The Role of Outcome and Experience in Hypothesis Testing about Food Allergy

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Abstract

It is important to understand the reasoning strategies that health behaviours are based on. Croker and Buchanan (2011b) found that the strategies people use when choosing how to test a hypothesis about oral health are affected by whether the participant is seeking to reproduce a positive outcome (i.e., good health) or eliminate an unwanted outcome (i.e., bad health). The aim of this study was to investigate the effect of outcome on reasoning strategies in a food allergy context. Participants with and without food allergy were given hypothesis-testing tasks and asked to choose which of three alternative patterns of food consumption could be used to test a hypothesis that a person is allergic to a particular food. Participants were more likely to select a controlled test of the hypothesis that a specific food causes an allergic reaction when a reaction to a food had been observed after eating, than when a reaction had not been observed due to food avoidance. Although the potential severity of making an incorrect choice in a food allergy context is both greater and more proximal than in an oral health context, the same bias in reasoning strategy was found. Logically appropriate hypothesis-testing behaviour may not, therefore, underpin real-world decision making.

Keywords: food allergy, scientific reasoning, hypothesis testing

The Role of Outcome and Experience in Hypothesis Testing about Food Allergy

Hypothesis testing includes searching through a space of experiments in order to select a test that will discriminate among competing hypotheses. In order to select a test of a hypothesis, predictions about experimental results must be made (Klahr, Fay, & Dunbar, 1993). Often, prior knowledge is used to guide the selection of predictions and the strategy for selecting a hypothesis. This is evidenced by the finding that participants in scientific reasoning studies often select or design experiments that will generate data that have the potential to confirm, rather than disconfirm, their hypotheses (Klayman & Ha, 1987). An important first step in the scientific reasoning chain is to select a test of a hypothesis that will generate valid data, regardless of whether the resulting data confirm or disconfirm the hypothesis. The Control of Variables Strategy (CVS) is a domain-general processing strategy whereby a single variable is isolated and manipulated while other variables are held constant. An understanding of CVS enables us to make a distinction between confounded and unconfounded experiments and gives us the ability to draw valid inferences from controlled experiments (Chen & Klahr, 1999).

A number of studies demonstrate that domain-specific knowledge is also a relevant factor (e.g., Chi & Koeske, 1983; Penner & Klahr, 1996), and recent approaches to scientific reasoning take into account both domain-general strategies and domain-specific concepts, suggesting that the two interact with one another: conceptual knowledge can help elicit experimentation strategies, and appropriate use of strategies generates new knowledge (Lehrer & Schauble, 2006; Schauble, 1996; Zimmerman, 2007). Given this interaction, context should have important implications for performance on reasoning tasks. Tschirgi (1980) examined hypothesis testing in familiar contexts, providing participants with scenarios such as baking a cake and making a paper airplane. In these scenarios the outcome could either be positive or negative (e.g., a great cake or a terrible cake).

Tschirgi found children were more likely to use a VOTAT (vary-one-thing-at-a-time) strategy (i.e., select a controlled test, in which only one variable is changed across two observations) when presented with a bad outcome (e.g., a terrible cake) and a HOTAT (hold-one-thing-at-a-time; i.e., keep just one variable constant across two observations) strategy when presented with a good outcome (e.g., a great cake). Younger children (6-7 year-olds) were also more likely to 'change all' the variables (CA) in a bad outcome situation in an attempt to make a change for the better. Both the HOTAT and CA strategies represent selection of confounded tests of a hypothesis.

Similarly, Zimmerman and Glaser (2001) provided 11-12 year-olds with hypotheses about whether certain liquids were good or bad for plant health. When a negative claim was presented ("water is bad for plants"), participants tended to propose controlled experiments, in which they manipulated the focal variable (e.g., rain water vs. tap water). In contrast, a positive claim ("coffee grinds are good for plants") led to confounded experiments in which participants attempted to preserve the good outcome (healthy plants) by manipulating other variables (e.g., type of plant) and not the focal variable (coffee grinds). The apparent aim to produce a positive outcome, reported in these studies, may reflect a distinction between an engineering approach and a hypothesis-testing approach. When adopting an engineering approach, the aim is to engineer a desired outcome rather than to test the causal status of individual variables (Schauble, Klopfer & Raghavan, 1991).

It is important to understand whether these reasoning strategies are used for decisions about health behaviours. Croker and Buchanan (2011b) found that the strategies children use when choosing a test of a hypothesis about good dental health are affected by whether the participant is seeking to reproduce a positive outcome (e.g., maintain good dental health) or eliminate an unwanted outcome (e.g., avoid bad dental health). This effect of outcome is consistent with Tschirgi's (1980) findings. Much of the literature on scientific reasoning and CVS is developmental, focusing on children's behavior. In order to examine whether children's biases are due to underdeveloped skills, or whether the same biases are observed in the adult population, Croker and Buchanan (2011a) included a sample of adults as well as children. They found that adults were also susceptible to effects of outcome valence; they were more likely to select controlled tests (i.e., vary only one thing at a time while holding all other variables constant) when presented with a bad outcome than when given a good outcome.

Croker and Buchanan (2011a, 2011b) used oral health contexts as children and adults all have basic knowledge regarding foods, drinks, and behaviours that lead to good or bad outcomes. In contrast, food allergy is not experienced by everyone. A recent meta-analysis estimates that up to 35% of the population self-report food allergy, therefore a substantial subset of the population has at least some direct experience with food avoidance and knowledge of the causes of negative reactions to foodstuffs. As the only effective treatment for food allergy at present is total avoidance of the allergen and emergency treatment of symptoms caused by accidental ingestion, quality of life can be affected in a profound way (Bock, Munoz-Furlong, & Sampson, 2001; Cummings, Knibb, King, & Lucas, 2010), extending beyond the immediate clinical effects of the patient's allergic condition. For example, dietary restrictions may compromise social activities such as dining out and necessitate careful reading of food labels (Knibb et al., 2000). Children diagnosed with food allergy and their parents are given a large amount of information at the clinic regarding diet and use of medication. However, little is known about the level of understanding children and adults might have about food allergy. Rushforth (1999) has noted that there is an increasing number of children who need to have a clear understanding of their condition and the behaviours they need to engage in or avoid.

Parents of children with food allergy have been reported to gather the majority of their information about food allergy from the media, family, and friends rather than medical sources (Knibb & Semper, 2013). The nature of beliefs about causes of food allergy may thus differ across individuals as a function of experience and exposure to information.

Although it has been noted that existing beliefs may affect some aspects of scientific reasoning, such as how evidence is evaluated (Koerber, Sodian, Thoermer, & Nett, 2005), there has been little investigation into the impact of these beliefs in hypothesis-testing tasks. Children and adults are both more likely to attend to variables they believe to be causal (Schauble, 1996), which may hinder or facilitate scientific reasoning. Children and adults often cling to their incorrect prior beliefs rather than changing them to be in-line with the evidence (Chinn & Brewer, 1993). However, familiarity with the content of a problem and the likely cause-effect relationships between variables can lead to adults adopting a successful theory-driven approach, whereas no prior knowledge leads to a less successful data-driven approach (Lazonder, Wilhelm, and Hagemans, 2008; Lazonder, Wilhelm, & Van Lieburg, 2009).

The aim of the present study was to investigate whether the effect of outcome on adult participants' strategy choice would be found in a food allergy context. We also hypothesized that participants' prior knowledge and experience would have an effect on their hypothesis-testing strategies. We predict that those who have personal experience with allergic reactions will be more likely to choose the HOTAT strategy when presented with a good outcome than participants who do not have personal experience. Although previous research has examined the effect of outcome on forced-choice hypothesis testing tasks (e.g., Tschirgi, 1980), these studies have not asked participants why they made the choices they did. In a series of evidence evaluation tasks, Kuhn, Amsel, and O'Loughlin (1988) asked participants to justify their answers; these were coded as being either theory-based or evidence-based. Using similar coding categories, we examined the explanations that participants gave for their answers in order to assess whether their hypothesis-testing strategies were driven by their domain-specific knowledge (belief-based) or whether they reasoned independently of the task content (evidence-based).

Method

Participants

We recruited adult participants (*N*=249) with a reported food allergy (*n*=45) and without food allergy (*n*=204) from the Illinois State University psychology department student participant pool, and from the Illinois State University family and child research participant pool. Students were given course credit in exchange for participation. Ethical approval for the study was granted by Illinois State University's Institutional Review Board.

Design and Procedure

We used a 2 (food allergy status) x 2 (outcome: good or bad) mixed design. Participants with and without food allergy were given two hypothesis-testing tasks in which they had to choose a set of food consumption patterns in order to test hypotheses about which foods do or do not cause symptoms (see Figure 1). Participants were presented with two scenarios, counterbalanced across participants, about individuals who either do or do not experience food-allergy symptoms. In the bad outcome condition, the characters in the story experienced food-allergy symptoms and had a belief about what food caused the symptoms. In the good outcome condition, the characters experienced no symptoms because they avoided several foods, but had a belief about which particular food was responsible. In both cases, the characters believed that peanuts were the potential cause of symptoms. Participants were asked to choose which of three alternative patterns of food consumption could be used to test the character's hypotheses. In one pattern, whether the character consumes the target food or not is the only variable that is changed (vary-one-thing-at-a-time; VOTAT). This is the logically appropriate test of a hypothesis. A second option is to change the characters consumption of the foods that are not hypothesised to have an effect (hold-one-thing-at-a-time; HOTAT). The third choice is to change the character's consumption of all foods (change-all; CA).

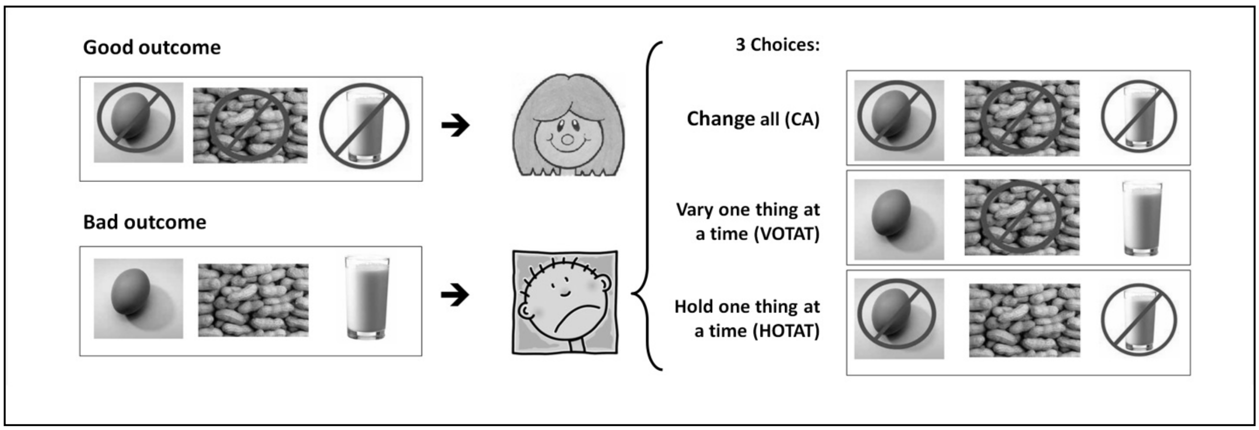

Figure 1. Hypothesis testing task. Participants were asked to select a test of the hypothesis that presence or absence of peanuts was the cause of the outcome. The labels VOTAT, HOTAT, and CA are provided here for clarity; these were not seen by the participants.

Participants were asked to give explanations in order to provide insight into the reasoning behind their answers. Participants' explanations were recorded using a digital audio recorder and transcribed. The transcribed explanations were coded as being either evidence-based or theory-based. Explanations in which participants mentioned proof (e.g., they explicitly stated that the reason the protagonist should choose a particular course of action was in order to 'prove their point' or 'will prove that it is/isn't the peanuts') or looking for an effect (e.g., start consuming peanuts to show that they cause symptoms) were coded as evidence-based explanations. If participants explained that they had chosen an answer because that was the correct behaviour (e.g., you shouldn't eat peanuts because they are known to cause allergic reactions) then it was coded as theory-based. All explanations were coded by two raters. Inter-rater reliability was good for both the good ($K = 0.70$) and bad ($K = 0.64$) outcome scenarios.

Results

Strategy

McNemar's tests were conducted to examine within-participants differences on the good and bad outcome tasks. There was an overall effect of outcome on strategy, $\chi^2(1) = 22.24$, $p < .001$; participants selected the VOTAT strategy more frequently in the bad outcome scenario (60.73%) than in the good outcome scenario (38.71%). Examining participants with and without food allergy separately, there was an effect of outcome for frequency of VOTAT selection for those without food allergy, $\chi^2(1) = 24.36$, $p < .001$, but not for those with food allergy, $p = .69$ (see Figure 2).

Although there were strategy differences across scenarios, there were no differences in strategy selection between participants with and without food allergy within either scenario. Overall, both HOTAT and CA responses were greater in the good outcome scenario than in the bad outcome scenario (see Figures 3 and 4). Thus, when the character was ill as a result of eating a type of food, participants were more likely to choose a controlled test of the hypothesis (the VOTAT response; avoid peanuts) than when the character remained healthy as a result of not eating the food , where the VOTAT response would be to suggest that the character consumes peanuts.

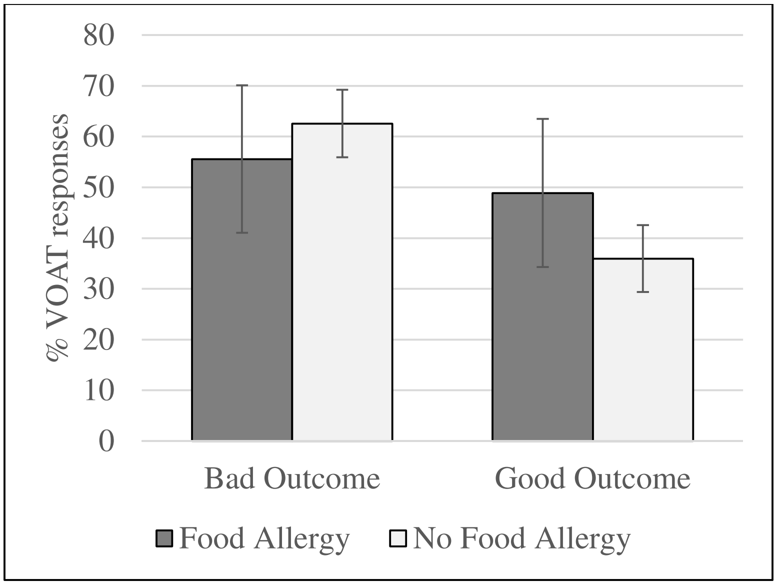

Figure 2. Frequency of selection of VOTAT strategy. Error bars represent 95% confidence intervals.

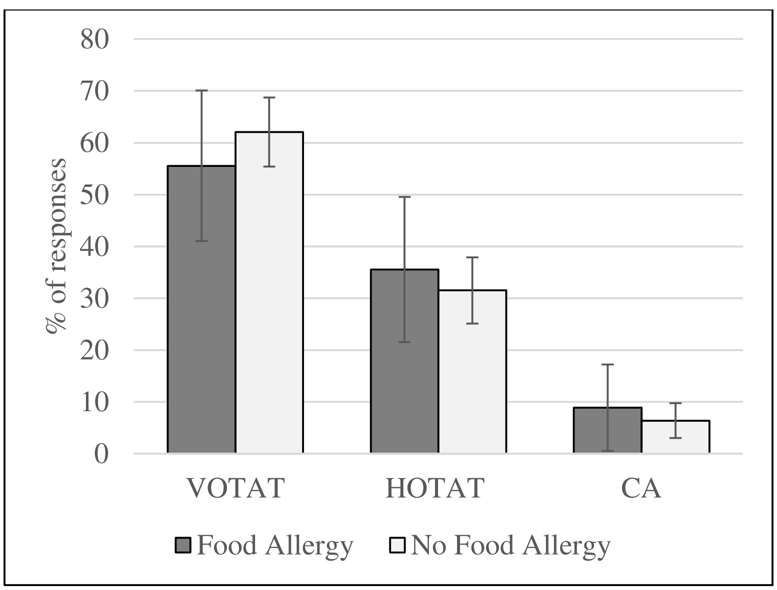

Figure 3. Strategy use in the bad outcome scenario. Error bars represent 95% confidence intervals.

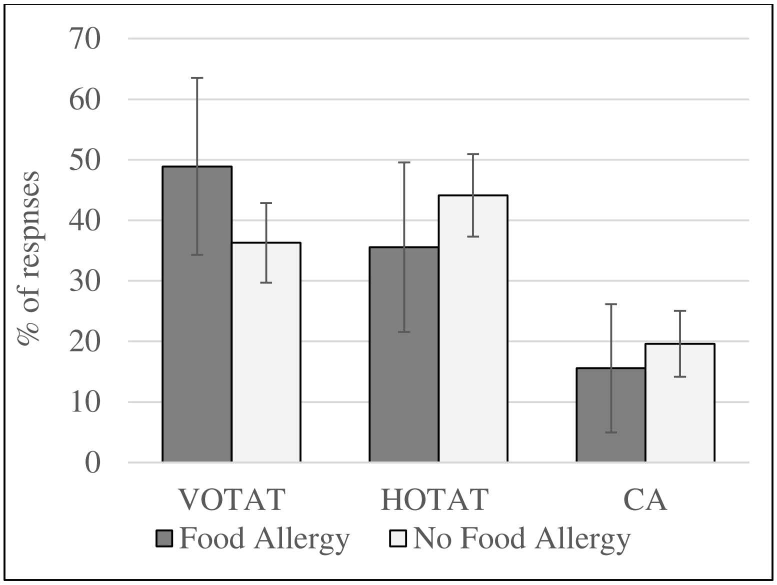

Figure 4. Strategy use in the good outcome scenario. Error bars represent 95% confidence intervals.

Explanations

The explanations participants gave in support of their choices on the task were coded as evidence-based or theory-based. Nine of the explanations given for the bad outcome scenario and six of the good outcome explanations could not be coded as either evidence- or theory-based. These data were omitted from the following analyses.

There was no overall association between outcome scenario and explanation type, so it was not the case that participants were more likely to give an evidence-based explanation for either a good or a bad outcome. Neither was there an association between participants' allergy status and explanation type in either the bad outcome or good outcome scenario.

Figures 5 and 6 illustrate the frequency of evidence-based and theory-based explanations for each strategy for the bad and good outcome scenarios. There was an association between strategy choice and explanation type in the bad outcome scenario, $\chi^2(2) = 44.213$, $p < .001$;

participants were more likely to give evidence-based explanations for VOTAT and HOTAT responses, and theory-based explanations for CA responses. There was also an association between strategy choice and explanation type in the good outcome scenario, $\chi^2(2) = 30.598$, $p < .001$. In this scenario, evidence-based explanations were dominant across all three strategy responses, but participants gave more theory-based answers for HOTAT responses than for VOTAT or CA responses.

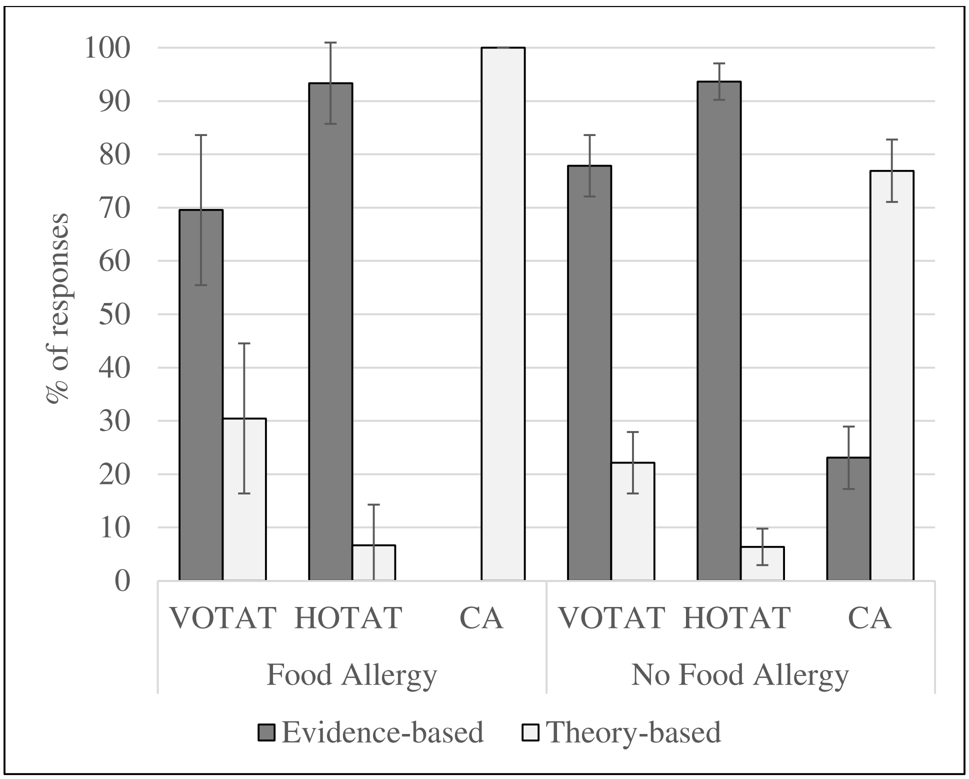

Figure 5. Frequency of evidence-based explanations accompanying each response strategy in the bad outcome scenario. Error bars represent 95% confidence intervals.

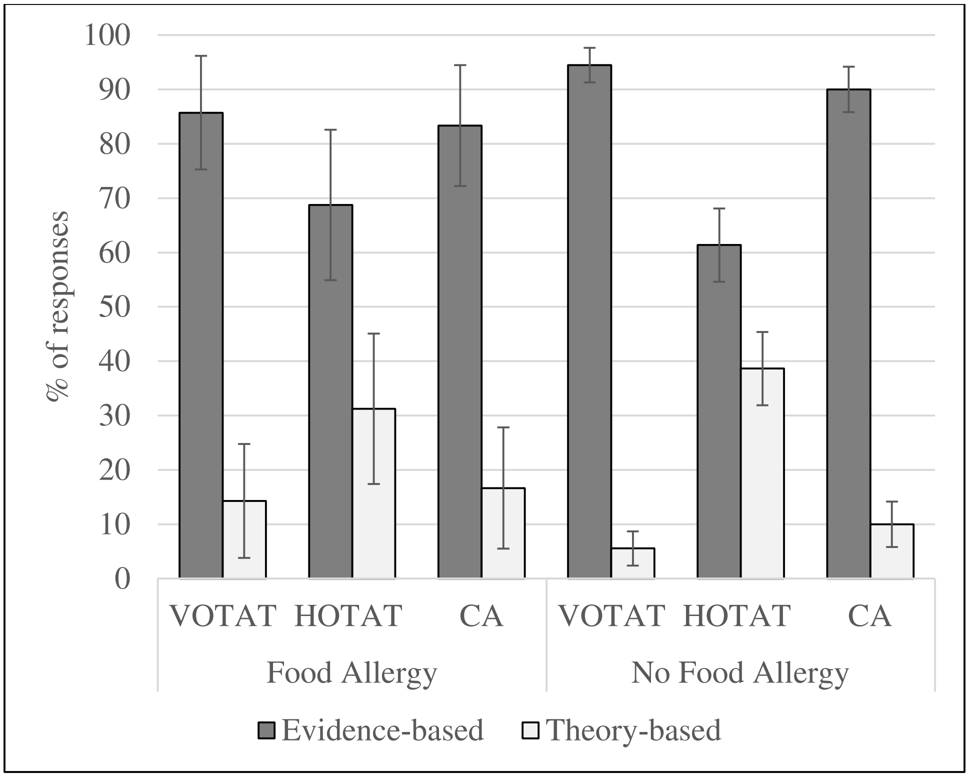

Figure 6. Frequency of evidence-based explanations accompanying each response strategy in the good outcome scenario. Error bars represent 95% confidence intervals.

We conducted the same strategy x explanation analyses for each allergy status group separately. We found an association between strategy and explanation in the bad outcome scenario for both participants with food allergy, $\chi^2(2) = 11.44$, $p = .003$, and without food allergy, $\chi^2(2) = 32.997$, $p < .001$. However, in the good outcome scenario there was only a significant association between strategy and explanation for participants without food allergy, $\chi^2(2) = 30.30$, $p < .001$.

Given the differences between the two participant groups on the good outcome scenario, we conducted three way loglinear analyses of allergy status, strategy, and explanation for both the bad and good outcome scenarios. The analysis for the bad outcome scenario produced a final model that retained the strategy x explanation interaction. The likelihood ratio of this model was

$\chi^2(5) = 2.474$, $p = .78$. The strategy x explanation interaction was significant, $\chi^2(2) = 39.898$, $p < .001$, but there were no interactions involving allergy status. The analysis for the good outcome scenario also produced a final model that retained the strategy x explanation interaction. The likelihood ratio of this model was $\chi^2(5) = 4.633$, $p = .46$. The strategy x explanation interaction was significant, $\chi^2(2) = 31.271$, $p < .001$, with no interactions involving allergy status.

Discussion

Our results show that outcome affects the strategies people use when testing hypotheses. When presented with a bad outcome, participants were more likely to choose a controlled test of the stated hypothesis (i.e., VOTAT; manipulate one variable) than when presented with a good outcome. In the good outcome scenario, participants were more likely to select confounded tests (HOTAT or CA responses) than in the bad outcome scenario. The potential severity of making an incorrect choice in a food allergy context is both greater and more proximal than in an oral health context, however the same bias in reasoning strategy was found. In the bad outcome scenario, the logical choice of excluding peanuts is consistent with the desire to avoid illness. However, in the good outcome scenario, the logical choice of eating peanuts in order to test the hypothesis that peanuts cause illness is in conflict with a desire to avoid illness. A large proportion of self-diagnosed food allergies cannot be clinically confirmed using standardised diagnostic tests (Rona et al., 2007) and people often misattribute symptoms to food, resulting in them avoiding that food from then on. This desire to avoid illness and not test a hypothesis of food allergy by trying the food again may explain why some people maintain these erroneous beliefs. Avoiding food due to an incorrect assumption it causes allergic symptoms could then have a needless impact on quality of life and psychological distress.

We also examined the explanation participants gave for why they chose the strategies they did. Evidence-based explanations were associated with VOTAT and HOTAT responses in the bad outcome scenario, and theory-based explanations were associated with CA responses. In the good outcome scenario, evidence-based explanations were associated with VOTAT and CA responses. The association between strategy choice and explanation in the good outcome scenario held only for participants without food allergy. Although participants with food allergy gave more evidence-based explanations for all three strategy choices, they also gave more theory-based explanations than participants without food allergy, suggesting that the former group's experience with allergy led them to make greater use of their knowledge when selecting a hypothesis-testing strategy. Normative, logically appropriate hypothesis-testing behaviour may not, therefore, underpin real-world decision making regarding health outcomes. Rather, decisions are guided by knowledge and beliefs. One could argue that holding prior beliefs in abeyance and attending only to the evidence is a superior strategy, as this will not lead to an incorrect rejection of causal variables or an incorrect inference that a non-causal variable is, in fact, causal. However, Koslowski (1996) notes that although there are many examples of covariation and correlation in the world, we tend to only take seriously those for which there is a causal mechanism. Considering causal mechanisms requires a knowledge base. Thus, the consideration of plausible mechanisms is a useful way of excluding artifactual causes and deciding whether a theory requires outright rejection or modification in the face of disconfirming evidence (Koslowski & Masnick, 2010). If participants' prior beliefs are correct, then they are likely to focus attention on the relevant aspects of a problem, such as what foods are likely to be responsible for an observed allergic reaction. However, in the case of a parent who has a child with food allergy, incorrect or incomplete knowledge may result in ignoring candidate causes of a reaction.

In order to assess the role of prior belief, we compared participants who reported having a food allergy with participants who did not have any food allergies. However, a limitation of our study is that some of the latter group may actually have had extensive knowledge of the causes of food allergy through a friend or family member. Future research, therefore, should take note of the many ways in which beliefs can be developed through indirect experience as well as through direct experience. A second limitation is the use of artificial scenarios concerning fictitious characters. We cannot be sure that the same results would be observed in a real life scenario. A third limitation is that we were only able to recruit a relatively small opportunity sample of participants with food allergy. It would be useful to replicate this study with a larger sample of adults with confirmed food allergy, recruited through allergy clinics. A larger sample would enable exploration of whether the specific foods that people are allergic to and the severity of allergy affect reasoning strategies.

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