from these experiments are reported as follows:

- Higher endorsement of pseudoscience was associated with stronger causal illusions in three different experiments, suggesting a possible role of this cognitive bias in the development and maintenance of pseudoscientific beliefs.
- The link between causal illusion and pseudoscientific belief endorsement appeared irrespective of the contingency learning task being framed in a neutral, pseudotherapy or medical scenario, suggesting that the association cannot be fully accounted by an effect of prior beliefs.
- The fact that the association between pseudoscience endorsement and causal illusion was observed both using a passive contingency learning task and when controlling for the effect of cause administration in two active tasks suggests that said association is related to variability regarding information interpretation strategies.
- Conflicting results obtained with two different active contingency learning tasks open the way to further study the role of information search strategies in the association between pseudoscience endorsement and causal illusion.
- Endorsement of pseudoscientific beliefs was associated with endorsement of other three types of unwarranted beliefs (*i.e.*, paranormal, conspiracy, and denialism), suggesting that, despite their conceptual differences, various types of epistemically unwarranted beliefs might share a common underlying basis.
- Cognitive correlates:
    - A positive correlation was found between pseudoscientific beliefs and gullibility.
    - Scientific knowledge seemed to provide protection against pseudoscience, conspiracy theories, science denialism, and paranormal beliefs.
    - Individuals who believed in pseudoscience, as well as the other three types of unwarranted beliefs (*i.e.*, paranormal and conspiracist beliefs, and science denialism), exhibited less reflective thinking.

- Concerning sociodemographic variables, the most significant factors linked to the endorsement of pseudoscience were age and political ideology. Older participants and those who identified as right-wing/conservative were more likely to support pseudoscientific beliefs.
- The Pseudoscience Endorsement Scale (PES), as well as its short version (sPES), appear to be solid tools to measure the endorsement of pseudoscientific beliefs.

In summary, the findings of this dissertation offer important insights into the cognitive mechanisms underlying pseudoscientific beliefs and their relationship with causal illusions. The consistent association observed across different experimental settings suggests that causal illusions may play a key role in the development and maintenance of pseudoscientific beliefs, regardless of the context in which they are framed. This highlights the potential cognitive bias at the core of pseudoscience endorsement and points to the importance of understanding how individuals process, interpret and search for information. The findings also indicate that pseudoscience endorsement is part of a broader tendency toward accepting various types of unwarranted beliefs, such as paranormal beliefs, conspiracy theories, and science denialism. This suggests a shared cognitive foundation across these belief systems, which could have implications for addressing misinformation and promoting scientific literacy. Furthermore, the significant role of sociodemographic factors, particularly age and political ideology, suggests that interventions aimed at reducing pseudoscientific belief might need to consider these broader socio-political contexts.

Taken together, these results highlight the need for a multifaceted approach to understanding and addressing pseudoscientific beliefs, one that considers cognitive biases, individual differences, and societal influences.

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SUPPLEMENTARY MATERIAL

9. Supplementary material

9.1. Appendix A (Study 1)

Pseudoscience endorsement scale (PES)

Answer the following questions with the greatest sincerity possible. There are no right or wrong answers, they simply indicate personal opinions, and it is to be expected that there exists some variability between individuals.

To what degree do you agree with the following statements?
Answer each question using a scale of 1 (strongly disagree) to 7 (strongly agree).

1. Radiation derived from the use of a mobile phone increases the risk of a brain tumour.
2. A positive and optimistic attitude towards life helps to prevent cancer.
3. We can learn languages listening to audios while we are asleep.
4. Osteopathy is capable of causing the body to heal itself through the manipulation of muscles and bones.
5. The manipulation of energies bringing hands close to the patient can cure physical and psychological maladies.
6. Homeopathic remedies are effective as complements in the treatment of some diseases.
7. Stress is the principal cause of stomach ulcers.
8. Natural remedies, such as Bach flower remedies, help overcome emotional imbalances.
9. By means of superficial insertion of needles in specific parts of the body one can treat problems with pain.
10. Nutritional supplements like vitamins or minerals can improve the state of one’s health and prevent diseases.
11. Neuro-linguistic programming is effective in curing mental disorders and the improvement of quality of life in general.
12. By means of hypnosis, it is possible to discover hidden childhood traumas.
13. One’s personality can be evaluated by studying the form of their handwriting.
14. The application of magnetic fields on the body can be used to treat physical and emotional alterations.
15. Listening to classical music, such as Mozart, makes children more intelligent.

16. Our dreams can reflect unconscious desires.
17. Exposure to Wi-Fi signals can cause symptoms such as frequent headaches, problems sleeping, or tiredness.
18. The polygraph or lie detector is a valid method for detecting if someone is lying.
19. Diets or detox therapies are effective at eliminating toxic substances from the organism.
20. It is possible to control others' behaviour by means of subliminal messages.

Escala de Adhesión a la Pseudociencia (EAP) – Original version in Spanish

Contesta las siguientes preguntas con la mayor sinceridad posible. No hay respuestas correctas ni incorrectas, simplemente indican opiniones personales y es de esperar que exista cierta variabilidad interindividual.

¿En qué medida estás de acuerdo con las siguientes afirmaciones?
Contesta cada pregunta utilizando una escala de 1 (Nada de acuerdo) a 7 (Totalmente de acuerdo).

1. La radiación derivada del uso del teléfono móvil aumenta el riesgo de tumor cerebral.
2. Una actitud positiva y optimista ante la vida ayuda a prevenir el cáncer.
3. Podemos aprender idiomas escuchando audios mientras estamos dormidos.
4. La osteopatía es capaz de inducir al cuerpo a curarse a sí mismo mediante la manipulación de músculos y huesos.
5. La manipulación de las energías acercando las manos al paciente permite curar dolencias físicas y psicológicas.
6. Los remedios homeopáticos son eficaces como complementos al tratamiento de algunas enfermedades.
7. El estrés es la causa principal de las ulceras de estómago.
8. Remedios naturales, como las flores de Bach, ayudan a superar desequilibrios emocionales.
9. Mediante la inserción superficial de agujas en partes específicas del cuerpo se pueden tratar problemas de dolor.
10. Los suplementos alimenticios como vitaminas o minerales pueden mejorar el estado de salud y prevenir enfermedades.
11. La Programación Neurolingüística es eficaz para la curación de trastornos psíquicos y la mejora de la calidad de vida en general.
12. Mediante la hipnosis es posible descubrir traumas infantiles ocultos.

13. Se puede evaluar la personalidad de alguien estudiando la forma de su letra.
14. La aplicación de campos magnéticos sobre el cuerpo puede utilizarse para tratar alteraciones físicas y emocionales.
15. Escuchar música clásica, como Mozart, hace a los niños más inteligentes.
16. Nuestros sueños pueden reflejar deseos inconscientes.
17. La exposición a ondas Wi-Fi puede provocar síntomas como dolores de cabeza frecuentes, problemas de sueño o cansancio.
18. El polígrafo o detector de mentiras es un método válido para detectar si alguien miente.
19. Las dietas o terapias *detox* son efectivas para eliminar las sustancias tóxicas del organismo.
20. Es posible controlar el comportamiento de los demás mediante mensajes subliminales.

9.2. Appendix B (Study 2)

Experiment 1 (on-campus participants plus on-line extension)

Participants of the on-line extension. The volunteers for the on-line extension of Experiment 1 were 92 Psychology students from the University of Barcelona (77 women and 15 men). Their average age was 23.39 years old (*SD* = 6.71), ranging from 20 to 70.

Materials and Procedure of the on-line extension. First, the participants completed the contingency learning task. This task was an online adaptation of that used in Experiment 1, with the following differences. First, the participants had a total of 40 trials instead of 48. Second, in each trial, they indicated whether they wanted to press the button or not, by clicking on the image of a button with a finger or the image of a button alone, respectively. Third, the randomized sequences of outcomes were pre-programmed on a single general matrix, where 6 out of every 8 trials the bulb lit up, regardless of the decision of the participant.

After finishing with the contingency learning task, the participants responded to the PES (Torres *et al*., 2020) but, different from the on-campus version, they did not complete the SBQ.

Results with the full sample (on-campus testing and on-line extension). The dataset is available at https://osf.io/f4jcx/?view_only=afb95c269c00499b96b6cdf3423b95e4. All the participants (on-line testing and on-campus extension) were analysed together. The data analysis was analogous to that performed with the on-campus participants alone, which is reported as Experiment 1 in the main article.

The outliers' analysis excluded three cases (1 from the on-campus testing and 2 from the on-line extension). Participants who always administered or never administered the medicine were also removed (11 from the on-campus testing and 3 from the on-line extension). Finally, the full sample consisted of 187 participants (160 women and 27 men; *mean age* = 22.61, *SD* = 5.27; *ΔP mean* = -0.01, *SD* = 0.10).

In relation to the PES questionnaire, its reliability was high for the experimental sample, α = 0.90 (*mean* = 3.27, *SD* = 0.91). Figure S1 shows the distribution of causal ratings in the contingency learning task (*mean* = 47.66, *SD* = 24.22). Figure S2 shows the association between mean scores on the PES and both the causal ratings (*i.e*., causal illusion) and the percentage of button presses (*mean* = 0.58, *SD* = 0.18). Shapiro-Wilk tests showed that causal ratings did not follow a normal distribution,

$W(186) = 0.93$, $p < .001$. Thus, all correlations were tested by means of Kendall's tau non-parametric test. Kendall correlation analysis showed a positive correlation between percentage of button presses and causal ratings, $r_\tau = 0.36$, $p < .001$, $BF_{10} = 3.726e+10$, and between causal ratings and scores on the PES, $r_\tau = 0.15$, $p = .004$, $BF_{10} = 8.23$. Critically, there was no significant correlation between the percentage of button presses and scores on the PES, $r_\tau = 0.05$, $p = .355$. The Bayesian analogue analysis showed moderate evidence favouring the null hypothesis, $BF_{01} = 6.48$.

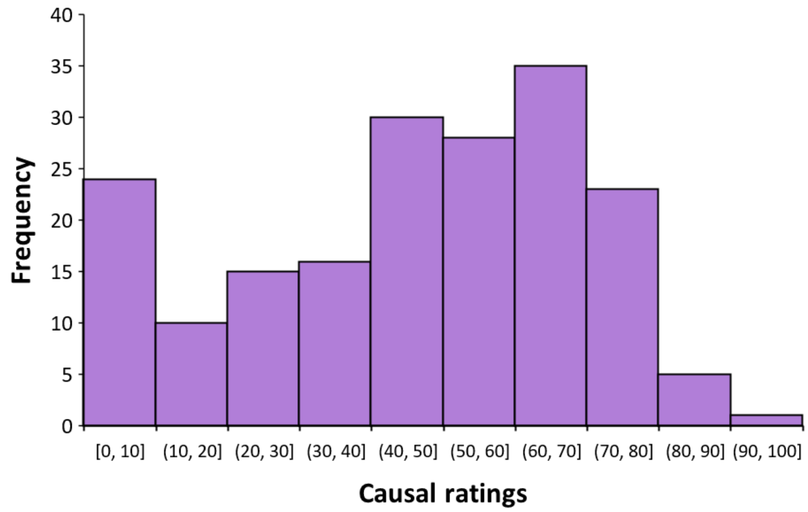

Figure S1. Distribution of causal ratings in Experiment 1 with the full sample.

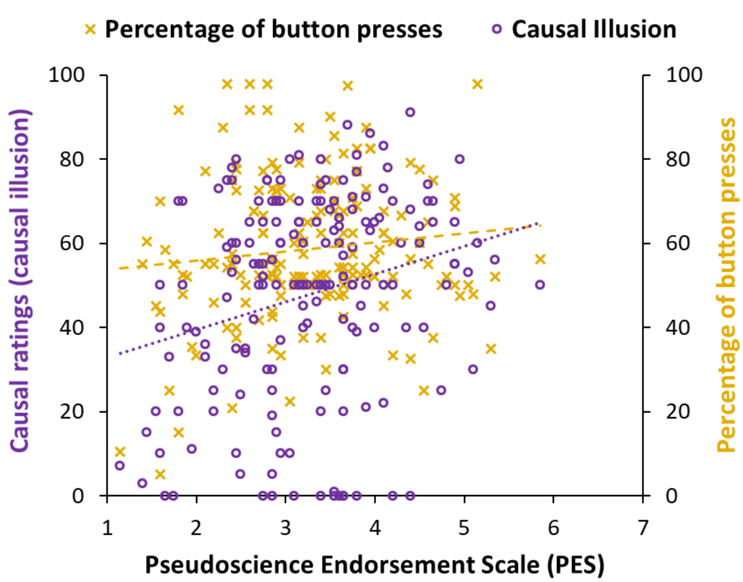

Figure S2. Scatterplot showing the association between the main variables in Experiment 1 with the full sample.

Regarding the additional partial correlations, when controlling for the experienced ΔP, we found a positive correlation between causal ratings and scores in PES, $r_\tau = 0.15$, $p = .003$, and between causal ratings and the percentage of button presses, $r_\tau = 0.36$, $p < .001$. When controlling both for the experienced contingency and for the percentage of button presses, causal ratings and scores on the PES were also positively correlated, $r_\tau = 0.14$, $p = .005$.

Instructions and cover stories for Experiment 1

We appreciate your participation in this study, because without the collaboration of people like you this, research would not be possible. You should know that in this task there are no right or wrong answers. What we want to study are the basic psychological mechanisms that are present in everyone. We need you to carry out the task with the greatest interest. The data you provide will be added to those of the whole group and will be statistically analysed.

Imagine that you have to find out if a switch controls the lighting of a bulb. The electrical installation is old and very complicated, and the switch and bulb are separated from each other, so you have to test the switch and then go to see if the bulb has turned on or not. Also, there may be other switches in another part of the building that control the same bulb. The bulb is on a timer and turns off some time after it has been turned on. Once it is turned off, the switch can be retested. You should not take notes while performing the task. Following, you will have the opportunity to test the connection between the switch and the bulb several times. Each time, you can decide whether or not to press the switch. The procedure will be as follows: for each trial, you must decide whether you want to press the switch or not, by clicking on the corresponding image. Once you have tested the switch several times, we will ask you some questions. Remember that in this study you cannot jot down notes.

Instructions and cover stories for Experiment 2

Welcome. You are going to take part in an experiment. Please concentrate on the task until it is completed. You are not allowed to take notes on the information presented during the task.

Imagine you are studying the extent to which an experimental medicine is effective as a treatment for headache. You will be shown several medical records of patients suffering a headache episode. For each patient, your task is to decide whether or not to administer the medicine during the headache episode. Remember you are not allowed to take notes while performing the task. For each patient, you will have 3 seconds to decide whether you want to administer the medicine, in which case you have to click on the medicine, or not to administer it, in which case you just have to wait without doing anything. After 3 seconds, you will receive feedback about whether or not the patient overcame the headache within two hours and you will move on to the next record. Remember: you should try to find out to what extent the experimental medicine is effective. Once you have observed several patients, we will ask you some questions.

9.3. Appendix C (Study 3)

Supplementary tables

Table S1. Frequency and percentage of participants' sex and ethnicity by ranges of age.

Age	Freq.	Females	Males	White	Black	Asian	Mixed	Other
18-27	85	49.41%	50.59%	64.71%	16.47%	9.41%	3.53%	5.88%
28-37	105	51.43%	48.57%	67.62%	16.19%	7.62%	3.81%	4.76%
38-47	76	46,05%	53.95%	69.74%	11.84%	10.53%	5.26%	2.63%
48-57	86	52.33%	47.67%	68.60%	16.28%	6.98%	4.65%	3.49%
58-67	117	41.03%	58.97%	84.62%	7.69%	3.42%	3.42%	0.85%
68+	41	63.41%	36.59%	82.93%	9.76%	4.88%	0.00%	2.44%

Table S2. Type of belief, topic and reference for each item included in the PES.

Item	Type	Topic	Reference
1	Myth	Electromagnetic radiation	Majima (2015)
2	Myth	Positive psychology	Lilienfeld, Lynn, Ruscio, & Beyerstein (2010)
3	Myth	Hypnopedia	Lilienfeld *et al.* (2010)
4	Discipline	Osteopathy	Guillaud, Darbois, Monvoisin, & Pinsault (2018)
5	Discipline	Reiki	Lee, Pittler, & Ernst (2008)
6	Discipline	Homeopathy	Ernst (2002)
7	Myth	Ulcers by stress	Lilienfeld *et al.* (2010)
8	Discipline	Bach flower remedies	Ernst (2010)
9	Discipline	Acupuncture	Colquhoun & Novella (2013)
10	Discipline	Vitamin supplements	Kamangar & Emadi (2012)
11	Discipline	Neuro-linguistic programming	Witkowski (2010)
12	Discipline	Hypnosis	Lilienfeld *et al.* (2010)
13	Myth	Graphology	Lilienfeld *et al.* (2010)
14	Discipline	Magnet therapy	Finegold & Flamm (2006)
15	Myth	Mozart effect	Majima (2015)
16	Myth	Interpretation of dreams	Lilienfeld *et al.* (2010)
17	Myth	Harmful effects of Wi-Fi	Vargas (2012)
18	Myth	Polygraph	Lilienfeld *et al.* (2010)
19	Discipline	Detox therapies	Ernst (2012)
20	Myth	Subliminal messages	Majima (2015)

Table S3. Mean and SD of the participants' scores on the unwarranted beliefs questionnaires and their correlations with the scores on the PES.

	Mean	***SD***	r_t	BF_{10}
Paranormal Beliefs (RPBS):	2.80	1.17	0.49***	1.062^{58}
Traditional Religious Belief	4.03	2.09	0.32***	2.332^{24}
Psi	2.62	1.43	0.43***	3.538^{43}
Witchcraft	2.94	1.79	0.42***	9.700^{42}
Superstition	1.52	0.97	0.31***	3.805^{22}
Spiritualism	2.86	1.66	0.42***	2.872^{42}
Extraordinary Life Forms	3.04	1.10	0.25***	1.390^{14}
Precognition	2.44	1.40	0.46***	9.835^{50}
Science Denialism (SD-PBS)	2.01	0.54	0.36***	1.320^{30}
Conspiracist Beliefs (GCBS)	2.32	0.98	0.37***	3.844^{31}

*** $p < .001$

Table S4. Mean and SD of the participants' scores on the cognitive questionnaires and sociodemographic characteristics, as well as their Kendall's τ correlations with scores on the PES.

	Mean	*SD*	r_t	BF_{10}
***Bullshit* Detection:**				
***Bullshit* receptivity**	2.11	0.87	0.33***	3.002^{25}
Motivational quotes	2.96	0.78	0.25***	4.650^{14}
***Bullshit* Sensitivity**	0.85	0.74	–0.10**	14.71
Science Literacy (SLKQ)	7.75	1.49	–0.27***	1.516^{17}
Cognitive Reflection (CRT)	3.73	2.25	–0.18***	3.140^{6}
Age	45.99	15.85	0.12***	276.33
Political ideology	3.13	1.64	0.16***	78615.11
Years of schooling	15.98	2.47	–0.08*	2.66
Socioeconomic status	5.23	1.65	0.05	4.37 (BF_{01})

* $p < .05$, ** $p < .01$, *** $p < .001$

RPBS stands for Revised Paranormal Beliefs Scale. SD-PBS stands for the science denialism items of the Pseudoscientific Beliefs Scale. GCBS stands for General Conspiracist Beliefs Scale. SLKQ stands for Science Literacy Knowledge Questionnaire. CRT stands for Cognitive Reflection Test.

Table S5. Kendall's τ correlations between mean scores of the different subscales of the RPBS and the short version of the PES (sPES).

	r_t	BF_{10}
Paranormal Beliefs (RPBS):		
Traditional Religious Belief	0.32***	1.870^{23}
Psi	0.42***	1.961^{41}
Witchcraft	0.43***	3.280^{44}
Superstition	0.32***	4.309^{23}
Spiritualism	0.42***	4.242^{42}
Extraordinary Life Forms	0.25***	9.370^{13}
Precognition	0.45***	3.716^{49}

*** $p < .001$

RPBS stands for Revised Paranormal Beliefs Scale.

Table S6. Summary of the regression model for the full version of the PES.

	Pseudoscientific beliefs (full PES)	
	B	***p***
(Intercept)		< .001
Cognitive Reflection (CRT)	-0.08	.076
***Bullshit* Sensitivity**	0.14	.001
***Bullshit* Reception**	0.48	< .001
Science Literacy (SLKQ)	-0.18	<.001
Sex	0.06	.150
Age	0.19	< .001
Years of schooling	-0.05	.171
Socioeconomic status	0.04	.256

CRT stands for Cognitive Reflection Test. SLKQ stands for Science Literacy Knowledge Questionnaire.

Table S2 references

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ANNEX

10. Annex

10.1. Study 1 front-page

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Causal illusion as a cognitive basis of pseudoscientific beliefs

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Causal illusion has been proposed as a cognitive mediator of pseudoscientific beliefs. However, previous studies have only tested the association between this cognitive bias and a closely related but different type of unwarranted beliefs, those related to superstition and paranormal phenomena. Participants (n = 225) responded to a novel questionnaire of pseudoscientific beliefs designed for this study. They also completed a contingency learning task in which a possible cause, infusion intake, and a desired effect, headache remission, were actually non-contingent. Volunteers with higher scores on the questionnaire also presented stronger causal illusion effects. These results support the hypothesis that causal illusions might play a fundamental role in the endorsement of pseudoscientific beliefs.

Previous studies have aimed to identify the mechanisms underlying unwarranted beliefs related to paranormal phenomena (Blackmore & Trościanko, 1985; Brugger, Landis, & Regard, 1990; van Prooijen, Douglas, & De Inocencio, 2018; Wiseman & Watt, 2006). In this study, we focus on a different, though closely related, domain of unwarranted beliefs: those related to pseudoscience. According to the demarcation criteria adopted by Fasce and Picó (2019, p. 618), for something to be considered a pseudoscience, it needs to be 'presented as scientific knowledge' (A) and also meet at least one of the following three conditions: 'refers to entities and/or processes outside the domain of science' (B), and/or 'makes use of a deficient methodology' (C), and/or 'is not supported by evidence' (D). As noted by these authors, the difference between pseudoscientific and paranormal beliefs lies in the fact that although the latter still refers to aspects outside the domain of science (it fulfils B), it is not presented as scientific knowledge (does not fulfil A). While paranormal and pseudoscientific beliefs tend to positively correlate (Fasce & Picó, 2019; Lindeman, 2011; Majima, 2015), they present different prevalence rates in the population. For instance, according to a national survey on social perception of science conducted in Spain (FECYT 2017), whereas only 22.4% and 27.5% of the population, respectively, believe in paranormal phenomena and superstitions (i.e., lucky charms or numbers),

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10.2. Study 2 front-page

PLOS ONE

RESEARCH ARTICLE

Causal illusion in the core of pseudoscientific beliefs: The role of information interpretation and search strategies

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Abstract

The prevalence of pseudoscientific beliefs in our societies negatively influences relevant areas such as health or education. Causal illusions have been proposed as a possible cognitive basis for the development of such beliefs. The aim of our study was to further investigate the specific nature of the association between causal illusion and endorsement of pseudoscientific beliefs through an active contingency detection task. In this task, volunteers are given the opportunity to manipulate the presence or absence of a potential cause in order to explore its possible influence over the outcome. Responses provided are assumed to reflect both the participants' information interpretation strategies as well as their information search strategies. Following a previous study investigating the association between causal illusion and the presence of paranormal beliefs, we expected that the association between causal illusion and pseudoscientific beliefs would disappear when controlling for the information search strategy (i.e., the proportion of trials in which the participants decided to present the potential cause). Volunteers with higher pseudoscientific beliefs also developed stronger causal illusions in active contingency detection tasks. This association appeared irrespective of the participants with more pseudoscientific beliefs showing (Experiment 2) or not (Experiment 1) differential search strategies. Our results suggest that both information interpretation and search strategies could be significantly associated to the development of pseudoscientific (and paranormal) beliefs.

Introduction

The term "epistemically unwarranted beliefs" [1] refers to beliefs endorsed in the absence of substantial evidence supporting them (e.g., believing in ghosts or astral journeys, in the therapeutic benefits of Bach flowers, or that "chemtrails" contain biological agents sprayed to psychologically control the population). Although they lack adequate scientific support, these kinds of beliefs are relatively common in western society: 40% of the European population believes in lucky numbers [2], and 37% of the U.S. population considers astrology to be scientific [3]. Several studies have investigated the conditions favouring the presence of

10.3. Study 3 front-page

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ARTICLE

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A validation of the Pseudoscience Endorsement Scale and assessment of the cognitive correlates of pseudoscientific beliefs

Marta N. Torres [1], Itxaso Barberia[1] & Javier Rodríguez-Ferreiro [1✉]

Pseudoscientific beliefs are widespread and have potentially harmful consequences. Being able to identify their presence and recognize the factors characterizing their endorsement is crucial to understanding their prevalence. In this preregistered study, we validated the English version of the Pseudoscience Endorsement Scale and investigated its correlates. A group of volunteers ($n = 510$), representative of the U.S. population, responded to this scale and to questionnaires measuring the presence of paranormal, denialist, and conspiracist beliefs. The validation resulted in a shorter version of the scale, the sPES. Participants also completed a scientific literacy questionnaire as well as *bullshit* detection and cognitive reflection tests. Scores obtained on the questionnaires corresponding to different unwarranted beliefs correlated with each other, suggesting a possible common basis. Scientific knowledge, cognitive reflection scores, and *bullshit* sensitivity were negatively associated with scores on the pseudoscience scale. Of note, *bullshit* receptivity was the main contributor in a model predicting pseudoscience endorsement.

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