Error Management in Learning and Generalisation: The Domain of Food.

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Summary

Whilst many societies today rely on industrially processed foods, this is atypical compared to other societies across the world and across history. Acquiring food through means of hunting or gathering poses risks that an individual must balance with a dependence on these means for survival. One strategy to help minimise these risks is to learn about the threats in one's environment, and it appears learning systems are specialised for this, with certain information being more learnable than others. Past research has shown that infants appear to possess learning biases relating to edibility for plants, and more broadly studies have demonstrated children and adults to be biased towards learning information pertinent to survival (e.g. danger, threat).One explanation for the emergence of such biases is Error Management Theory, which argues that in instances where certain mistakes are more costly than others, cognitive biases emerge to minimise the more costly errors. The present dissertation reasons that this logic may also apply to generalisation processes, and looks to examine whether different kinds of information are generalised differently, and how this differs across the lifecourse, whilst also further investigating learning biases towards certain types of information.

Chapter 2 (Rioux, Russell & Wertz, 2022) investigates whether generalisation systems are biased in regards to certain types of information, testing whether generalisation of edibility and toxicity information reflects the relative costs of generalisation errors for these kinds of information in adults and in children. We find this to be the case, with adults generalising toxicity more and edibility information less. Interestingly, it is observed that this appears to only be the case under the highest level of uncertainty, and the effect is not observed in children Moreover, we find evidence that there does appear to be an overall negativity effect on generalisation, but that this cannot fully account for the differences in generalisation for edibility and toxicity information. These results offer the first indication that human generalisation is biased to reflect the relative costs of possible generalisation mistakes and support the notion of a generalisation system shaped to minimise costly generalisation errors.

In Chapter 3 we investigate the effects of information type on generalisation further using a different method, look deeper at the role of uncertainty, and examine the role played by individual differences, specifically anxiety, on generalisation. We also looked to build upon existing work demonstrating learning is biased towards certain kinds of information (e.g., threat, danger) by examining learning biases towards danger and edibility information in the domain of food. We find a limited effect of information type on generalisation for adults, but unlike in Chapter 1, did not observe this effect to be greater under uncertainty. Moreover, whilst we did not find the predicted effect of information type on recall accuracy observed in previous research, it was found that information type influenced the kinds of mistakes made, with participants making more false positive errors compared to the more costly false negative for toxicity information. Finally, we present evidence that, contrary to predictions, individual differences do not increase risk minimising behaviour, rather in certain circumstances greater anxiety may lead to risk increasing behaviours.

In Chapter 4 we looked to replicate a finding from Wertz & Wynn (2014), who observed 18-month-old infants would selectively associate plants with edibility over a control artifact. We were not able to replicate this finding. Following this non-replication we tested the effect using an alternative method to examine possible methodological reasons for our results and again did not observe an effect.

Taken in concert the results presented in this dissertation provide evidence that generalisation, but not learning, appears to be sensitive to the type of information being generalised. Consistent with the predictions of Error Management Theory, generalisation systems seem to be biased towards reducing the more costly mistakes, yet only under certain circumstances. This calls for further research to elucidate the moderating factors on the generalisation of potentially costly information, and further replications in the study of learning biases.

Chapter 1: General Introduction

"Variety's the very spice of life"

William Cowper (1785)

One may argue whether or not variety is indeed the spice of life, but it is certainly the reality. Everyday life for humans and non-humans alike is filled with various novel occurrences, some of which are similar—perhaps exceptionally so—but not identical to our previous experience. Being able to extrapolate and generalise from the known to the novel is a fundamental building block of cognition, and, in its simplest form, requires solving two problems: identifying what it is important to learn, and how best to generalise that information. We are so accustomed to solving these problems that one might overlook their importance in certain contexts. For example, knowing that a cup you have never seen before is a suitable vessel for your orange juice may not seem overly consequential, but incorrectly thinking that a novel berry is edible can be fatal. Similarly, forgetting that a particular television remote requires AA batteries does not have quite the same consequences as forgetting that a particular mushroom is exceedingly poisonous. The present dissertation will focus on examining how our cognitive systems of learning and generalisation might have been shaped by such environmental asymmetries over evolutionary time.

1. Managing Naturalistic Risk

All species routinely face potential opportunities for obtaining benefits such as food and resource acquisition, and risks such as predation or injury. Yet for many people alive today industrially processed foods have become the norm (Baraldi et al., 2018), mitigating many risky tasks of locating, identifying and harvesting food sources in wild environments.

However, the rise of such technology over the previous centuries is quite recent, relative to the emergence of *Homo Sapiens* over 200,000 years ago and earlier members of the Homo genus around 2 million years ago (e.g., Schlebusch et al., 2017). It has long been argued that cognitive science should not ignore the environment in which our mind was shaped, with Evolutionary Psychologists arguing for the importance of a fitness perspective on human psychology over recent decades (e.g., Cosmides & Tooby, 1994). Similar arguments have been made external to an evolutionary perspective, with Anderson (1991) arguing for the importance of considering cognitive processes as optimised for their respective goals and environment, and Simon (1956) who famously argued that decision makers adapt to their environment in ways that are satisfactory or sufficient, rather than optimal. Given the seemingly anomalous food acquisition environment for humans in western and industrialised societies, considering the problems faced by other human societies may offer insight into human psychology. Indeed, this is not only the case relative to ancestral societies, many recent societies rely on hunting and gathering for food resources (e.g., Cordain et al., 2000). The acquisition of resources and avoidance of threat are key drivers of evolutionary fitness—likelihood of successfully having offspring—and just as protection from foodborne threats may result in physical adaptations such as stomach acidity (Beasley et al., 2015; Lambert, 1998; Smith, 2003), it has been suggested that psychological systems may also be adapted to reduce foodborne risks in the form of a “behavioural immune system” (Schaller, 2011). For example, it has been argued elsewhere that human learning systems are also shaped by selection pressures to mitigate risk (Barrett et al., 2016; Wertz & Wynn, 2014a).

Psychological adaptations towards threats posed by dangerous animals and humans have been relatively well studied through this adaptive lens (for reviews see Barrett, 2015; Duntley, 2015; LoBue, 2014). For example, it has been proposed that humans have a specialised system for detecting agents (Atran, 2005; Johnson, 2003), and research has indicated a heightened attention for threatening and negative faces and prototypically threatening animals (Eastwood et al., 2001; Lipp & Derakshan, 2005; Maratos et al., 2008; New & German, 2015; Öhman et al., 2001; Waters & Lipp, 2008; see also LoBue & Rakison, 2013 for review). Yet, as noted by Wertz (2019) and colleagues, plants have received less attention as a source of threat, despite evidence suggesting plants provide a substantial portion of the human diet and that of our non-human ancestors (Andrews & Johnson, 2020; Cordain et al., 2000b), along with being an important source of traditional medicines and construction materials (Begossi et al., 2002; Figueiredo et al., 1993). In addition to these potential boons, however, the co-evolutionary arms race between plants and animals has resulted in plants evolving a number of passive defences (Mithöfer & Boland, 2012; Occhipinti, 2013). Some of these are visible, structural defences such as spines (Hanley et al., 2007), yet many of the defences plants have evolved to protect against herbivores are toxic chemical compounds (Belovsky & Schmitz, 2006; Keeler & Tu, 1983; Manners, 1996), which have fewer, if any, reliable visible cues (Włodarczyk et al., 2018). As Wertz (2019) notes, the kinds of threat posed by plants mean any harm incurred is a function of human error or miscalculation; outside of science fiction plants do not actively hunt humans. If one consumes a toxic berry and gets sick it is due to an error, such as miscategorising or misremembering that item as edible when in fact it is not. This poses the adaptive problem, which our psychology has to solve, of how to reduce these miscalculations and effectively navigate various plant dangers whilst being reliant on them for food and other resources (Wertz, 2019; Wertz & Moya, 2018). Recent work has demonstrated human learning may be an important way to manage this problem. Infants show behavioural avoidance of plants (Wertz & Wynn, 2014b; Włodarczyk et al., 2018), and exhibit behavioural avoidance and social referencing for plants and plant foods (Elsner & Wertz, 2019; Rioux & Wertz, 2021), indicating a reliance on social information. They also appear to selectively learn about plant edibility (Wertz & Wynn, 2014a). These findings, coupled with evolutionary models demonstrating how social learning of plants could evolve (Oña et al., 2019), suggest humans may have a domain-specific psychology, in which learning plays an important role, to deal with the problem of plant-based risks (see Wertz, 2019 for overview). The domain of plants provides a strong case study for the specialisation of cognitive systems and the present dissertation looks to develop this by examining further how our learning systems have been shaped to minimise risks faced in plant based food acquisition (Chapters 3 and 4), and testing for the first time whether our generalisation systems have been similarly shaped (Chapters 2 and 3).

2. What to Learn?

Despite the seeming importance of specialisation, the study of learning has been dominated by more general, associationist accounts of learning mechanisms. Associationist philosophies of mind have existed for centuries, with notable foundations in the work of British empiricists John Locke and David Hume. Fundamentally empiricist, in the crudest sense associationist philosophies of mind conceptualise the mind as associations between thoughts. Whilst associationist approaches to learning were transformed and advanced by the cognitive revolution (for analyses see Shanks, 2007, 2010), principles of associationism and behaviourism derived from the seminal works of Thorndike (1898), and Pavlov (1927) remain dominant, and underlie a lot of modern cognitive and computer science. For example, the popular Rescorla & Wagner (1972) instantiation of reinforcement learning is a staple across psychology, neuroscience and artificial intelligence. However, the classical notion of a domain-general learning system, that is to say one where the laws of learning apply equally to all manner of stimulus or responses, faces a number of issues and has been long challenged. Both theoretical and empirical evidence indicates the existence of selective learning mechanisms favouring learning that information which offers fitness advantages (Seligman 1970, Seligman 1972, Gallistel 1991). Indeed, in the scope of things one could learn in food acquisition, remembering that a particular berry is highly toxic may be more advantageous than remembering how juicy it is when one bites into it.

One issue any learning organism faces is this problem identifying what to learn. Out of the cacophony of observed interactions, associations, and experiences we face, our learning machinery must decide what is important. In the domain of language learning Chomsky (1986) put forward the *Poverty of The Stimulus* argument in favour of some degree of nativism in grammar learning— that is, that the structure of grammar is not entirely derived by experience (see also Berwick et al., 2011; Laurence & Margolis, 2020). He argued that given the amount of linguistic data available to children, and the different possible grammars compatible with that data, children being able to learn the correct grammatical structures without some pre-existing psychological structure is implausible. An evolutionary variation of this principle was proposed by Cosmides & Tooby (1994), who noted that the knowledge that a behaviour is (mal)adaptive might not be plausibly gained—and therefore not be learnable—within one lifetime. They illustrate and evidence this point by noting that the negative effects of incest are not visible in an individual's lifetime, one would require longitudinal and/or genetic data to see the consequences. This example has led to the proposal of specific psychological mechanisms for kin detection and disgust to avoid this problem (Borg et al., 2008; Lieberman et al., 2007), and speaks to the advantages and possible fitness benefits of domain specificity in cognitive mechanisms. However, the negative effects of incest have been consistent across species and evolutionary time and therefore provide a reliable environment in which a highly specialised response may adapt. This may not be the case in other domains, such as food. As noted above, plants do not possess reliable visual cues of toxicity, which is especially pertinent given the diversity of human ecologies—a visual cue that may be associated with toxicity in one environment might not be in another. In these diverse environments a cognitive system favouring efficient learning about such associations, rather than an innate response such as disgust, may prove more adaptive. Finally, Tooby & Cosmides (1992) make a related argument of a combinatorial explosion, noting that "with each new successive choice in a chain of decisions, the total number of alternative possibilities faced by a computational system grows with devastating rapidity" (pg. 102; see also Frankenhuis & Ploeger, 2007 for discussion). If one considers 'what to learn' as a decision problem, then this argument illustrates the difficulty in learning from all the possible outcomes and associations we experience in everyday life. Again one way that this problem can be reduced is by having specialisation in learning, that is, learning systems with specific sensitivity towards certain information to reduce the possibility space of things one learns.

In addition to the theoretical arguments noted above, empirical research has found evidence for specialised learning systems in a number of species and domains. Indeed, it has been argued that certain species have evolved to be 'prepared' to more easily learn about information pertinent to their evolutionary fitness (Seligman, 1970). Perhaps the most famous example of preparedness is Garcia & Koelling (1966)'s work on avoidance learning, part of a series of studies demonstrating that some stimuli are more readily associated with certain responses than others. Garcia & Koelling (1966) gave rats either a shock or induced nausea after eating from a food tube which had already been associated with an audio-visual stimulus. They found that rats would learn to associate the shock response with the audio-visual stimuli, but not the food tube, and the nausea would be associated with the food tube, but not the audio-visual stimuli. These findings indicate that, at least in rats, certain ecologically relevant associations (food causing nausea) are more easily learned. Another example of this specificity in learning has been observed by (Shettleworth, 1975) who found that food was effective as reinforcement for relevant behaviours (e.g., digging), but not for other behaviours (e.g., face washing) in Golden Hamsters. Again, it is not unreasonable to assume digging behaviours are more likely than face washing to lead to food sources in the wild. The existence of specialised learning mechanisms is further supported by evidence that selective associations such as those observed by Garcia & Koelling (1966) emerge even after substantial time delays between food stimulus and induced illness (Revusky, 1968), similar selectivity in the association between certain stimuli (e.g. snakes) and fear being shown in non-human animals and humans (Öhman & Mineka, 2001), and prepared learning for environmentally recurrent associations having been induced in lab populations of *Drosophilia* (Dunlap & Stephens, 2014). Finally, this evidence builds upon the theoretical arguments for specialisation in learning for certain information, suggesting that, at least in those domains and species mentioned, certain kinds of information are more readily learned or associated than others.

Specialisation for learning certain information is not the only way learning seems to be biased, learning systems also appear to be specialised for the use of socially transmitted information. Whilst individual learning is valuable, it can also be very costly. English satirist Jonathan Swift was not wrong when noting the bravery of the first man to eat an oyster. In the domain of food an organism has to deal with a potentially enormous volume of possible food candidates. For example, one single population of chimps was found to have eaten 117 parts of 100 species of plant (Yoshikawa & Ogawa, 2015), which would make learning about these, along with those plants that are not used, difficult for an individual to do by direct experience, and chimps have a vastly smaller ecological range than humans, who have resided on all continents. For this issue too, evolution seems to have made some headway. Humans like many other species are social, and as such we don't have to learn all this information through direct experience, we can also learn from our conspecifics. The ability to learn from others has been observed in a number of species (see Heyes, 1994 for review; see also below) and the human ability to learn socially has been argued to be a key driver of human success in varied environments (Boyd et al., 2011; Henrich, 2016). Indeed, it has been argued that human social and cultural learning facilitate a collective brain (Muthukrishna & Henrich, 2016), which allows an individual to learn, and build upon, knowledge they could not individually recreate in a single lifetime. An example of the value of social learning and reliance on culturally transmitted information is given by Boyd et al. (2011), who note the plight of the Franklin expedition, an incredibly well-equipped arctic expedition. The expedition became trapped and despite good expertise and equipment, everyone perished. They were trapped on King William Island, in Netsilik Inuit territory. The Netsilik had culturally endowed knowledge that allowed them to make use of the island's abundant resources for things such as food, navigation and clothing, practices which, despite having access to the same resources, the Franklin expedition were not able to master in their two years on the island. Later, a Norwegian expedition would also visit the island, this expedition sought out the Netsilik and successfully learned from them how to survive on the island. This example provides a good illustration of how a learning system specialised for social learning offers fitness benefits where or individual learning may not suffice. Indeed, evolutionary models have shown social learning to be valuable strategy when individual learning is costly (Feldman et al., 1996; Kendal et al., 2018).

One example of valuable social learning is the use of social danger cues, which has been observed in a number of species. American Crows have been shown to gather around dead conspecifics to learn about danger (Swift & Marzluff, 2015), and knowledge about dangerous humans has been shown to spread through Crows via social learning (Cornell et al., 2012). Social information has also been found to help Bumblebees locate safe foraging locations (Dawson & Chittka, 2014), and foraging innovations and lobtail feeding are socially transmitted in Humpback Whales (Allen et al., 2013). There is extensive further research on the roles of social influences on foraging and eating behaviours across different species (Galef & Giraldeau, 2001), including, rodents (Galef, 2012), birds (Slagsvold & Wiebe, 2011), non-human primates (Gustafsson et al., 2014; Rapaport & Brown, 2008; Schuppli et al., 2016; van de Waal et al., 2013), and also human children and infants (Hamlin & Wynn, 2012; Shutts et al., 2013). Such social learning, however, is not mutually exclusive with the selective (or prepared) learning outlined above. It has been proposed, based on evolutionary models, that social learning co-evolves with the aforementioned prepared learning in dangerous environments (Lindström et al., 2016). Moreover, it has been argued that selectivity in social learning for certain kinds of information, termed "content biases" are part of a broader suite of biases within social learning (Henrich & McElreath, 2003).

Evidence for selective social, or indirect, learning in humans can be found in the domain of fear, where human infants tend to selectively associate snakes with fear (DeLoache & LoBue, 2009). That this study was with American 9- month-old infants living in an urban environment is of note. This suggests that the selective association between snakes and fear may not be a function of prior experience, rather a reliably developing feature of human cognition. Another example of selectivity is in danger learning. It has been found that children in the USA, Ecuadorian Amazon, and Fiji all show preferential retention of danger information provided to them, in particular about animals (Barrett et al., 2016; Barrett & Broesch, 2012; Broesch et al., 2014), with Broesch et al. (2014) finding a similar effect for information about toxicity. The similar findings across ecologically distinct cultures provides good evidence for a reliably developing bias for learning about dangerous information about animals in children. Studies have also shown preferential retention of information pertinent to survival in adulthood (Nairne & Pandeirada, 2008, 2010; Stubbersfield et al., 2015), and for disgusting stimuli (Chapman et al., 2012; Fernandes et al., 2017; Moeck et al., 2021), with disgust being argued to be a disease avoidance mechanism (Oaten et al., 2009; Tybur et al., 2013). Recently work has looked at how selective learning may also be applied in the domain of plants and food learning (Barrett et al., 2016; Wertz & Wynn, 2014a). Wertz & Wynn (2014a) ran a number of studies with 6- and 18- month-old infants, and found that they would preferentially identify plants as a food source over non-plant controls, when both the plant and non-plant objects were presented with the same cues of edibility. This dissertation looks to replicate and extend this finding in 18- month-olds (Chapter 4), and will look to build upon the findings of Barrett, Broesch and colleagues by further testing whether the effect of increased danger learning is also present for plant based foods in adulthood, and examining whether there is also a learning advantage for edibility information (Chapter 3).

3. How to Generalise?

The evidence outlined above would indicate that humans and non-human animals have selectivity towards certain types of information in their learning systems—they are prepared to learn some things and make certain associations more readily than others. However, individual objects do not exist in a psychological vacuum, they are part of a broader lexicon of concepts and categories. When one learns a particular plant or fruit is dangerous that informs these broader categories. And, when one is deciding if a novel object is safe or dangerous, one can bring to bear their knowledge of an array of more or less similar things they have encountered previously. This poses the question however, of when, and to what extent to bring this knowledge to bear. The risky evolutionary puzzle of managing risks during food acquisition is not solved by learning a particular item is edible, or it is toxic. Indeed, if we have learned a red fruit is toxic, and come across a similar looking reddish fruit, should we assume this new fruit is toxic too? The present dissertation looks to examine whether, just as learning appears sensitive to the kind of information being learned, generalisation processes are sensitive to the type of information being generalised in order to minimize the risks of such calculations.

That humans organise knowledge into such categories and concepts is uncontroversial (Murphy, 2002). Categorisation has been shown according to a number of different domains such as colour (e.g. Franklin et al., 2005; Franklin & Davies, 2004; Pitchford & Mullen, 2010; Skelton et al., 2017) but also for domains which are not purely perceptual, such as food (DeJesus et al., 2018; Nguyen, 2020; Rioux et al., 2018), and animals. 9- month-old infants, for example can distinguish between animals and non-animals even when perceptually similar in shape (Mandler & McDonough, 1993). Moreover, categories are used to make inferences about novel items. Infants as young as 9- months can generalise properties based on the appearance of a single exemplar (Baldwin et al., 1993), and children as young as 3- 4-years can use non-perceptual properties to make inferences (Fisher & Sloutsky, 2005; Gelman, 1988; Gelman & Davidson, 2013; Gelman & Markman, 1986, 1987; Walker et al., 2014). Moreover, the cases of both colour and taxonomic categorisation offer examples of how the structure and boundaries of categories are culturally malleable (Atran & Atran, Scott, 1998; Skelton et al., 2017).

An underlying feature of many models of categorisation is similarity (Goldstone, 1994; Goldstone & Son, 2012; Kruschke, 2008; Sloutsky, 2003), and the role of similarity in how one generalises knowledge about one stimulus to another has been the subject of research for over a century (Ghirlanda & Enquist, 2003). This area encompasses a number of different problems of induction (for review see Kemp & Jern, 2014), but perhaps the field’s most influential finding is Shepard (1958)'s “Universal Law of Generalization". This posits generalisation to be a function of distance in an *n* dimensional feature space. Roughly put, the likelihood of generalising from object A to object B declines as B becomes less similar to A. Whilst these curves may vary across perceptual domains (Shepard, 1958), species (Ghirlanda

& Enquist, 2003), or after discrimination training (Hanson, 1959; Jenkins & Harrison, 1960), they appear to consistently follow a Gaussian curve around the original stimuli based on similarity (Ghirlanda & Enquist, 2003). That is, generalisation declines the farther away from the original stimuli one gets. As outlined above there appears to be sensitivity towards certain kinds of information in attention and learning (e.g., threat and danger). Yet, with the exception of .some classic evidence showing that an aversive shock is generalised more broadly than a food reward, in rats at least (Hearst, 1962; Murray & Miller, 1952, though see Hoffman & Fleshler, 1963 for the reverse pattern), whether human generalisation systems are also sensitive to certain kinds of information has received less attention.

In addition to these more content specific biases outlined above, a number of more broad biases have been observed which might influence generalisation systems. It has been noted humans appear to privilege negative information (Baumeister et al., 2001; Ito et al., 1998; Peeters & Czapinski, 1990; Rozin & Royzman, 2001; Vaish et al., 2008), and patterns of negativity bias have been observed in a number of areas and age groups such as in social evaluations by infants (Hamlin et al., 2010), the attribution of agency (Morewedge, 2009), and in the transmission of social information (Bebbington et al., 2017). Moreover, loss aversion, a tenet of Prospect Theory that posits decision makers weight prospective gains over losses, is a prominent example of such a negativity bias (Kahneman & Tversky, 1979; Novemsky & Kahneman, 2018; Tom et al., 2007). Not only has it been observed that not people loss averse, but that losses elicit a greater Autonomic Nervous System response than gains, even when loss aversion is not observed behaviourally (Hochman & Yechiam, 2011). It has also been proposed, contra to folk wisdom, that mental heuristics such as these are not erroneous or irrational mistakes in human cognition, rather they allow the mind to better handle uncertainty (Gigerenzer & Brighton, 2009). Under the auspices of Error-Management Theory (EMT), it has been argued that many biases may in fact be adaptive (Haselton et al., 2009; Haselton & Buss, 2000; Haselton & Nettle, 2006), and reflect the costs of making mistakes over evolutionary time.

EMT is a framework which applies principles of Signal Detection Theory (Peterson et al., 1954; Tanner & Swets, 1954) to the evolution of decision making processes, and is based upon minimising costly errors, even if this leads to an overall increase in the number of errors (Haselton & Buss, 2000; Haselton & Nettle, 2006). The smoke detector provides a good illustration of this (Johnson et al., 2013; Nesse, 2001, 2005). A smoke detector can make two types of error, it can trigger when there is no fire (a false positive), or it can not trigger when there is a fire (a false negative). In this example it is the latter that most people would agree is more costly, and as such would likely opt for a smoke detector that was over, rather than under sensitive. Haselton & Nettle (2006) have argued that these principles explain biases in domains such as food aversions, and responses to dangerous animals and people. We reason that EMT principles can also be applied to the problem noted above of when to generalise information, specifically as pertains to generalising information about edibility and toxicity. If you have learned a fruit is safe to eat and encounter a new similar fruit, you can decide whether or not to generalise this knowledge and consider the new fruit safe to eat. In this case, like with our smoke detector, there are two errors you can make, the costs of which are uneven. You might generalise and decide the new fruit is also safe when it is not, and get gravely ill. Or you could decide that it is not safe when in fact it is, and miss a meal. Conversely, if you have learned a particular red berry is toxic, and come across a similar looking reddish berry you could make the mistake of generalising when you should not, and avoid something which may otherwise have been valuable, or you may not generalise when in fact the item was toxic, and possibly ingest something toxic. In such cases Error Management principles would predict that generalisation systems might have evolved biases over time to avoid these more costly errors. The present dissertation will look to test this for the first time in humans, examining how generalisation differs for different kinds of information, specifically information about the edibility and toxicity of foods, and whether this reflects the asymmetry of the cost in the mistakes for these information types.

Whilst EMT suggests cognitive systems are shaped over evolutionary time to reflect recurring asymmetries in the costs of decision-making mistakes, such systems may also vary across individuals. Nesse (2001, 2005) has argued that what we may conceive of as mental illness (e.g., disordered anxiety) may in fact be the incorrect activations of what are otherwise functional systems. Indeed, one could conceive of heightened anxiety as an overactive defence mechanism, and some evidence supports this. A link between anxiety and sensitivity to threat is well established, with evidence suggesting heightened threat attention and perception (Sussman et al., 2016; Wieser & Keil, 2020). White et al. (2016) observed that higher anxiety participants had a lower threat threshold on a signal detection task, and Armstrong & Olatunji (2012), conducted a meta-analysis and found anxiety to be linked with greater visual threat vigilance in visual tasks. Similar findings have been found in regards to fear learning in non-humans with research showing that Rhesus Monkeys selectively associate fear with snakes and crocodiles but not flowers or rabbits (Cook & Mineka, 1989; Öhman & Mineka, 2003), and observed that Rhesus Monkeys show individual differences in their vicarious conditioning of fear responses (Nelson et al., 2003). In humans too there appears to be individual differences in fear responses, with a subset of the population (7.4%) developing specific phobias, a type of anxiety disorder, in their lifetime (Wardenaar et al., 2017). Machado-de-Sousa et al. (2010) reviewed over 40 research articles and observed that individuals with social anxiety appear to show a bias for negative emotions in facial processing. Similarly, Garner et al. (2006) found that individuals with high social anxiety recalled more negative social cues than those with low social anxiety. Moreover, Coles & Heimberg (2005) replicated earlier work by Lundh & Öst (1996) finding a response bias where participants with social phobia recognised more critical than accepting faces. Yet, Coles & Heimberg (2005) also note the mixed results in recall differences between those with social phobia and those without in studies that used linguistic as opposed to visual stimuli (see also Staugaard, 2010 for review of mixed effects of social anxiety on memory and attention), and in other phobia domains Sawchuk et al. (2002) found no response-bias between phobics and non-phobics, with all participants showing a bias towards surgical and disgust images. Finally, in addition to anxiety showing effects on threat sensitivity, personality has also been associated with risk perception and risk-taking behaviours (Chauvin et al., 2007). For example, Weller & Tikir (2011) found a significant effect of the anxiety-related emotionality subscale of the HEXACO personality inventory on perceived risk in the health domain, mediating an effect on risk taking behaviours, and it has also been observed that emotionality predicted perceived threat of Covid-19, indirectly influencing stockpiling behaviours (Garbe et al., 2020). Finally, in the food domain the food specific anxiety related trait of food neophobia—the aversion towards novel foods— has been linked with greater pathogen disgust sensitivity, and with germ aversion (Çınar et al., 2021).

As we outlined above, food acquisition is a risky business, and humans and animals alike seem to possess specialised learning systems to minimise these risks. Moreover, we have reasoned that generalisation systems, too, might be similarly specialised. Given that anxiety appears to be associated with risk minimising perception and behaviours in a number of domains, we also reason that anxiety might be associated with risk-minimising learning and generalisation too. In addition to testing how different information is learned and generalised, the present dissertation will also look to examine the influence of anxiety in learning and generalisation biases in the food domain.

4. The Present Thesis

This dissertation will replicate and build upon existing work demonstrating biases in learning for certain types of evolutionarily relevant information. Specifically, it looks to replicate and extend the finding by Wertz & Wynn (2014a) that infants selectively associate edibility with plants, and also to build upon findings showing a preferential learning of information about danger (e.g. Barrett et al., 2016) by examining further whether there is preferential learning for danger information for plant based foods, and testing if there is a learning advantage for edibility information for plant based foods. It will also investigate, based upon research demonstrating learning biases and principles of Error Management Theory (Haselton & Nettle, 2006), whether similar biases exist in generalisation of edibility and danger information about foods. Finally, given the links between anxiety and risk minimising behaviours, it will investigate the role of anxiety and related traits in these learning and generalisation biases.

In Chapter 2, we examine for the first time whether similar biases to those observed in learning are also present in generalisation, specifically whether certain kinds of information are generalised differently. Previous research has found preferential learning for information about danger (Barrett et al., 2016) in children, selective associations of plant edibility (Wertz & Wynn, 2014a) and fear associations (DeLoache & LoBue, 2009) in infants, along with learning biases for other survival relevant information (Nairne et al., 2009; Nairne & Pandeirada, 2008, 2010; Stubbersfield et al., 2015) and for the faces of cheaters (Mealey, 1996) in adults. Under Error Management Theory it has been argued that such biases may emerge over evolutionary time to reduce costly mistakes(e.g. Haselton & Nettle, 2006), we reason that this logic also applies to generalisation of survival relevant information in the food domain, where different mistakes in generalisation may be more or less costly (e.g.

spuriously generalising edibility to something inedible is perhaps more costly than generalising inedibility to something edible). Chapter 2 looks to test whether this is the case, and if generalisation is biased to reflect cost asymmetries in the generalisation of information about the edibility and dangers of foods.

Chapter 3 looks to develop this further. In Chapter 2 we find evidence that toxicity information is generalised at a rate above chance, and edibility at a rate lower than chance, but only under the highest level of uncertainty. Chapter 3 looks to investigate this further, testing generalisation using a different paradigm, and examining further the role of uncertainty in biased generalisation. Chapter 3 will also look to build upon work showing enhanced danger learning in children (Barrett et al., 2016), by examining whether adults show a learning bias for danger and edibility information about foods, as adults do appear to show attentional and learning biases for survival and threat relevant information (Mather & Knight, 2006; Nairne & Pandeirada, 2010; Stubbersfield et al., 2015; Waters et al., 2004). Moreover, given the evidence showing that anxiety and related traits are linked with threat perception (e.g. Garbe et al., 2020; White et al., 2016), we also look to test whether higher anxiety predicts greater learning and generalisation of edibility and toxicity information.

Finally, given the replication crisis facing psychological science (e.g. Camerer et al., 2018; Open Science Collaboration, 2015), and the relative novelty of this specific research area, in Chapter 4 we looked to replicate a finding from Wertz & Wynn (2014a) that 18-month-old infants would selectively learn about edibility for plant stimuli compared to non-plant stimuli. This was a pre-registered replication and initially planned to replicate and extend the study to examine whether disgust too was selectively associated with plant-foods. As we were not able to replicate this particular finding from Wertz & Wynn (2014a), though the finding with 6-month-olds has been replicated elsewhere (Rioux & Wertz, 2022), we did not extend the paradigm, rather ran a series of follow-up experiments with the aim of examining possible explanations for the non-replication.

4.1. Covid-19

The present dissertation originally planned to extend the work of Chapter 2 by testing generalisation of edibility and toxicity information in infants, which would have provided an examination of information type on generalisation across the lifespan. This project looked to examine whether infants preferentially generalised information about edibility and inedibility for plant based foods, also testing the relative roles of colour and shape on such generalisation. This project started data collection shortly before the Covid-19 pandemic, and as such was cancelled due to an inability to collect infant data during this time. Similarly, in addition to those reported, additional follow-up experiments were planned to investigate reasons for the non-replication reported Chapter 4, these are outlined in Chapter 4. However, these too were prevented by testing limitations imposed during the Covid-19 pandemic.

5. References

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Chapter 2: Managing Costly Generalisation Errors in the Food Domain

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Abstract

A bias towards certain kinds of information such as danger, has been observed in a number of domains, for instance learning and attention. Under Error Management Theory (EMT) it has been argued that these biases reflect the costs of making mistakes with this kind of information (Haselton & Nettle, 2006). Based on EMT principles we reasoned that such biases may also exist in generalisation, specifically for information where generalisation mistakes are costly (edibility and toxicity information). Experiment 1 tested this in adults (N = 88), and found that participants generalised toxicity information more, and edibility information less than control information. Experiment 2 tested this in 4- to 5-year-olds (N = 91) and did not find the same pattern, but observed the only effect of information type being in those children scoring high on food neophobia. In Experiment 3 results from Exp. 1 were compared with an additional categorisation condition (N = 30) for the same stimuli, and a different pattern was observed for categorisation compared to generalisation, indicating that participants were not relying primarily on category-based generalisation. Finally, Experiment 4 looked to test whether the findings of Exp. 1 are a function of negativity and positivity effects more broadly, and tested negative and positive information without the same direct costs to an individual (polluting and sustainability information). We found some indication of a broad negativity/positivity effect in generalisation, though this appears less strong than in Exp. 1, indicating a negativity bias effect cannot fully account for these results.

1. Introduction

Inductive inference, or generalisation of the known to the unknown, is a critical component of human cognition (Feeney & Heit, 2007; Murphy, 2002). It enables us to apply learned knowledge to make predictions about novel situations or objects. However, making inductive inferences is not error-free and some mistakes may be more costly than others. Consider the problem of identifying which foods are safe to eat, particularly for an omnivorous species like humans, who need to gather a wide variety of foods to ensure nutritional health while avoid ingesting something harmful (Drewnowski et al., 1997; Rozin & Todd, 2015; van Duyn & Pivonka, 2000). When confronted with a novel food candidate, an individual must decide whether or not it is edible based on their knowledge of edible foods in the environment. Food items of the same type may vary visually (e.g., ripening fruits), and different types of foods may look remarkably similar (e.g., edible redcurrants and toxic holly berries). This means that when one encounters a novel food candidate there is a degree of categorical uncertainty and, importantly, the consequences of making errors in generalisation are not uniform. For example, erroneously choosing to eat a novel fruit that is in fact toxic is generally more costly than erroneously choosing to forgo a novel fruit that is in fact edible. This asymmetry of errors is a core tenet of Error Management Theory (EMT; Haselton & Buss, 2000; Haselton & Nettle, 2006; Johnson et al., 2013) and here we explore the effects of this asymmetry on generalisation decisions in the food domain.

Generalisation is a complex process, and a number of factors may influence whether or not one generalises. Research on inductive inference has demonstrated that similarity is a key factor at play when deciding whether to generalise a specific property from a known exemplar to a novel item(Gelman & Markman, 1987; Murphy, 2002; Sloutsky & Fisher, 2004b). More formally, it has been argued that generalisation is a declining function of similarity, with generalisation declining as a novel item becomes less like a known exemplar (Shepard, 1958; Sloutsky, 2003). The ability to extrapolate known knowledge to novel items develops early in ontogeny, with infants as young as 9 months of age generalising nonobvious properties to novel items based on the visual appearance of a single known exemplar (Baldwin et al., 1993a; Welder et al., 2016). In certain domains, some features seem to be more important than others in judging to what extent two items are similar. For instance, in the food domain, colour similarity seems to play a key role in both children's and adults' decisions to generalise a property to a novel item (Lavin & Hall, 2002; Macario, 1991; Rumiati & Foroni, 2016, but see Rioux et al., 2018 for the importance of shape similarity as well), while shape similarity seems to be more important in the artefact domain (Landau et al., 1998; Welder et al., 2016).

Whilst the role of perceptual similarity appears clear, it has also been argued that category membership plays an important role in generalisation. Category-based induction is observed early in life, for example, 4-year-old children generalise a known property of an owl to a flamingo because both are from the same category “bird” (Gelman & Markman, 1986, 1987; Mandler & McDonough, 1993). Categorisation appears to develop as early in ontogeny as 3 months (Ferry et al., 2010; Quinn et al., 1993), young children are able to flexibly deploy different types of categories in the food domain (e.g., script, taxonomic and evaluative categories;Nguyen, 2020; Nguyen & Murphy, 2003), and selectively generalise a property depending of its type (e.g., incidental, functional or biological; Gelman, 1988; Nguyen, 2012; Thibaut et al., 2016). However, how such inductive processes function under categorical uncertainty—that is, when the category membership of the novel item is unclear—has received far less attention, with a few notable exceptions (Chen et al., 2014; Hayes et al., 2008; Hayes & Newell, 2009). Moreover, the question of whether humans engage in selective generalisation based on the type of information—that is, whether they generalise knowledge from known to novel instances differently depending on the content of that knowledge—does not appear to have been studied. In some areas, errors in generalisation decisions may have asymmetric costs. For example, incorrectly generalising edibility to something toxic is more costly than incorrectly generalising toxicity to something edible. In line with Error Management Theory (EMT; Haselton & Buss, 2000; Haselton & Nettle, 2006) when there are asymmetries in the costs of generalisation errors, one might expect to see selective generalisation of information. EMT posits that when the costs of false-positives (e.g., needlessly forgoing an edible fruit) and false-negatives (e.g., inadvertently eating a toxic fruit) have been asymmetric over phylogeny, cognitive systems should have arisen that reduce the rate of costly errors. These kinds of systems can evolve even if reducing costly errors results in more errors overall (e.g., one might prefer a smoke alarm that has greater sensitivity, and thus a greater number of overall errors, but reduced probability of a highly costly false-negative; Nesse, 2005).

It is not yet clear whether humans engage in selective generalisation depending on the type of information, but a growing body of evidence suggests that content selectivity is present in another crucial component of human cognition—learning (e.g., Barrett et al., 2016; Barrett & Broesch, 2012; Broesch et al., 2014; DeLoache & LoBue, 2009; Wertz & Wynn, 2019; Wertz & Wynn, 2014a). In fact, decades of evidence suggests that several species have selective learning mechanisms, such that certain evolutionarily relevant information and associations are learned more readily (e.g., Öhman & Mineka, 2001; Seligman, 1970; Seligman, 1971). Given the broad possibility space of what one could learn in any given environment, such selective learning systems could facilitate the learning of information most relevant to successful survival and reproduction. Indeed, evidence from experiments with fruit flies and computational models have shown environments in which preparedness can develop (Dunlap & Stephens, 2014; Lindström et al., 2016). In their seminal example of preparedness in animal learning, Garcia & Koelling (1966) demonstrated that rats learned to associate ingestion of a novel food with the experience of nausea in a single trial, but not with the experience of bright lights or novel sounds, even after many trials. These findings indicate that, at least in rats, certain ecologically recurrent associations (food causing nausea) are more easily learned. Similarly, monkeys have been shown to learn fear responses to snakes more readily than other non-dangerous stimuli like flowers (see Öhman & Mineka, 2001, 2003, for reviews).

Evidence for selective learning of different types of fitness-relevant information has also been found in humans. Human infants tend to selectively associate snakes, but not flowers or inoffensive animals such as frogs, with fear (DeLoache & LoBue, 2009; see LoBue & Rakison, 2013 for a review). Adults also appear to show preferential learning of fear associations for snakes and spiders (see Öhman & Mineka, 2001 for a review), including reduced habituation (Öhman et al., 1974) and non-conscious conditioning to fear-relevant but not fear-irrelevant stimuli (Öhman & Soares, 1998). Moreover, infants selectively associate edibility with plants compared to non-plants (Wertz & Wynn, 2014a). Children also appear to show preferential learning of danger information about animals, and their performance is similar across cultures(Barrett & Broesch, 2012). For example, children from Los Angeles, USA and from Indigenous Shuar communities in the Ecuadorian Amazon showed heightened recall of information about dangerous animals, compared to danger information about other stimuli (foods, artefacts), and other information (location, feature), and this advantage persisted with only minor attenuation a week later (Barrett et al., 2016). This preferential memory for danger information appears to reduce with age and is not present in adulthood (Broesch et al., 2014), suggesting differences across the lifespan in selective learning.

Given this evidence demonstrating that learning appears to be selective towards evolutionarily relevant information, the present study looks to examine whether this extends to how that information is used. That is, is there a selectivity in inductive inferences of evolutionarily relevant information? Specifically, we aimed to investigate how the type of information learned influences the generalisation of that information to novel stimuli, notably when the category membership of the novel stimulus is uncertain. Whilst the effect of information type on the degree of generalisation in humans has not been tested, some limited evidence suggests people do pay attention to such information type when generalising (Zhu & Murphy, 2013), and it has been found that rats would generalise a shock more broadly than a food reward (Hearst, 1962; Murray & Miller, 1952, though see Hoffman & Fleshler, 1963 for the opposite pattern), demonstrating, in rats at least, that generalisation is sensitive to what is being generalised. Our predictions were based on Error Management Theory, which, as outlined above, posits that selectivity in cognitive processes arises when there is an asymmetry in the cost of errors (Haselton et al., 2005; Haselton & Buss, 2000; Haselton & Nettle, 2006; Johnson et al., 2013). As a first step, we chose to examine selective generalisation about candidate food items. Decisions about what can (or cannot) be eaten are highly fitness-relevant and a single error when deciding whether or not to consume a novel food candidate can lead to severe negative consequences (e.g., poisoning; Hagen et al., 2009; Mithöfer & Boland, 2012). Importantly, the costs of different types of errors are asymmetric. Specifically, if you learn a food item is toxic you can make two generalisation errors: (1) you can incorrectly generalise this danger to another candidate food item that is in fact not dangerous (false-positive), or (2) you can fail to generalise this danger to another candidate food item that is in fact toxic (false-negative). The cost of the false-positive might be a missed dinner, but the cost of a false negative might be one’s life or a serious illness due to poisoning. Therefore, we predicted that participants would exhibit different generalisation patterns when presented with an ambiguous candidate food item depending on the type of information being generalised. In the present research we tested the generalisation of information about a candidate food's edibility or toxicity. Specifically, we predicted that, to avoid costly errors, humans will generalise toxicity information more broadly and edibility information more narrowly than neutral information.

To examine the effect of differing information on generalisation we tested adults and children in a series of four experiments. Participants performed a classical induction task in which they were asked questions about a series of 20 image triads (after e.g.,Gelman & Markman, 1986) of different fruits. Each triad consisted of two target images at the top and the test image below. Each test image was one stage of a five-stage transformation between the two target images (see Figure 1). Participants were told that one of the target images had a property (e.g., “This is edible”) and the other did not (e.g., “This is *not* edible”), and then were asked whether the test image also had that property (e.g., to select “This is edible" or "This is not edible”). Adults (Experiment 1) and children (Experiment 2) were asked to generalise three types of properties (across three independent conditions), edibility (positive condition), toxicity (negative condition) or seasonality (neutral condition). In these experiments, we predicted different generalisation patterns for edibility and toxicity information relative to neutral or control information. Specifically, we predicted that, to avoid costly errors, humans will generalise toxicity information more broadly and edibility information more narrowly than neutral information. We tested both children and adults in Experiments 1 and 2 as previous literature on content-specific learning mechanisms has revealed differences across the lifespan and mixed evidence in adult populations (e.g., Broesch et al., 2014; Öhman & Mineka, 2001). For the child age-group, we chose 4- to 5-year-olds because previous studies found that by this age children already selectively generalise properties based on their type (Gelman, 1988; Nguyen, 2012; Thibaut et al., 2016), and can use both visual similarity and category membership in inductive inference (Gelman & Davidson, 2013).

We ran two additional experiments to examine the role of categorisation (Experiment 3) and the possible effect of broader negativity or positivity biases (Experiment 4) in selective generalisation processes. In Experiment 3, adults were asked to categorise the same stimuli used in Experiments 1 and 2 based on name labels (e.g., "This is a Daxon/Sudeb") in order to measure their category membership judgements. This allowed us to examine whether participants form categories that guide their generalisation decisions or if they rely on similarity judgements alone. Finally, to test whether any effects of edibility or toxicity are a function of broader negativity or positivity biases, Experiment 4 looked the effects of negative and positive information more broadly on generalisation. In this experiment adults were asked to generalise three different properties (sustainability, polluting, storage instructions), similar in valence to those used in Experiment 1 (edibility, toxicity, season of growth), but which are not fitness-relevant properties and do not offer the same asymmetric costs and benefits as edibility and toxicity judgements.

2. Experiment 1

Experiment 1 examines whether type of information one learns about a stimulus influences how that information is generalised to similar stimuli. As outlined in more detail above, human learning systems seem to be particularly sensitive to information about danger (Barrett et al., 2016; Barrett & Broesch, 2012; Broesch et al., 2014; DeLoache & LoBue, 2009; LoBue et al., 2010; LoBue & DeLoache, 2008; New & German, 2015). In particular, it has been argued that biases in learning systems may reflect asymmetries in the costs of making errors about dangerous stimuli over evolutionary time (Haselton & Nettle, 2006). We reasoned that the selection pressures which give rise to these specialized learning systems may also have led to specialization in generalisation. We examined this in the domain of food because of the important role they play in human sustenance, the many risks they pose (Belovsky & Schmitz, 2006; Hagen et al., 2009; Hanley et al., 2007; Keeler & Tu, 1983; Manners, 1996; Mithöfer & Boland, 2012; Wertz, 2019), and an apparent psychological sensitivity to information about this domain (Barrett et al., 2016; Krasnow et al., 2011; Wertz, 2019; Wertz & Wynn, 2019; Wertz & Wynn, 2014b, 2014a). Given the asymmetry in costs in generalisation, mistakes in these domains (i.e., generalising edibility to something toxic vs. generalising toxicity to something edible), we predicted that information about danger (i.e., toxicity) would be generalised more broadly, and information about edibility less broadly than neutral information. For the neutral seasonality information (whether the item grows in summer or not) was selected as a piece of information consistent with the domain of food that does not necessarily have the same cost of generalisation errors.

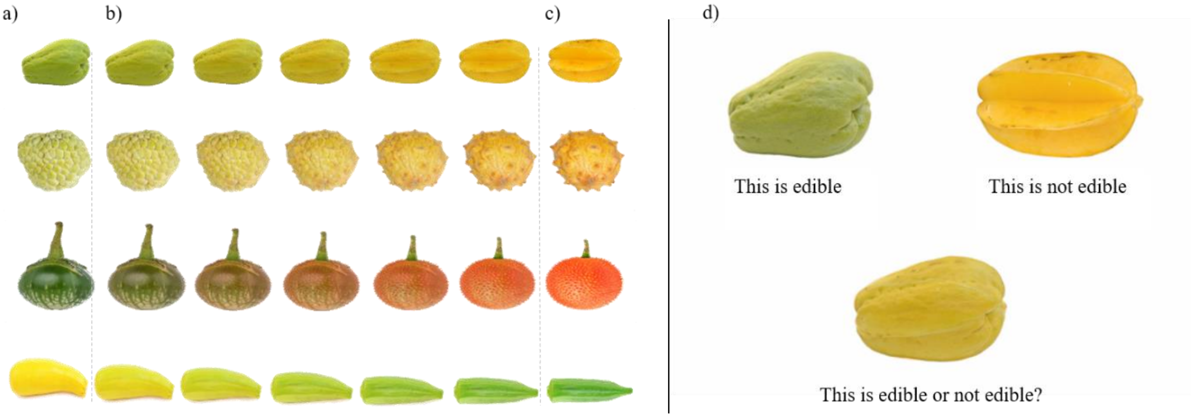
2.1. Method

Participants were 88 adults (43 females, 25 males, mean age = 33 years, range = 17 – 64, due to an error in the demographic survey 21 participants did not provide demographic information), divided evenly across three independent information conditions (edibility, toxicity, and seasonality), who were recruited via the online *Prolific.ac* platform. Data from two participants (in the edibility condition) were excluded for meeting our a priori exclusion criteria of giving the same response to at least 19 out of 20 questions (e.g. stating for 19 of 20 items “This is edible” for those in the edibility condition). Adult participation was restricted to those based in the United Kingdom and United States in order to limit the geographical range and thereby familiarity with the fruits from other regions that were used in the study. The study was approved by a local ethics committee and participants were compensated with 2.5 GBP (rate of 10 GBP/ hour).

The materials for the study included four image pairs of real fruits, and a spectrum of five morphs between each pair, created with *Abrosoft: Fanatmorph* software version 5.4.8. We chose images of fruits that are not typically found in the UK and the US to ensure participants did not draw on prior knowledge to answer the task. There were originally nine different pairs of real fruit images and their respective morphs, which were piloted online with 30 English and American adults. The final four image pairs selected were those adults in the pilot rated least familiar and that had the most consistent similarity gradients across the morph sequence (i.e., the difference between morphs one and two were rated similarly to the difference between four and five, see Supplemental Material section 1.1). In addition, we chose this food category because fruits in their raw state can either be edible and nutritious, or they may contain secondary toxic components harmful to humans (e.g., Mithöfer & Boland, 2012). The morph sequences are shown in Figure 1 (left panel). The original images of the real fruits are shown at each end, and the five stages of the objects morphing into one another between. The morphs are at approximate degrees of similarity to the left real fruit picture of 83%, 67%, 50%, 33% and 17% (e.g., first row: a guava fruit transformed into a star fruit).

Image triads were created using *Affinity: Photo* software version 1.7.2.471, by presenting a final image pair at the top of the card (target pictures) alongside one level of their respective image morphs at the bottom of the card (test picture). This resulted in 20 triads (five morphs for each of the four pairs; see Fig. 1, right panel). The image triads were presented with the relevant information noted in text below each image. In each triad, one target had a property (the left top picture) and the other did not (the right top picture). Depending on the condition this was ``This is edible” / “This is not edible" (edibility condition, see Fig. 1 right panel), ``This is toxic” / “This is not toxic" (toxicity condition), or ``This grows in summer” / “This does not grow in summer" (seasonality condition). Which fruit of each pair was on the left varied across participants, with the item on the left always having the property; therefore, the fruit-property correspondence was counterbalanced across participants. The different pictures were never named, but referred to only as “this” to keep category membership ambiguous.

Figure 1. Stimuli used in all experiments. Left Panel depicts the four morph sequences, with (a) and (c) showing the original images and (b) showing the five-point morph sequence between each pair. Right Panel (d) depicts an example trial from the edibility condition; the images on the top of the triad are from (a) and (c) and the image on the bottom is from (b).



Participants completed the study online through the browser-based *Qualtrics* platform. To ensure relative parity across participants, participation was only possible on desktop browsers—not mobile phones or tablets. After reviewing the study information, and providing consent for participation and the use and storage of their data, participants were presented with the 20 image triads. The triads were presented in a pseudo-random, counterbalanced order such that no two triads from the same fruit pair would be presented back-to-back. This was done to prevent direct comparison between two morphs from the same morph sequence. For each of the 20 triads we recorded whether participants generalised the property to the test picture (morph picture) by asking explicitly whether the test picture had the property or not (see Fig. 1 right panel). A score of 1 was given when participants generalised the property to the test picture and a score 0 when they did not.

2.2. Results and Discussion

Statistical analyses were conducted using R 3. 6.1 (R Core Team, 2019), with main analyses completed using the lme4 package. Data and R scripts are available on the Open Science Framework page for this project: https://osf.io/smcy7/?view_only=7b12be167f484d5b8e3c626680f21fde.

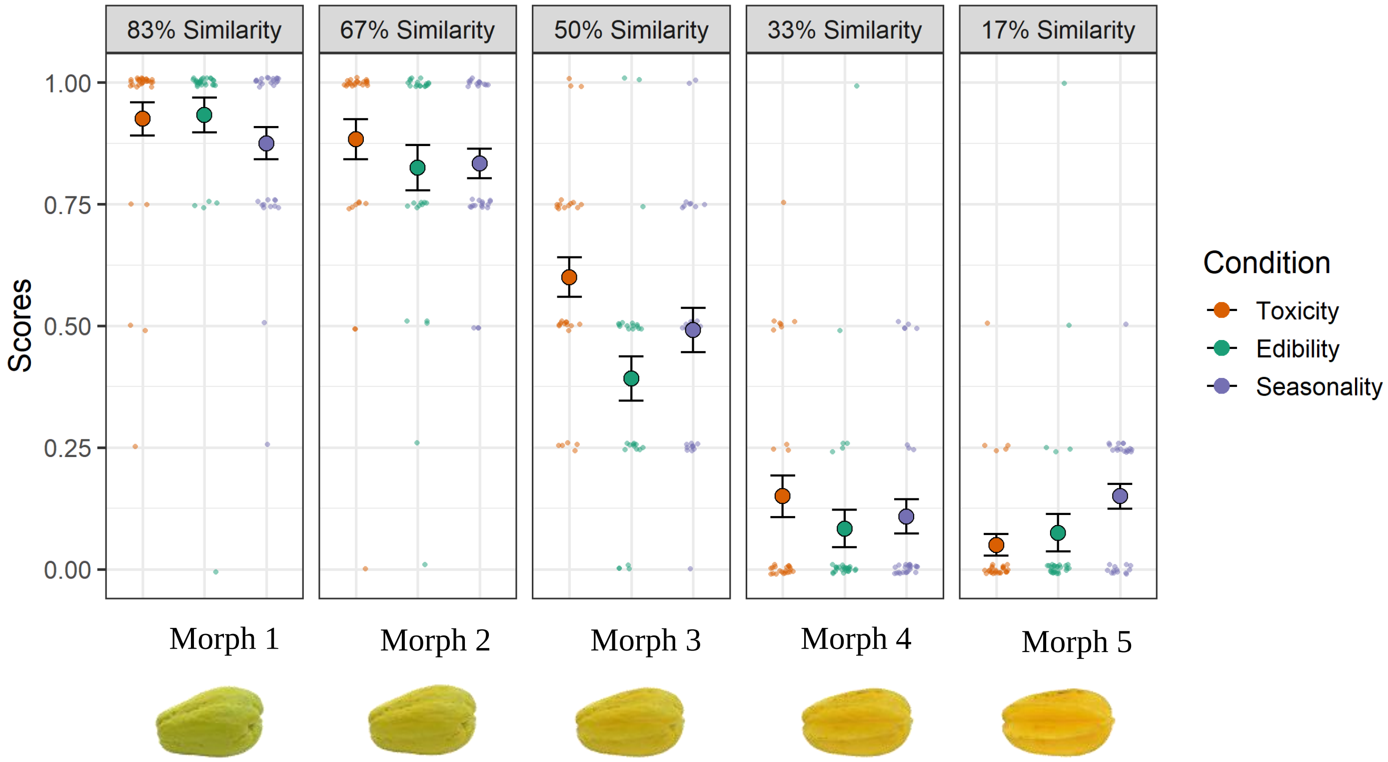
A Binomial generalised linear mixed effect model (GLMM) with a logit link function was used to assess generalisation patterns across the 20 triads. Preliminary analysis found no improved model fit of different image pairs modelled as a random factor in the model. We also found no improved fit including sex and age as fixed factors in the model. Therefore, these variables were left out for further analysis. In the main analysis both participants and individual triads served as a random factor to account for shared variances within subjects and inter-triad variability. Similarity between the target picture that had the property and the test picture (83%, 67%, 50%, 33% and 17%), Condition (edibility, toxicity and seasonality information), as well as their interaction were modelled as fixed effects. The best fit model was selected according to Akaike's Information Criterion and was the full model including the main effects and the interaction between Similarity and Condition ($\chi 2$ (2) = 18.51, $p < 0.001$, marginal R2 = 0.57, conditional R2 = 0.63).

In line with previous findings (Gelman & Markman, 1987; Sloutsky & Fisher, 2004b), effect of Similarity between the target picture that had the property and the test picture was significant (χ^2 (1) = 131.87, $p < 0.001$, see Table S4 in the SM section 2.1), with likelihood of property generalisation decreasing with similarity (see Fig. 2). This supports the established finding that similarity effects generalisation (e.g., Feeney & Heit, 2007; Murphy, 2002; Shepard, 1958; Sloutsky, 2003) and demonstrates our stimuli to successfully elicit this effect. As predicted, we also found a main effect of Condition (χ^2 (2) = 6.65, $p = 0.036$, see

Table S4 in the SM) which was qualified by the interaction effect of Similarity*Condition (χ^2 (2) = 18.13, p < 0.001, see Fig. 2, see Table S4 in the SM), with the decrease of property generalisation with similarity in the seasonality condition being significantly steeper than in the edibility ($z = 4.04$, p < 0.001) and toxicity conditions ($z = 2.60$, p = 0.025).

To examine the interaction further we looked at generalisation rates at each point of our morph sequence (i.e., each level of similarity). This was done using Fisher's Exact Tests. Multiple comparisons were controlled for using the Bonferroni-Holm correction within each similarity level. In the *least* ambiguous morphs, we found a significant pairwise difference between the edibility and seasonality conditions (morph 1 (the most similar), p = 0.048, morph 5 (least similar), p = 0.024), with participants generalising edibility information at a higher rate in morph 1 and at a lower rate in morph 5 (see Fig. 2). For morph 5, a significant difference was also observed between the toxicity and seasonality conditions (p = 0.033), with participants generalising toxicity information at a lower rate (see Fig. 2). Finally, with the *most* ambiguous morph—morph 3, the halfway point in the morph sequence between the two original real food images (i.e., when similarity between the target that had the property and the test picture was 50%)— we found a significant pairwise difference between the edibility and toxicity conditions (morph 3, p = 0.003), with participants generalising toxicity information at a higher rate (see Fig. 2). As predicted, participants were more likely to generalise toxicity and less likely to generalise edibility to an ambiguous food candidate, yet this appears to only be the case in situations with greater uncertainty. That is, when told one item is toxic and another is not toxic, and then presented with a test item that is 50% similar to both, participants judge this item to be toxic at a rate significantly greater than chance (binomial P = 0.60 [95% CI: 0.51 – 0.69], p = 0.035). In the case of edibility, we see the opposite pattern, participants state this item to be edible at a rate significantly below chance (binomial P = 0.38 [95% CI: 0.29 – 0.48], p = .017), and in the neutral condition participants stated the item grew in summer at a rate no different from chance (binomial P = 0.49 [95% CI: 0.40 – 0.58], p = 0.93).

Figure 2: Generalisation scores in Experiment 1 at each point of the morph sequence (i.e., each level of Similarity), depending of Condition. Large dots show group means with 95% CI error bars, smaller dots show individual participant means. Morph images from an example triad after Fig. 1, the real green fruit has the property



Finally, in order to examine participants' response stability, we analysed participants' response patterns across the different stimulus pairs. More than 90% participants exhibited a stable strategy (responding the same for 3 of the 4 image pairs) for the 4 least ambiguous morphs, but only 63% exhibited a stable strategy for the most ambiguous morph indicating greater choice uncertainty at this level of similarity (see SM Section 2.2 for details).

The results of Experiment 1 support the hypothesis that adults use selective generalisation strategies. Specifically, as predicted, adults overgeneralised toxicity information and undergeneralised edibility information, relative to a neutral information.

Notably, our findings suggest that such selective generalisation strategies are deployed in situations with greater uncertainty. Participants generalised differently across the information conditions only for the most ambiguous morph.

3. Experiment 2

Previous studies have demonstrated selective learning mechanisms for information about danger and edibility (Barrett et al., 2016; Barrett & Broesch, 2012; Wertz & Wynn, 2014a). In Experiment 1 we observed similar selectivity in generalisation, with toxicity (i.e., danger) information being generalised more broadly, and edibility more narrowly, than neutral information. However, the literature on specialized learning for danger information has revealed differences across the lifespan, with this effect diminishing with age and not being present in adulthood (Broesch et al., 2014). Further, induction abilities develop early in ontogeny with developmental changes (Baldwin et al., 1993; Gelman & Markman, 1986; Welder et al., 2016). Therefore, we aimed to examine whether there were developmental differences in the type of selective generalisation we found in Experiment 1. To examine if selective generalisation based on information type (toxicity, edibility) is also present early in life, and to compare any effect with that found in adults, we ran an adapted version of the task from Experiment 1 with preschool age children.

3.1. Method

Participants were 91 preschoolers between 4 and 5 years old (41 female, 50 male, mean age = 4 years, 11-months, range = 4 years, 0 months – 5 years, 11 months), divided evenly across three independent information conditions (edibility, toxicity, and seasonality). Children were recruited and tested at kindergartens, museums, or a research lab in or around

Berlin, Germany. Due to the 2020 Covid-19 pandemic, in-person data collection had to conclude prematurely and the final 14 children were tested online with stimuli presented via video chat with the software *WebEx*. These children were recruited from the institution's participant database. Participants were compensated with a participation certificate. Data from 26 participants were excluded for meeting the a priori exclusion criteria of giving the same response to at least 19 out of 20 questions, missing 5 successive answers, failing the initial task example trials, or failing to complete the session due to inattentiveness. This study was reviewed and accepted by a local ethics committee. Written parental consent was obtained prior to testing, and children were first asked by the experimenter if they wanted to play a game. Upon providing verbal consent, the children who were tested in person sat at a table across from the experimenters in a quiet area. Two experimenters were present, one who ran the task, and the other who recorded the child’s responses. The in-person testing sessions were also filmed to allow checking of any discrepancies or missing reporting from the live sessions

The study began with a cover story, where the participant was told that they will be shown some foods from an alien planet and they will help sort them. Then, in a warm-up phase, children were presented with two practice trials. In these practice trials, children were shown triads of fruit images, like those used in the test phase, with two images at the top. Participants were told that one of the two images at the top had a property (the property differed depending on condition – see next paragraph for details) and asked whether the third image had the property or not. However, in the practice trials, the image at the bottom of the triad was identical to one of the two above so there was a clear *correct* and *incorrect* answer, which enabled us to assess children's understanding of the task. Data for participants who did not exhibit understanding in this phase was not included in the analysis.

For the test phase, children were presented with the 20 test triads (similar to Experiment 1). The experimenter showed the child the card and pointed at each of the two target images at the top of the triad and said whether it had or did not have a particular property. We used the same three properties as in Experiment 1: edibility, toxicity, and seasonality. The wording was adapted to be appropriate for preschool-aged children and the testing was conducted in German. In the edibility condition children were told "*Look! This is edible*" [German: "*Schau mal! Das hier ist essbar*"]. In the toxicity condition, "*Look! This is toxic*" [German: " *Schau mal! Das hier ist giftig*"] and in the seasonality condition "*Look! This grows in summer*" [German: " *Schau mal!Das hier wächst im Sommer*"]. For example, a participant in the edibility condition was shown an image triad, the experimenter pointed to one target image and said "Look! This is edible" [German: "*Schau mal! Das hier ist essbar*"], then pointed to the other and said "Look! This is not edible" [German: "*Das hier ist nicht essbar*"], and then asked the child if the test picture at the bottom was edible like the first target, or not edible like the second “Now it’s your turn! Do you think this {pointing to the third picture} is edible like this {pointing to edible picture} or not edible like this {pointing to the not edible picture}? [German: *Jetzt bist du dran! Glaubst du das hier* {pointing to the third picture*} ist essbar wie das hier* {pointing to edible picture} *oder nicht essbar wie das hier* {pointing to not-edible picture}? In the online version of the task, participants saw the triads presented on shared PowerPoint slides, alongside a video stream of the experimenter, and the experimenter gestured to the foods with a red cursor.

In order to examine possible individual differences parents were also given a German translation of the Children Food Rejection Score (CFRS) questionnaire developed by Rioux et al. (2017) because previous work has shown that food rejection behaviours influence generalisation in the food domain (Rioux et al., 2018). Parents were also given a questionnaire about their child's familiarity with the fruits used in the present experiment and their answers confirmed that the fruits were unfamiliar to children (on average they already saw or ate only 1 fruit out of 8).

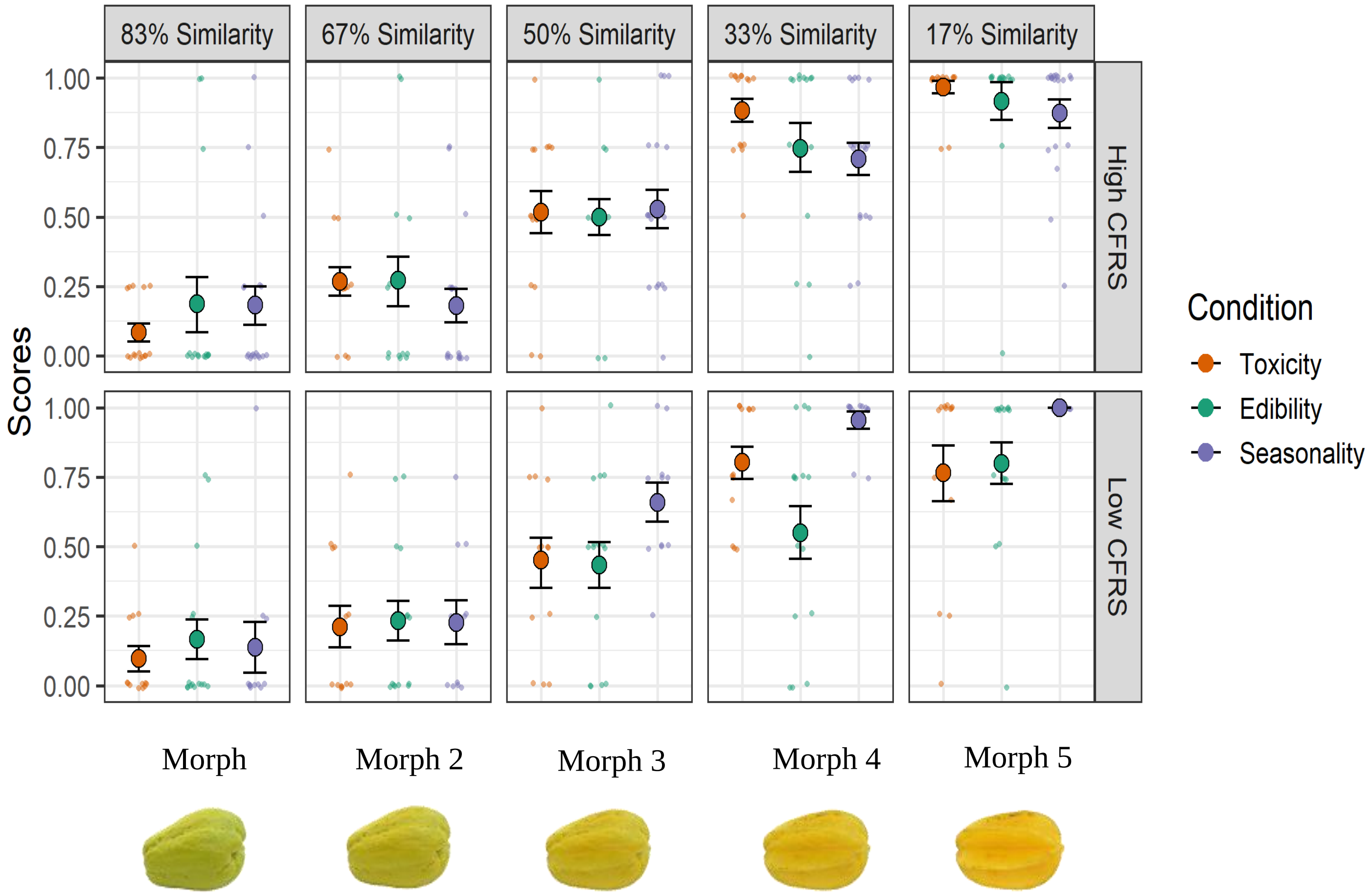
3.2. Results and Discussion

As with Experiment 1, the results from Experiment 2 were analysed using a Binomial GLMM with a logit link function. We found no improved model fit of including image pair, age or sex in the model. Due to the variation in testing location, we also included testing location as a random factor and found no improved model fit, and as such all these variables were excluded from further analysis. In order to examine the effect of neophobia we divided children into two groups—High-CFRS and Low-CFRS—using the average CFRS scores as the cut-off point (M = 35.72, SD = 5.94; no CFRS mean difference across experimental conditions). In the main analysis, Participant and Individual Triads served as random factors. Similarity between the left target picture and the test picture (83%, 67%, 50%, 33% and 17%), Condition (label, neutral property), CFRS group (High, Low) as well as their interaction were modelled as fixed effects. The best fit model was the full model according to Akaike's Information Criterion ($\chi^2(11) = 103.07$, $p < 0.001$, marginal $R^2 = 0.46$, conditional $R^2 = 0.55$).

As in Experiment 1, and concurrent with previous research (e.g., Murphy, 2002; Shepard, 1958b; Sloutsky, 2003), we found a significant effect of Similarity (χ^2 (1) = 304.27, $p < 0.001$, see Fig. 3, see Table S5 in the SM section 2.1), demonstrating that as with adults, the likelihood of property generalisation is decreasing with similarity. We also found a significant Similarity*Condition interaction (χ^2 (2) = 6.32, $p = 0.042$, see Table S5 in the SM), which was qualified by a significant three-way interaction between Similarity*Condition*CFRS group (χ^2 (2) = 17.66, $p < 0.001$, see Fig. 3, see Table S5 in the SM). In the High-CFRS group, the decrease of property generalisation with similarity in the seasonality condition was significantly steeper than in the toxicity condition ($z = 2.59$, $p = 0.046$). In the Low-CFRS group, the decrease of property generalisation with similarity in the seasonality condition was significantly more gradual than in the toxicity ($z = 4.02$, $p < 0.001$) and edibility conditions ($z = 3.56$, $p = 0.0020$).

As with the analysis of Experiment 1, we also conducted Fisher's Exact Tests to examine the 3-way interaction further. Specifically, in both CFRS groups we looked at generalisation rates at each point of our morph sequence, depending on the condition. The only significant differences were found in the two most similar morphs (i.e., morphs 1 and 2, see Fig. 3), with children high in food rejection scores (High CFRS group) generalising toxicity information at a higher rate overall, while children low in food rejection scores (Low CFRS group) generalised seasonality information at a higher rate overall (See SM section 2.3 for further details). Therefore, the three-way interaction noted above seems to be driven by the effect of information type for the morphs most similar to the target.

Figure 3: Generalisation scores in Experiment 2, at each point of the morph sequence (i.e., each level of similarity), depending on Condition and CFRS group. Large dots show group means with 95% CI error bars, smaller dots show individual participant means (minimally jittered for clarity). Example morph sequence for example triad after Fig. 1, where the real green fruit has the property.



The results of Experiment 2 do not provide strong evidence that children use selective generalisation strategies consistent with minimizing costly errors. Whilst an effect of condition and similarity was observed, it did not follow the prediction of broader generalisation of toxicity information and narrower generalisation of edibility information relative to neutral information that was observed in adults in Experiment 1. Nevertheless, we found that children high in food neophobia appear to generalise toxicity at a higher rate. This suggests individual differences in the degree to which evolutionarily relevant information impacts generalisation, a finding that is consistent with the view that neophobia is a protective strategy against the risk of ingesting potentially toxic foods (Cashdan, 1994; Foinant et al., 2021; Lafraire et al., 2016; Rozin & Todd, 2015). Moreover, our results are in contrast with the lifespan findings from Broesch et al. (2014), who found preferential recall of danger information in children, but not in adults. Our results suggest that selectivity in generalisation seems to be limited to adulthood. Therefore, we explored the effect from Experiment 1 in adults in more detail in Experiments 3 and 4.

4. Experiment 3

The results from Experiment 1 suggest that, when confronted with ambiguous stimuli, adults use a cautious generalisation strategy in which they overgeneralise toxicity and undergeneralise edibility when asked about ambiguous novel candidate foods. One outstanding question is the role of categorisation in this generalisation process. Specifically, to what extent do participants form categories of the stimuli presented and use this categorical information in their responses? That is, are adult participants forming categorical judgements of the stimuli and using these to decide whether an item has or does not have a property, or are they relying solely on perceptual similarity? In the former case, the results from

Experiment 1 would mean that adults engage in selective generalisation when they are not able to assign category membership to ambiguous stimuli.

It is possible that participants in Experiment 1 formed categorical judgements about the target images, and then evaluated whether or not the test (morph) image had the shared property based on whether they considered the test morph to be a member of the relevant category. Alternatively, it could be the case that participants relied on similarity judgements alone to make this decision and did not form categorical judgements. In order to distinguish between these possibilities, we ran an additional experiment using a task similar to that in Experiment 1, but that tested whether or not participants engage in categorisation. Specifically, we examined categorisation by giving the stimuli from Experiment 1 labels (e.g., “This is a Daxon”) instead of properties (e.g., “This is edible”), thereby stating what a stimulus is, not a property it has. Such use of labels is an established way of inducing categorisation (e.g., Deng & Sloutsky, 2013; Fisher et al., 2011, 2015). The comparison of this new naming condition in Experiment 3 with the existing neutral seasonality condition of Experiment 1 allows us to examine the extent to which performance in the generalisation task (Experiment 1) is a function of categorisation. We used the neutral condition from Experiment 1 because the artificial name labels used in the Experiment 3 have no inherent costs associated (as is the case with edibility and toxicity information used in Experiment 1). Therefore, this provides a comparison of generalisation of neutral information with categorisation based upon neutral information. If participants in Experiment 1 did indeed base their decisions on categorisation, we would expect similar performance in generalisation of neutral information (seasonality information, Experiment 1) and categorisation of neutral information (Experiment 3).

4.1. Method

Participants were 30 adults (19 female, 11 male, mean age = 33 years, range = 20 – 59). This study was reviewed and approved by a local ethics committee. Recruitment and consent procedure were identical to Experiment 1. The stimulus pictures and procedure were identical to the Experiment 1, except that instead of assigning a property (edibility, toxicity, seasonality) to the target pictures, they were given a name. The names were novel labels based upon or taken from previous research using novel words and labels (e.g., Fusaro & Harris, 2013; Gaskell & Dumay, 2003). These words were selected to be plausible for the testing language (English) and were all disyllabic (See SM, section 1.2 for the list of names used).

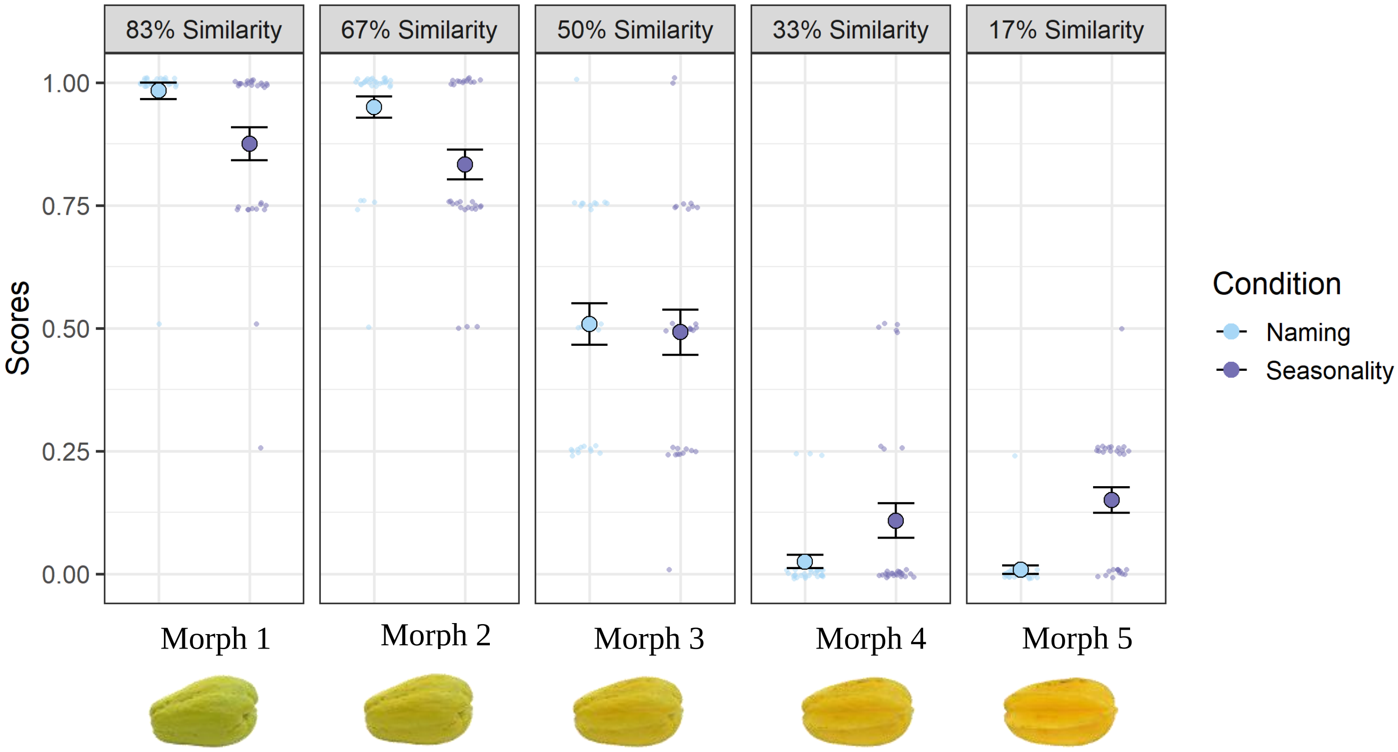
In each trial of the task, an image triad was presented on the screen and one target fruit was given one name (e.g., Daxon for the left top picture), the other target fruit a different name (e.g., Sudeb for the right top picture). Participants were asked which of the two names the test fruit had (e.g., This is a Daxon or a Sudeb?). Randomisation and counterbalancing was the same as for the conditions used in Experiment 1. In order for data to be comparable with Experiment 1, a response was coded as 1 (yes) when participants categorised the target as the stimuli on the top left (e.g., Daxon) and a score 0 for right top target picture (e.g., Sudeb).

4.2. Results and Discussion

Categorisation scores were modelled in Binomial GLMM with a logit link function and were modelled alongside data from the seasonality condition from Experiment 1. As before, there was no model improvement from including sex and age as fixed factors and image pair as random factor, so these variables were excluded from further analysis. In the main analysis, Participant and Individual Triads served as random factors. Similarity between the left target picture and the test picture (83%, 67%, 50%, 33% and 17%), Condition (label, neutral property), as well as their interaction were modelled as fixed effects. The best fit model according to Akaike's Information Criterion was the full model including the main effects and the interaction between Similarity and Condition (χ^2 (1) = 52.27, p < 0.001, marginal R^2 = 0.69, conditional R^2 = 0.76).

As in Experiment 1, there was a significant effect of similarity (χ^2 (1) = 66.73, p < 0.001, see Table S4 in the SM section 2.1), indicating categorisation (naming condition, Experiment 3)/generalisation (neutral property, Experiment 1) declined with decreasing similarity (see Fig. 4). We also found a significant interaction effect of Similarity*Condition (χ^2 (1) = 34.56, p < 0.001, see Table S4 in the SM), indicating that, with decreasing similarity, the decrease of neutral property generalisation differed significantly from the decrease in categorisation ($z = 5.88$, $p < 0.001$). Fisher's Exact Tests at each stage of the morph spectrum demonstrate a statistically significant difference between the naming (Experiment 3) and seasonality information (Experiment 1) conditions in all morphs (all $p <$ 0.017) except the most ambiguous morph, morph 3 ($p = .90$). When similarity between the target picture and the test picture was more than 50% (morph 1 and 2), the response rate was higher for naming (categorisation) relative to seasonality (generalisation, see Fig. 4). We observed the opposite pattern when similarity was lower than 50% (morph 4 and 5, see Fig. 4).

Figure 4: Generalisation scores in Experiment 1 seasonality condition and categorisation scores in Experiment 3, at each point of the morph sequence. Large dots show group means with 95% CI error bars, smaller dots show individual participant means. Morph images from an example triad after Fig. 1, the real green fruit has the property.



Finally, for all morphs, the percentage of stable responders was high (ranging from 73% for the most ambiguous morph and more than 96% for the other points of the morph spectrum), indicating that a majority of participants adopted a stable strategy regardless of the stimuli and the task (generalisation vs. categorisation), see SM Section 2.2 for further details.

In summary, when categorization is made explicit through naming, it differs from generalisation for our stimuli. This indicates that in generalisation, such as that observed in Experiment 1, participants are not generalising entirely based upon their categorical judgements. If this were the case, we would have observed the same results for both categorisation and generalisation, but we did not. Participants appear to show greater certainty when categorising the test pictures by labels compared to when generalising by a neutral information to them, even when the stimuli are the same. This suggest that participants are overall more cautious to generalise a property to a novel stimulus than to assign it a category, however under the highest degree of uncertainty generalisation and categorisation mechanisms appear to operate similarly

5. Experiment 4

In Experiment 1 we found that, under uncertainty, namely when adult participants did not know the category membership of the test picture, they generalised more broadly for toxicity (danger) information, and less broadly for edibility information, compared to seasonality (neutral) information. While these findings are consistent with the asymmetrical costs of generalisation errors in the food domain, one possible alternative explanation for these findings could be a broader negativity bias. This is a well-established asymmetry in the way adults and children process and use positive versus negative information in several psychological domains, such as decision-making, social learning, emotional processing (Baumeister et al., 2001; Bebbington et al., 2017; Stubbersfield et al., 2015; Vaish et al., 2008). If this was the case, and there is a broader negativity bias in generalisation, we would expect adults to generalise any kind of negative information more broadly than neutral information. However, if the selective generalisation we observed in Experiment 1 reflect the specific asymmetries in the costs of the two types of errors in generalising the edibility or toxicity of foods (false-positives and false-negatives; Haselton & Buss, 2000; Haselton & Nettle, 2006), we would predict different generalisation for information about danger than other negative information.

To test this, we ran a final experiment where we asked adults to generalise three novel properties with the same valence as in Experiment 1 (negative, positive, neutral) but where mistakes do not pose the same direct costs or benefits. In Experiment 1 we used the property “toxic”, which is both negative and offers direct costs to an individual if incorrectly generalised. In Experiment 4 we used the property “polluting” [this is polluting/ not polluting] which also has negative connotations, but does not have the same direct costs. That is, many more instances of incorrectly attributing the negative property "polluting" to food items would be required for the individual to experience adverse effects, if at all, from polluting foods. Likewise, the positive property “edible” used in Experiment 1, was replaced in Experiment 4 with the positive property of “sustainable” [this is sustainable/ not sustainable]. This property is positive but again without the same direct costs associated with errors in attributing it. A single instance of incorrectly generalising edibility to an inedible item is more costly than incorrectly generalising sustainability to something that is not sustainable. Finally, the neutral property of Experiment 1 “grows in summer” was replaced in Experiment 4 with another neutral property “stored in a cool dry place” [this is stored/ not stored in a cool dry place]. We replaced the seasonality control used in Experiment 1 to examine whether participants treated a different kind of neutral information in a similar way.

Adult participants once again evaluated triads of the same images used in the previous experiments, but with the properties polluting, sustainability, and storage instead of toxicity, edibility and seasonality. If the generalisation effects we observed in Experiment 1 are a function of a broader negativity/positivity effect we would expect to see a similar pattern in generalisation in Experiment 4, with an overgeneralisation of polluting information and undergeneralisation of sustainability information. However, if the effects in Experiment 1 are reflect the asymmetry in costs in generalising edibility and toxicity information in the food domain over evolutionary time, we would not expect to see this effect in Experiment 4.

5.1. Method

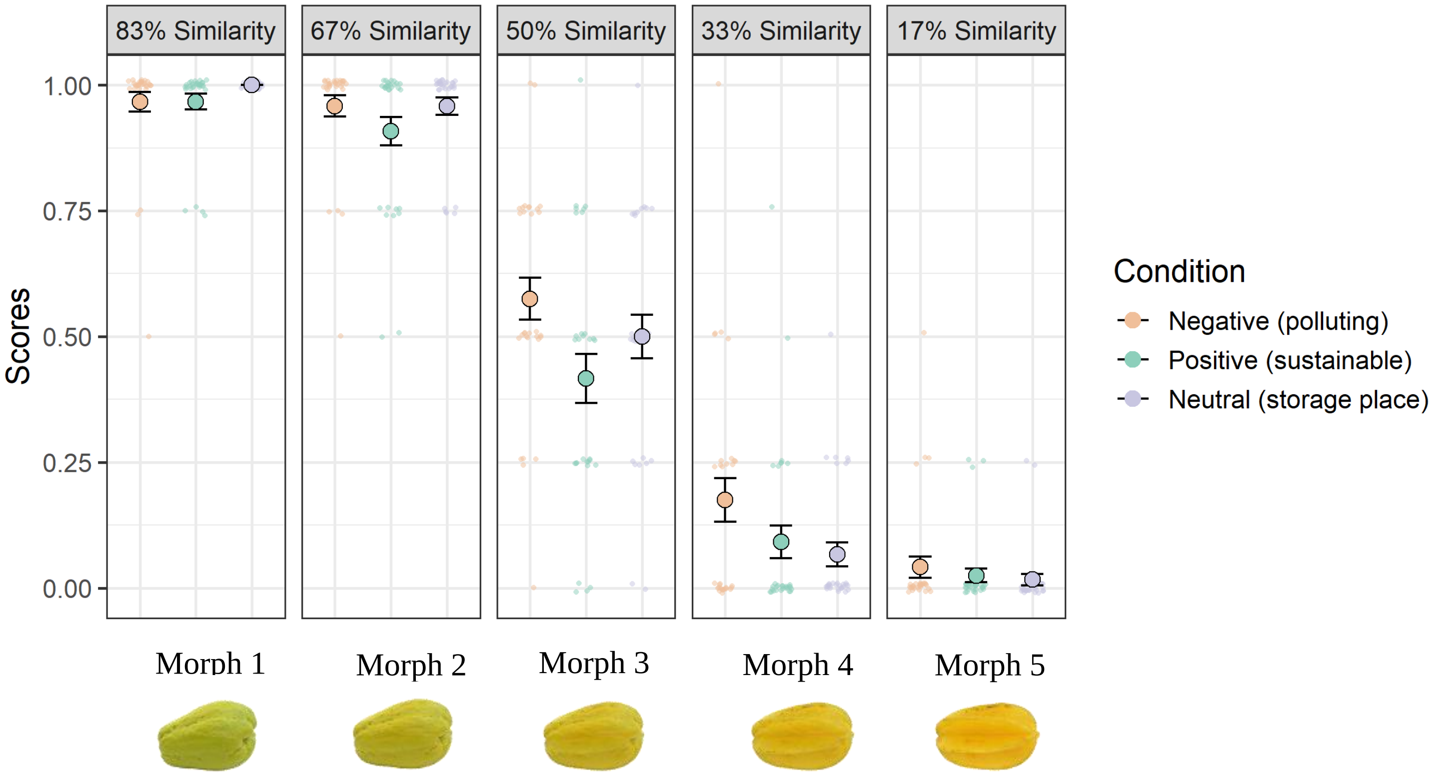
Participants were 90 adults (47 female, 41 male, mean age = 31 years, range = 17 – 77, 2 participants did not provide demographic information), divided evenly across three independent informational conditions (positive, negative, and neutral). As with previous experiments Experiment 4 was reviewed and approved by a local ethics committee, and the recruitment and consent procedure were the same as Experiments 1 and 3. The stimulus pictures and procedure were identical to the Experiment 1, except that the properties assigned to the target pictures were different. To determine the properties most relevant to food and with our desired valences, we ran a pilot experiment. We piloted two different properties per valence (positive, negative, neutral), which were online with 30 adults. The properties selected (i.e., polluting, sustainable, and stored in a cool dry place) were those adults rated most relevant to describe a food and that had the *a priori* expected valence (i.e., the property "polluting" was rated strongly negatively; see SM Section 1.3 for details).

5.2. Results and Discussion

As with previous experiments, results from Experiment 4 were analysed using a Binomial GLMM with a logit link function. We found no improved model fit of including image pair, age, or sex in the model. As such, these variables were again excluded from further analyses. In the main analysis Participants served as a random factor as well as Individual triads. Similarity between the left target picture and the test picture (83%, 67%, 50%, 33% and 17%), Condition (negative, positive, neutral), as well as their interaction were modelled as fixed effects. The best fit model according to Akaike's Information Criterion was the full model including the main effects and the interaction between Similarity and Condition (χ^2 (2) = 9.68, p = 0.0079 marginal R^2 = 0.74, conditional R^2 = 0.76).

Consistent with our previous findings, a significant main effect of Similarity was found, with the likelihood of generalisation decreasing as similarity decreased (χ^2 (1) = 291.09, p < 0.001, see Table S4 in the SM section 2.1). As in Experiment 1, we found a significant main effect of Condition (χ^2 (2) = 9.87, p = 0.0072, see Table S4 in the SM), which was qualified by an interaction effect of Similarity*Condition (χ^2 (2) = 8.39, p = 0.015, see Table S4 in the SM). The decline in generalisation due to decreasing similarity in the neutral condition was significantly steeper than in the positive condition (*z* = 2.42, p = 0.041) and negative condition (*z* = 2.83, p = 0.013). However, Fisher's Exact Tests at each point of our morph sequence (i.e., at each level of similarity) indicated that, in contrast to Experiment 1, no significant pairwise comparisons were found between the negative, positive, or neutral conditions. This indicates that there was no significant difference between generalisation rates of positive, negative and neutral information in Experiment 4. In particular, we compared generalisation rates where the morph test picture was most ambiguous (i.e., 50% similar to each of the original items) to the chance level. In contrast to Experiment 1, generalisation rates in neither experimental condition, negative (P = 0.58 [95% CI: 0.48 – 0.66], p = 0.12), nor positive (P = 0.42, [95% CI: 0.33-0.51], p = 0.082), differed significantly from chance. This indicates again that there was no significant difference between the generalisation of positive, negative and neutral information in Experiment 3.

Figure 5: Generalisation rates in Experiment 4 at each point of the morph sequence (i.e., each level of Similarity), depending of Condition. Large dots show group means with 95% CI error bars, smaller dots show individual participant means. Morph images from an example triad after Fig. 1, the real green fruit has the property.



To examine the difference between Experiment 1 and Experiment 4 further we compared generalisation rates in cases where the test picture was most ambiguous (i.e. 50% similar to each of the original items) between the original toxicity condition from Experiment 1 and the negative (polluting) condition from Experiment 4, and also between the edibility condition and positive (sustainable) conditions from Experiments 1 and 4 respectively. This was done using Fishers Exact tests. We found no significant difference between the edibility and positive ($p = 0.69$), or toxicity and negative conditions ($p = 0.79$), indicating that the effect of edibility is not necessarily distinct from a general positivity effect, nor is toxicity distinct from a general negativity effect. However, we observed edibility and toxicity to be significantly different from chance in Experiment 1, and did not observe a similar pattern for positivity and negativity here. Further, we did find a significant difference between positivity, negativity, and neutral conditions in Experiment 4 while we did for toxicity and edibility in Experiment 1.

Finally, consistent with previous experiments, more than 93% of participants adopted a stable strategy for morphs at the beginning and end of the spectrum. For the most ambiguous morph, only 62% of participants adopted a stable strategy. This was significantly lower than for the other points of the morph spectrum ($p < .001$ for all; see SM Section 2.2 for further details), again indicating greater uncertainty in generalisation for the most ambiguous morph.

In summary, results of Experiment 4 give some indication that a general negativity/positivity effect is present in generalisation, however it is less pronounced than the effect for toxicity and edibility information we observed in Experiment 1, suggesting some level of specificity in generalisation.

6. General Discussion

When making inductive inferences under uncertainty, some generalisation errors are more costly than others. Generalising knowledge from one exemplar to a novel and ambiguous item, based on categories or similarity alone, is insufficient because the consequences of errors are not always uniform. Decisions about candidate food items provide a particularly clear example: Incorrectly deciding a toxic item is edible is a higher cost than incorrectly deciding that an edible item is toxic. In these cases, some selectivity is necessary to guide generalisation processes. Following the predictions of Error Management Theory (EMT; Haselton & Buss, 2000; Haselton & Nettle, 2006) and research showing that selective learning is present for certain fitness-relevant information (e.g., dangerous animals, foods, Barrett & Broesch, 2012; Wertz & Wynn, 2014a), the present work investigated how the type of information learned influences the generalisation of that information to novel items. Further, based on Broesch et al. (2014)'s finding that the selective learning for dangerous animals declined with age and was not present in adulthood, we also looked at age differences in selective generalisation processes by testing preschool-aged children and adults.

Our results demonstrate that both children and adults consistently generalise along a declining function of item similarity, consistent with the literature (e.g., Murphy, 2002; Shepard, 1958; Sloutsky, 2003), however adults were overall more cautious in generalising a property to a novel stimulus than assigning the same stimulus to a category. Moreover, as predicted, in Experiment 1, the findings reveal evidence of selective generalisation dependent on the information learned. Specifically, adults' generalisation decisions across the entire morph sequence show that generalisation of fitness-relevant information with asymmetric costs of errors (i.e., toxicity and edibility information about food) differs from generalisation of neutral content. Specifically, generalisation of toxicity information was less stringent (declined less rapidly with similarity) and edibility information more stringent (declined more rapidly with similarity), than neutral information. This is consistent with the error minimising principles of Error Management Theory (Haselton & Nettle, 2006), as this pattern appears to show a strategy that minimises the more costly error in each case. For edibility information, it would be more costly to incorrectly generalise edibility to entity that is not in fact edible, and we see reduced generalisation that would minimise this possibility. For toxicity information, the more costly error would be to fail to generalise toxicity information to an entity that is in fact toxic, and we see higher generalisation levels reflecting this. To our knowledge, this is the first demonstration of selective generalisation based on informational content.

This effect was driven by participants' generalisation decisions for the most ambiguous morph— the image that was halfway between the two target images in similarity. When confronted with the most ambiguous morph, and therefore under a state of categorical uncertainty (as shown by Experiment 3), it led participants generalise toxicity to a greater extent, and edibility to a lesser extent than neutral information. That this only appears in the most ambiguous morph highlights the role of uncertainty in selective generalisation. In fact, adults exhibited less certainty in their generalisation responses (Experiment 1) than in their categorisation responses (Experiment 3) in general, which could indicate that formation of categories requires less evidence than induction. This is consistent with the notion of minimizing costly errors— the mistakes involved in using information are possibly more costly than mistakes in learning that information That participants did not generalise (Experiment 1) or categorise (Experiment 3) neutral information differently from chance for the most ambiguous item, suggests that the differences in generalisation at this level of similarity in Experiment 1 are a function of the type of information to be generalised. More specifically, and consistent with the predictions drawn from EMT (Haselton & Buss, 2000;

Haselton & Nettle, 2006), generalisation patterns of fitness-relevant information (i.e., the toxicity and edibility of food) reflect the asymmetry in possible errors costs in those domains.

These findings are in line with previous research showing selective learning for danger and edibility information in infants and children (Barrett et al., 2016; Barrett & Broesch, 2012; Wertz & Wynn, 2014a), but differ in that selectivity in generalisation appears limited to adulthood. Given that selective learning is observed in younger age groups, we also examined selective generalisation with 4- to 5-year old children, who were given an adapted version of the generalisation task in Experiment 1. In contrast to the adults in Experiment 1, we did not find that children generalised toxicity to a greater extent and edibility to a lesser extent than neutral information. However, we found some hints of selective generalisation depending on type of information. Specifically, for the two most similar morphs, children in the high food neophobia group generalised toxicity to a higher degree than their counterparts, who generalised neutral information to a higher degree. These findings are consistent with the view that neophobia is a protective strategy against the risk of ingesting potentially toxic foods and suggest that neophobic individuals pay particular attention to negative information about foods (Cashdan, 1994; Foinant et al., 2021; Lafraire et al., 2016; Rozin & Todd, 2015). Notably, Foinant and colleagues presented children with a property generalisation task in which one target fruit was given a property (either positive or negative) and children were asked which other real fruits and vegetables also had the property. They found that neophobic children assign negative properties to more foods (e.g., “This food makes you throw up”) compared to individuals with less neophobic disposition, (Foinant et al., 2021). In addition, our findings are convergent with recent work showing that neophobic children show an attentional bias toward negatively perceived food stimuli, such as novel fruits and vegetables that are more likely than other types of foods to contain toxic compounds (Maratos et al.,

2008) and may be more reluctant to approach those kinds of foods as infants (Rioux & Wertz, 2021).

Contrary to the findings of Broesch and colleagues (2014) showing more pronounced learning biases in children, we found evidence of selective generalisation in adults but not children. It has already been established that generalisation processes can unfold differently than other processes (Gelman & Markman, 1986, 1987; Sloutsky & Fisher, 2004a, 2004b; see also the results of Experiment 3 where we found a difference between categorisation and generalisation responses). It could be that differences between the developmental trajectories of selective learning of fitness-relevant information and selective generalisation are a function of the difference in the use of knowledge at different ages. That is, that selectivity in the process of acquiring knowledge is of higher value earlier in life than selectivity in generalisation of that knowledge, particularly when the overall structure of the generalisation processes is sufficient (e.g., the decrease in generalisation we observed over declining similarity between the target and test stimuli in Experiment 2). The importance of the human extended juvenile period for learning about our environment has been well established (e.g.,Crittenden et al., 2013; Joffe, 1997; Muthukrishna et al., 2018), with Gopnik et al. (2017) noting specifically that children learn better than adults across several domains.

Finally, Experiment 4 investigated to what extent the selective generalisation effect found in Experiment 1 may be a function of a broader valence effect. A general negativity bias is a well-established asymmetry in the way adults and children process and use positive versus negative information in several psychological domains, including decision-making, social learning, and emotional processing (Baumeister et al., 2001; Bebbington et al., 2017; Stubbersfield et al., 2015; Vaish et al., 2008). Therefore, in Experiment 4, we compared the generalisation of the fitness-relevant information used in Experiment 1 (toxicity and edibility information about foods) to information that was similarly valanced (negative, positive), but without the direct fitness risks of generalisation errors. Specifically, participants generalised negative and positive information about food (i.e., being polluting or sustainable) that does not pose the same kind of direct risks and benefits to an individual as decisions about edibility and toxicity information. For example, whilst costly on a broader scale, mistakenly deciding that something is sustainable when does not pose the same direct risk to an individual as thinking something is edible when it is not.

The results of Experiment 4 showed that, across the entire morph sequence, adults' generalisation decisions for valanced information (i.e., positive [sustainable] and negative [polluting] information) was *less* stringent than generalisation of neutral information (storage location). In addition, in contrast to Experiment 1, when participants were confronted with the most ambiguous morph items, participants did not show evidence of selective generalisation of positive and negative information. These results speak against a mere valence bias account for the findings of Experiment 1 and instead suggest that participants engaged in selective generalisation based on informational content in a manner consistent with the EMT prediction of minimizing of costly mistakes. However, we acknowledge that this interpretation must be taken with caution given that direct comparisons between generalisation of information with high vs cost of errors (*Toxic* vs. *Polluting* and *Edible* vs. *Sustainable*) revealed no significant differences.

6.1. Limitations and Future Directions

That the effect of information type on generalisation was only observed in the most ambiguous morph illustrates one limitation in the present design which warrants further investigation. We observed clear differences between how participants generalised to our most ambiguous morph (morph 3) and those on either side of it in the morph sequence (morphs 2 and 4). One outstanding question is the boundary condition for this difference, and whether this differs between information types. That is, at what degree of similarity to the target do these content effects appear? The current study limited the morph sequence to only five items, and thereby the ability to answer this question. This was done to limit the total number of questions presented to the child sample in Experiment 2. Future research could investigate the relationship between similarity and information type on generalisation by extending the morph sequence and systematically manipulating specific features of the exemplars. For example, previous research has shown that colour and shape play important roles in food categorisation (e.g., Rioux et al., 2018). In morphing the foods were items into one another, however the relative degrees of change of colour and shape along this morph sequence were not measured explicitly. Given the debate around the relative roles of these factors in food categorisation (e. g. Lavin & Hall, 2002; Macario, 1991; Rioux et al., 2018), further research could examine how similarity along each of these dimensions independently influences generalisation of different information types.

Finally, our results raised questions about the role of age in selective generalisation. As noted, we found an inverse pattern to Broesch et al. (2014), finding selectivity in generalisation was observed in adults but not children. We did not find an age effect within the sample, suggesting that the change occurs between the ages of our child sample, and adulthood. However, it should be noted that the effect of age within our adult sample was not a planned investigation so we may not have had enough power to examine this. This suggests the need for further research to examine the developmental trajectory of selectivity in generalisation, specifically the age at which the informational content effects observed here arise in later childhood or the teenage years. Alternatively, it could be the case that there is indeed an effect of informational content in children, but we did not observe it. For example, the difference between children and adults could be a function of differences in task competence, that is children’s ability to understand and complete the task rather than their performance on the task, a well-known issue in developmental research (e.g. O’Brien & Overton, 1982; Surian & Leslie, 1999). It would therefore be of value to replicate the present findings using alternative methods to examine this.

7. Conclusions

The present work investigated the effect of different types of informational content on generalisation in adults and preschool-aged children. In line with the Error Management Theory (Haselton & Buss, 2000; Haselton & Nettle, 2006), we found evidence of selective generalisation. Specifically, under conditions of uncertainty, adults generalised danger information (i.e., toxicity) more broadly and edibility information more narrowly than neutral information. The present results also suggest a distinction between generalisation of fitness-relevant information with direct costs and benefits, and a generalisation of negative and positive information more broadly. Contrary to our predictions we did not find evidence of selective generalisation in young children, yet we did find some evidence of increased generalisation of danger information by children who scored higher on measures of food neophobia. Although previous work has found selectivity in other cognitive processes, such as learning and attentional biases (e.g., (Barrett et al., 2016; DeLoache & LoBue, 2009; LoBue & DeLoache, 2008; Soares et al., 2014; Wertz & Wynn, 2014a), to our knowledge, our findings constitute the first evidence that human generalisation systems reflect evolutionarily recurrent asymmetries in costs. When confronted with ambiguous candidate food items, adults use a cautious generalisation strategy consistent with minimizing costly errors.

8. References

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Chapter 3: Content Bias in Learning and Generalisation: Anxiety and Uncertainty

1. Introduction

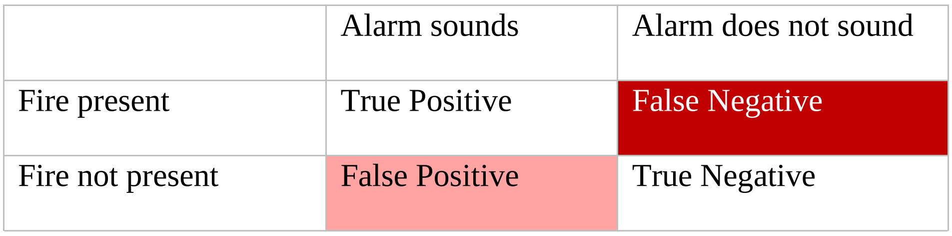
Foraging for food is not a risk-free endeavour, something that may be easy to overlook in many modern societies. Industrialisation and globalisation have fundamentally changed the way humans acquire and consume food, allowing for more processing and a broader range for importing, and thereby variety of foods, than for most of human history. This is acutely illustrated by Baraldi et al. (2018), who found that between the years 2007-12 ultra-processed foods—that is foods which have gone through multiple stages of industrial processing—accounted for almost 60% of calories in a nationally representative sample in the United States. The task of food acquisition in this environment of industrially processed and packaged food is quite different to that faced by humans in other societies, humans across history, and to other species. For contrast, ethnographic data from 229 hunter-gatherer societies, along with quantitative data from a smaller number of hunter-gatherer societies indicates a heavy reliance on hunted (or fished) animal foods, with a majority of societies also relying to some extent on gathered plant foods, with average subsistence from plant-foods being between 32-35% (Cordain et al., 2000, 2002). In these societies individuals must manage the myriad risks of hunting or gathering with a dependence on these sources for food, and both the threats posed by animals (Barrett, 2015), and the risks from plants, have started to receive attention regarding their influence on human cognition (Wertz, 2019).

As Wertz (2019; see also Włodarczyk et al., 2018) argues, risks from plant-based foods pose a unique psychological puzzle in that any harm incurred is due to mistakes on the part of the agent that interacts with them. Plants possess both non-visible defences in the form of toxic compounds (Belovsky & Schmitz, 2006; Manners, 1996) and visible defences such as spines (Hanley et al., 2007), the result of a co-evolutionary arms race with foraging animals (Occhipinti, 2013). Humans must therefore balance the risks posed by plants with the importance of gathering plant-based products not only for our diet, but also for medicinal and equipment purposes (e.g., Begossi et al., 2002; Figueiredo et al., 1993). Indeed, Wertz and colleagues have argued that these trade-offs have shaped cognition and behavioural strategies to minimise the risks from plants such as behavioural avoidance (Wertz & Wynn, 2014b; Włodarczyk et al., 2018), social referencing (Elsner & Wertz, 2019), and specialised learning (Wertz & Wynn, 2019; Wertz & Wynn, 2014a).

1.1. Error Management

It has been argued that environments like these, where mistakes are costly, provide an environment for the evolution of cognitive biases (Haselton et al., 2005; Haselton & Buss, 2000; Haselton & Nettle, 2006; Johnson et al., 2013). Error Management Theory (EMT) is based around balancing the two kinds of error one can make when making a decision under uncertainty, false-positives or false-negatives. Specifically, it is argued that when the costs of these mistakes are asymmetrical over evolutionary time, this favours the emergence of cognitive biases to minimise the more costly errors. Similarly, Nesse (2005) provides a valuable analogy with a smoke detector here— a smoke detector can go off when it should not (false positive), or not go off when it should (false negative; see Figure 1). In this instance, the false negative would be the more costly error; being needlessly irritated or woken by a smoke alarm is less costly than not being alerted when there is a fire. A smoke detector with low sensitivity would reduce the number of false positive errors whilst increasing the number of false negatives, whereas a highly sensitive smoke detector would reduce the number of false negatives whilst increasing the number of false positives. In this example smoke alarms appear to be highly sensitive, in that they favour the minimisation of costly false negatives over accuracy. This framework may an offer explanation as to, and predictions about, cognitive mechanisms humans and non-humans possess to manage risks in food acquisition.

Figure 1. Smoke detector analogy



	Alarm sounds	Alarm does not sound
Fire present	True Positive	False Negative
Fire not present	False Positive	True Negative

Figure showing the errors in a smoke detector, with dark red indicating the more costly error, and light red the less costly error.

1.2. Selectivity in Learning

One cognitive domain that appears to be specialised to help navigate this risk-reward problem of food acquisition is learning, an area Haselton & Nettle (2006) note as an example of where cognitive biases towards error-minimization might develop. It has been argued that learning is not domain general, that is, some things are learned more readily than others and certain associations are more readily made (Seligman, 1970). For example, rats preferentially associate gustatory stimuli and illness (Garcia & Koelling, 1966)—an effect observed even with a delay between stimulus and response (Kalat & Rozin, 1973)— and both humans and non-humans preferentially associate prototypically threatening stimuli (e.g., snakes) and fear (Öhman & Mineka, 2001, 2003). Similarly, Shettleworth (1975) found food to be a more effective reinforcer for certain relevant behaviours than other less relevant behaviours. Although specialised learning about dangerous information may minimize costly errors, learning first hand whether or not a possible food is toxic is still highly risky. Evolutionary models have shown that in situations where learning through individual experience is costly, evolution can favour the emergence of social learning strategies (Boyd & Richerson, 1985; Oña et al., 2019). Moreover, in addition to being high risk, individually learning about all possible food items is inefficient, as outlined in Chapter 1. These selective learning and social learning are not mutually exclusive systems. Indeed, models developed by Lindström et al. (2016) show the co-evolution of these strategies, and empirical research appears to show selective learning of risk relevant information appears in both social and asocial learning. Young children will preferentially retain socially provided information about danger (Barrett et al., 2016; Barrett & Broesch, 2012; Broesch et al., 2014) and threatening faces (Kinzler & Shutts, 2008), and infants preferentially associate plants and edibility (Rioux & Wertz, 2021; Wertz & Wynn, 2014a). In addition to this research with children, findings in adults have shown stronger learned associations between fear and certain stimuli (Ohman & Dimberg, 1978; Ohman et al., 1976), and increased recall for survival-relevant information (Nairne et al., 2007, 2009; Nairne & Pandeirada, 2008), the faces of cheaters (Barclay & Lalumière, 2006; Mealey, 1996), threatening stimuli (Leding, 2019), and for social and survival based legends (Stubbersfield et al., 2015). This evidence suggests the presence of selective learning systems biased towards learning evolutionarily relevant information in both adults and children.

It should be noted that Broesch et al. (2014) reported a learning advantage for children but not adults for information about danger. However, this conclusion should be treated with caution for a number of reasons. Firstly, it appears that the difference between adults and children in their study was not necessarily a difference in the recall of danger information about animals, rather a dramatically greater recall of animal diet information, a control information type, in adults as compared to children. Secondly, the types of information compared were danger information, poison information, diet information, and habitat information, which the authors themselves note are also important domains. The aforementioned information about animals' diet is not necessarily a valid comparison group due to its high variation between age groups in their sample, and information about animal habitat also may not be a useful comparison to danger as location of threatening animals appears to have a learning advantage itself (Wilson et al., 2011), and humans appear to have specialised spatial memory for food (de Vries, de Vet, et al., 2020; de Vries, Morquecho-Campos, et al., 2020; Krasnow et al., 2011; New et al., 2007). As such, whilst there is evidence for specialised learning of fear and for survival information, it remains unclear as to whether there is a learning bias for danger information in adulthood. The present study looks to build on this by testing whether there is preferential recall for danger information about foods in adulthood, whilst also testing whether a learning advantage is present for information about the edibility of foods.

1.3. Selectivity in Generalisation?

It seems that learning, both socially and asocially, may be specialised to minimise the risks posed in food acquisition. However, deciding whether an item is safe or not is not only predicated upon our knowledge of that item. Indeed, we are unlikely to have seen the same item before, very similar items perhaps, but not identical. It is said that no two snowflakes are the same, however you do not need to have seen a particular snowflake before to reason that it will be cold. Likewise, if you were to learn that a green apple from a particular tree was toxic, would you assume no knowledge of the other green apples from that tree? Even from a young age humans form categories based upon visual and conceptual similarity (Fisher & Sloutsky, 2005; Godwin & Fisher, 2015; Mandler, 2009; Sloutsky, 2003; Sloutsky et al., 2007; Sloutsky & Fisher, 2004), and we use information about these categories to make inferences about other items. Infants as young as 9-months-old are able to generalise information based upon perceptual properties (Mandler & McDonough, 1993), and young children can generalise over conceptual dimensions (Gelman, 1988; Gelman & Davidson, 2013; Gelman & Markman, 1986, 1987; Walker et al., 2014). If, as it appears, our learning systems have been shaped to minimise costly errors as per EMT, it may be the case that generalisation systems also have been similarly shaped.

If one has learned that a particular item has a property (e.g., toxicity), should one decide that a similar item does or does not have that property? Applying the principles of EMT to the context of food acquisition we can see two inverse patterns in generalising learned information about food edibility and toxicity. We reason that for toxicity information the more costly error would be the false-negative, treating something as not toxic when in fact it is. Whereas when one has learned an item is edible it follows that the false-positive would be the more costly error, treating something as edible when, in fact, it is not. EMT would therefore predict generalisation systems to have evolved reflect to this asymmetry and favour greater generalisation of toxicity information (to minimise false negatives at the possible cost of more false positives; see Figure 2a), and reduced generalisation of edibility information (to minimise costly false positives at the possible cost of more false negatives overall; see Figure 2b).

Figure 2a. Error Management in Generalisation of Toxicity

	Assume is Toxic	Assume is Not Toxic
Item is Toxic	True Positive	False Negative
Item is Not Toxic	False Positive	True Negative

Figure showing the errors in generalisation of toxicity information to similar items, with dark red indicating the more costly error, and light red the less costly error.

Figure 2b. Error Management in Generalisation of Edibility

	Assume is Edible	Assume is Not Edible
Item is Edible	True Positive	False Negative
Item is Not Edible	False Positive	True Negative

Figure showing the errors in generalisation of edibility information to similar items, with dark red indicating the more costly error, and light red the less costly error.

Indeed, some evidence offers some indication this may be the case. In classic work on rats it has been observed that rats will generalise a shock to a greater degree than a food reward (Hearst, 1962; Murray & Miller, 1952, though see Hoffman & Fleshler, 1963 for the reverse pattern), and Zhu & Murphy (2013) found participants pay more attention to emotionally charged categories when considering multiple categories in category based induction. Rioux, Russell & Wertz (Chapter 2; 2022) provide what is to our knowledge the first evidence that human generalisation is biased to reflect the cost of errors in the information being generalised. It was found that when an item's identity was uncertain (i.e. when a target item C was 50% similar to both A and B, where item A has a property and item B does not), participants would say C had the property at a rate above chance if A was toxic, and at a rate below chance if A was edible.

Yet uncertainty around the identity of an item is not the only uncertainty in generalisation problems. If I have learned that red berries are toxic and come across a novel red berry, I have uncertainty around whether these belong to the same category, but also uncertainty about whether being in the same category means this new fruit is toxic. Rioux, Russell & Wertz (2022, Chapter 2) follow a typical paradigm in studies of induction wherein the premise is certain, presenting a reference stimulus that explicitly "*is* toxic/edible" or "*is not* toxic/edible". So, whilst there is uncertainty around an item's identity (whether C is an A or a B), there is no uncertainty about whether As or Bs have or do not have a property. Yet, outside of lab experiments such degree of certainty is not likely to be the case. Indeed it would only take one black sheep in a million to counter the premise "sheep are white" and lend some uncertainty to sheep as a predictor of colour. Whilst seemingly a largely overlooked area of study, previous research offers some indication that degree of certainty around a category's predictive power may influence generalisation. Participants' inductive inferences have been shown to be influenced by causality (Lassaline, 1996; Wu & Gentner, 1998), and by the homogeneity of a category (e.g., Gelman, 1988), both of which could be interpreted as increasing participants' certainty about the predictive power of a category. Moreover, it appears to be the case that in *deductive* reasoning participants reflect the uncertainty of a premise in their conclusions derived from said premise (Stevenson & Over, 2018). The present study will build upon the work of Rioux, Russell & Wertz (2022; Chapter 2) by further testing the effects of information type, namely edibility and toxicity, on generalisation. Moreover, it will look to test how uncertainty around the predictive power of categories influence the generalisation of these kinds of information.

1.4. Individual Differences

EMT proposes that, at a population level, cognitive systems are calibrated to minimise costly errors. However, whilst cognitive systems may be calibrated at a population level, so to do they vary on an individual level. Bateson et al. (2011) argue that the function of anxiety is to prepare an individual for threat, and that clinical anxiety is on a continuum with normal, protective, anxiety. Similarly, it has been argued by Nesse (2001, 2005) that a number of what we call mental disorders, are in fact spurious activations of systems which offer utility in other contexts. Indeed, the link between anxiety and cognitive biases such as threat perception and attention is well established (see Sussman et al., 2016; Wieser & Keil, 2020 for reviews). For example, Green & Phillips (2004) argue that small differences in the neurocognitive systems underlying threat perception may antecede the heightened threat perception observed in disorders such as social anxiety. Analysis of signal detection for threat by White et al. (2016) further found that high-anxiety participants had a lower threat threshold than low-anxiety participants, and in a large meta-analysis of eye-tracking studies by Armstrong & Olatunji (2012) it was observed that anxious individuals showed greater threat vigilance in visual tasks (however, see Blair & Blair (2012) for a review challenging the presence of heightened threat perception in Generalized Anxiety Disorder). The effect of anxiety on threat perception has also been observed in children, with children high on anxiety showing heightened threat perception, and an association between anxiety and threat perception found in both threatening and non-threatening contexts (Muris et al., 2000, 2010). Anxiety has also been shown to have an impact on decision making, being linked with heightened perception of the probability and scale of negative outcomes in risky decision making (Maner & Schmidt, 2006), and risk avoidance in decision making (Maner et al., 2007). There also is some evidence that anxiety is also linked to greater recall of threatening information, with a recent meta-analysis finding this to be the case (Herrera et al., 2017, though cf. Mitte, 2008 for some inconsistency). The present study looks to investigate whether anxiety is related to survival and danger related learning effects noted in section 1.2. Given the effects of anxiety on risk perception and decision making, and that anxiety has been proposed as a system to protect against threats, we reason that anxiety may also influence generalisation of risky information, in this instance information about the edibility and toxicity of foods.

Finally, previous research on anxiety and phobias has demonstrated domain specificity in fear and anxiety, indeed 7.4% of the population develop specific phobias (Wardenaar et al., 2017). In social anxiety, for example, it has been observed that individuals show bias for negative emotions in face perception (Machado-de-Sousa et al. (2010), and social phobics have higher recognition for critical than accepting faces (Coles & Heimberg (2005). I the domain of food, Food Neophobia, defined as the avoidance or fear of novel foods (Marcontell et al., 2003; Pliner & Hobden, 1992a; see Rioux, 2020 for review), has been linked with anxiety (Maiz & Balluerka, 2018; Maratos & Sharpe, 2018), disgust sensitivity (Çınar et al., 2021), and noted to be a protective strategy and to influence category inductive reasoning in the food domain (Rioux, Leglaye, et al., 2018). Indeed, a blanket reluctance to try novel foods can be considered an error minimising strategy facilitating the avoidance of food-based threats. Given this, we will also look to examine whether food neophobia correspondingly influences generalisation in the food domain.

1.5. The Present Study

Given the literature outlined above, the present study looks to answer the following questions: Is there selectivity in *learning* for information about danger and edibility of foods in adulthood? Is there a selectivity in *generalisation* for information about danger and edibility of foods in adulthood, and how does uncertainty affect this? And, finally, do individual differences influence sensitivity to information type in learning and generalisation?

Using a similar structure to that used by Barrett et al., (2016) with children, participants completed a simple recall task comprised of a presentation phase where they saw a series of images of foods and were given information about whether these had or did not have a property (edibility [“This is edible”/ “This is not edible”], toxicity [“This is toxic” / “This is not toxic”], or a neutral control property [“This grows in summer”/ “This does not grow in summer”]). They then completed a response phase where they saw the images again and were asked whether the items had or did not have the property.

Each image was a food of one of three colours, with the colour corresponding to the rate at which the property occurred for items of that colour (e.g., 25% of red items they saw have had the property). Colour in particular was used to induce categorisation here as similarity, and more specifically perceptual similarity, are well-established as a key component of category formation (e.g. Gelman & Meyer, 2011; Sloutsky, 2003; Sloutsky & Fisher, 2004; Smith & Heise, 1992), and colour appears to be important in property generalisation for foods, both in children and adults (Lavin & Hall, 2002; Macario, 1991; Rumiati & Foroni, 2016, but see Rioux et al., 2018). Participants therefore saw items of three colour categories, each of which had the property at a different rate, allowing us to examine the effect of the predictive power of a category on property generalisation for that category.

To examine generalisation participants were presented with generalisation trials in addition to the recall trials in the response phase They saw novel images of each colour and were asked if these did or did not have the property. To test the effects of anxiety on generalisation and recall participants completed questionnaires on anxiety related traits after the task.

1.5.1 Predictions.

The present study therefore has the following five predictions:

Prediction 1:

Participants will generalise toxicity information (that the item is toxic) at a higher rate, and edibility information at a lower rate, relative to control information.

Prediction 2:

The effect of information type on generalisation will be higher under uncertainty. Specifically, when the colour category less clearly predicts the presence of the property.

Prediction 3:

Participants will demonstrate more accurate recall for toxicity and edibility information relative to control information.

Prediction 4:

Participants will show a different pattern of errors for different kinds of information. We predict that, where they make mistakes, participants in the toxicity condition will show more false positives than negatives, participants in the edibility condition more false negatives than positives, no difference in the type of errors will be observed in the neutral condition.

Prediction 5:

Participants who score higher on measures of anxiety will show greater sensitivity to type of information, thereby showing a greater degree of bias in both recall and generalisation.

2. Method

2.1. Participants

Participants were 162 (M_{Age} = 39 years; Female = 81, Male = 79, prefer not to say = 2), based in the United Kingdom, recruited via the online study recruitment platform *Prolific*, and tested using a study built on the online questionnaire platform Qualtrics. This study was approved by the ethics committee of the Max Planck Institute for Human Development. Participants were paid £7.50 for their participation.

The planned sample size was based upon on a power analyses by simulation (using the *SimR* package; Green & Macleod, 2016) for the main effect of condition on generalisation. Simulated data was created with generalisation rates for edibility and toxicity being based upon the mean rate found under uncertainty in Rioux, Russell & Wertz (in prep.; Chapter 2). Power analysis were also run for error type (what kind of recall mistake participants made) and recall accuracy, based on pilot data (see section 2.3.1). These yielded an expected power exceeding 90% in all case[1].

2.1.1 Exclusions and Missing Data.

From an original sample of 180 participants, 10 were excluded for failing an attention check, and 5 were excluded for meeting the a priori exclusion threshold of providing the same response for 95% of their responses (the same threshold used in Rioux, Russell & Wertz, 2022; Chapter 2). Three further participants were removed for taking longer than 3 SD

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[1] Power analysis for generalisation was conducted for 8 generalisation items per colour. After final image piloting the image set included 7 items per colour.

greater than the mean to complete the study. This resulted in the final sample of 162 participants.

Additionally, individual trials were also removed from the analysis if participants had a stimulus presentation time (during the presentation phase), or a response time (during the response phase) 3 SD above or below the mean. This resulted in 57 generalisation trials being removed due to response times exceeding this threshold (out of 3400 total trials), and 168 recall trials (out of 7762) being excluded for meeting this threshold for response time (115 trials) and presentation time (53 trials). Finally, an experiment error resulted in 6 participants seeing a question repeated in place of a different trial, these were therefore excluded (12 trials total).

For the questionnaire responses data was missing at the item level for 21 questions across all participants, less than 0.1% of questions asked. This missing data did not appear systematic by either question or participant. Missingness in questionnaire data was accounted for in two ways when scoring questionnaires. For questionnaire scores calculated by the mean, missing data was omitted, and the mean calculated in its absence. For scores calculated by summation, the missing value was imputed with the mean for that participant for that scale, taking into account any reverse scoring.

2.3. Procedure

After completing consent and demographic information, participants were informed they would see a series of images along with some accompanying information. Participants were assigned to one of three independent information conditions which determined the property accompanying the food images: edibility, toxicity, or a neutral control. Participants in each condition were presented with 48 images of possible foods. These images were either red, green or yellow, with participants seeing 16 images of each colour. Each image was accompanied with a statement that the food candidate either had or did not have the property being tested in that condition: edibility (“This is edible” / “This is not edible”), toxicity (“This is Toxic” / “This is not toxic”), or the neutral control (“This grows in summer” / “This does not grow in summer”).

For each colour category the property occurred at a different rate, this allowed us to examine how the degree to which a category (in this case colour) predicted a property to occur influenced generalisation. For one colour category 25% of items had the property, for another colour 50% had the property, and the third 75%. For example, for one participant in the edibility condition 25% of yellow items may be accompanied with “This is edible” with 75% being accompanied with “This is not edible”, 50% of red items accompanied with “This is edible” with 50% being accompanied with “This is not edible”, and 75% of green items accompanied with “This is edible” with 25% being accompanied with “This is not edible”. The colour-occurrence rate correspondence was counterbalanced across participants. All participants saw all three occurrence rates and all three colours, only which colour (red, yellow, green) represented each occurrence rate (25%, 50%, 75%) varied across participants. Presentation order was also counterbalanced. Items were presented in a pseudo-random order, with items being in a random order but in such a way that items of the same colour were not presented back-to-back.

After this presentation phase, participants completed an attention check and brief distractor task (simple mental arithmetic, e.g., 37 +19) before being told they would see a series of images and would be asked about them. Participants then saw the 48 images from the presentation phase again (recall trials) along with 7 new items of each colour (generalisation trials) and were asked whether the items did or did not have the property (edibility, toxicity, grows in summer). Asking participants whether the items they had seen before had a property was used to measure recall, and asking about items that had not been seen before, but were of one of the three colours seen before (i.e., novel red, yellow and green foods) allowed us to measure generalisation.

After completion of the recall phase participants completed the questionnaires noted in the materials section below. We also included additional questions about diet, and hunger (which has been linked to neophobia, Çınar et al., 2021), and asked participants to explicitly estimate the rate at which each colour had the property.

2.3.1. Pilot study

Two pilot studies were run. Firstly to examine possible ceiling or floor effects in recall accuracy, and secondly to examine stimuli (see section 2.2.3). The recall pilot was done by testing the recall accuracy for 3 different study lengths and was tested with 60 participants across two independent information type conditions (edibility and toxicity). Within each information type condition participants saw either 20 items of each colour, 16 items of each colour, or with 12 items of each colour. There was a significant difference in recall accuracy in study length ($\chi^2(2) = 15.00$, $p < .001$), with a recall accuracy of 68.5% for participants in the short length, 62.4% in the medium length, and 59.9% in the long study length. Following this the medium length of 16 items per colour was used for the recall element of the final study. Pilot results also showed a significant difference between edibility (65.3% correct) and toxicity (59.7% correct) in recall accuracy ($\chi^2(1) = 9.33$, $p = .002$), and in response type (false positive, false negative, true positive, true negative) between the toxicity and edibility conditions ($\chi^2(3) = 22.80$, p < .001).

2.2. Materials

2.2.2 Questionnaires

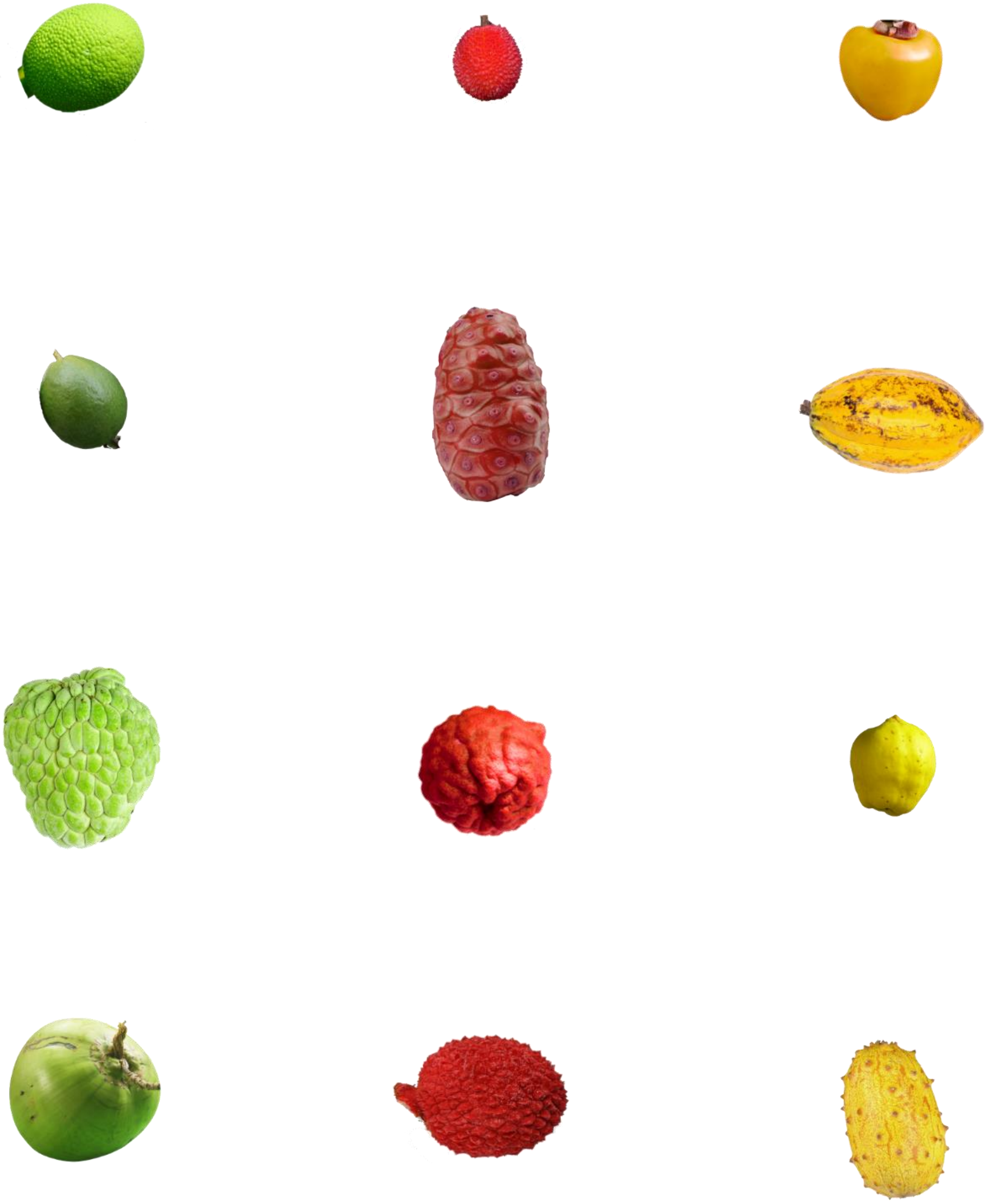
To measure the role of anxiety and related traits, participants completed three separate questionnaires. Firstly, to measure state and trait anxiety levels participants completed the State Trait Anxiety Inventory for Adults (STAI; Spielberger et al. 1983; published by Mind Garden inc.), which has been used in previous research measuring anxiety in relation to risk perception (e.g., White et al., 2016). We also looked at the anxiety related personality facet, emotionality, of the HEXACO personality model (Lee & Ashton, 2018), which has been linked with specific phobias (Ashton et al., 2008), and with domain-specific risk-taking behaviour in the health domain (Weller & Tikir, 2011). Previous literature has indicated domain specificity in anxiety effects, such as higher sensitivity to negative emotions in faces in individuals with social anxiety (Machado-de-Sousa et al., 2010), face recognition in social phobias (Coles & Heimberg, 2005), higher recall of unlikeable trait words in participants high in social anxiety (Claeys, 2007), and content specificity in attention to threat (Pergamin-Hight et al., 2015). We therefore also included the food specific measure of food neophobia, the Food Neophobia Scale (FNS; Pliner & Hobden, 1992), which has been shown in children to influence inductive reasoning of food stimuli (Rioux, Leglaye, et al., 2018) and linked with anxiety (Maiz & Balluerka, 2018; Maratos & Sharpe, 2018).

2.2.1 Stimuli

The stimuli were comprised of images of possible foods that were of 3 different colours, either red, yellow, or green, with 23 of each colour (see Figure 3. For example images). The final 69 images used were from a larger selection of 88 images that were piloted for familiarity and colour categorisation. 30 participants were asked to record their familiarity with the images (whether they had seen it before, and if they could name it), and to record what colour they considered it to be. The final image selection were those items least familiar, and which had the clearest colour categorisation. The initial selection of potential images were chosen to be of food items relatively unfamiliar items to the UK sample, and to be perceived by participants to belong to one of the three colour categories noted above; some images were edited to remove the background and enhance or change the colour.

All images were presented within an image size of 750 x 500 pixels, to account for variance in possible screen size of participants.

Figure 3. Example stimuli images



3. Results

Our primary analyses were conducted using binomial generalised linear mixed effects models (GLMM) with a logit link function, fitted in R using R Studio (version 4.1.3; R Core Team, 2020; R Studio Team 2019) using the *lme4* package (Bates et al., 2015). The use of GLMMs here allows us to account for elements of non-independence in the study design, specifically the multiple responses per participant within the independent conditions. Moreover, this method allows the inclusion of stimulus item as a random effect, allowing for us to account for variation amongst our stimuli set.

Across the different models specified below, we modelled Experimental Condition, a factor with 3 levels (Edibility, Toxicity, Neutral), and Occurrence, also a factor with 3 levels (Low, Medium, High). Occurrence refers to the rate at which the feature occurred (e.g., "is toxic, "is edible") in the presentation phase. As noted above, this was mapped onto the three colours, where items of one colour had the property at a Low Occurrence (e.g. 25% of items "is toxic", 75% of items "is not toxic"), another colour a Medium Occurrence (50% "is toxic", 50% "is not toxic"), and the final colour a High Occurrence (75% "is toxic", 25% "Is not toxic"), with colour-occurrence correspondence counterbalanced across participants. Occurrence therefore represents the degree to which a colour category predicted the property being present in that colour category

In addition, we included Age, Sex, item Response Time and Presentation Time, Trait Anxiety, Emotionality, and Neophobia. When included, Age, Trait Anxiety, Emotionality and Neophobia were standardised (Z-score transformation; grand mean centred and standardised via standard deviation division), and time variables were log transformed. Due to the high correlation between Trait Anxiety and State Anxiety in our sample (r = .79, t (161) = 15.441, *p* < .001), we did not include both in our models. Trait Anxiety was included over State

Anxiety as a measure of anxiety due to its use in previous literature examining the effects of individual differences in anxiety on decision making (e.g., Maner & Schmidt, 2006).

3.1. Generalisation

To examine the effect of information type on generalisation we ran a series of binomial GLMMs with generalisation rate as the outcome variable. Generalisation was coded as present if a participant indicated that an item had the property (e.g., “is edible”), and not present if they said an item did not have the property (“is not edible”), for the items in the response phase that participants had not seen in the presentation phase.

Hypothesis testing was done via model comparison, comparing full models including the hypothesised terms of interest to a simpler nested model without these terms (Bolker et al., 2009). We compared a baseline model including demographic information (Age, Sex) and possible nuisance variables (Colour, Response Time, Hunger) as fixed effects, along with participant and stimulus item as random effects, to an experimental model also including the fixed effects of Occurrence and Condition and their interaction to test predictions 1 and 2, and to further experimental models also including anxiety measures to test prediction 5. The addition of Occurrence and Condition did offer significant model improvement relative to the nested model, supporting predictions 1 and 2. Yet, the broader models including anxiety measures did not offer significant improvement, contradicting prediction 5. The selected model included a significant main effect of Occurrence ($\chi^2(2) = 62.83$, $p < .001$) and a significant Condition*Occurrence interaction ($\chi^2(2) = 24.70$, $p < .001$). However, no main effect of Condition was found ($\chi^2(2) = 1.94$, $p = .380$), indicating that the effect of Condition differed depending on level of Occurrence. There were also no main effects of Colour, Age, Sex, Response Time or Hunger.

To examine whether participants' generalisation rate was sensitive to the rate at which they had observed the property occur, we examined the main effect of Occurrence comparing generalisation rate between each level of Occurrence. Pairwise comparisons were conducted using the *emmeans* package in R, with p-values adjusted for using the Tukey method (Lenth, 2021). These comparisons showed significant differences between each level of Occurrence (see Table 1). Indeed, this suggests that participants generalised a property differently depending on the predictive power of that category for the property, with participants generalising more when the category predicted the property to occur at a High rate, and less at a Low rate, relative to the Medium rate. Moreover, this indicates that participants were sensitive to the colour induced categories representing Occurrence.

Table 1. Pairwise comparison of generalisation rate between levels of Occurrence (model predicted values)

Comparison (Occurrence)	Odds Ratio	SE	p-value
High - Med	1.33	0.07	**=.004**
Med -Low	1.57	0.14	**<.001**
Low - High	0.48	0.04	**<.001**

Note. P-values were adjusted using the tukey method for a family of 3 estimates.

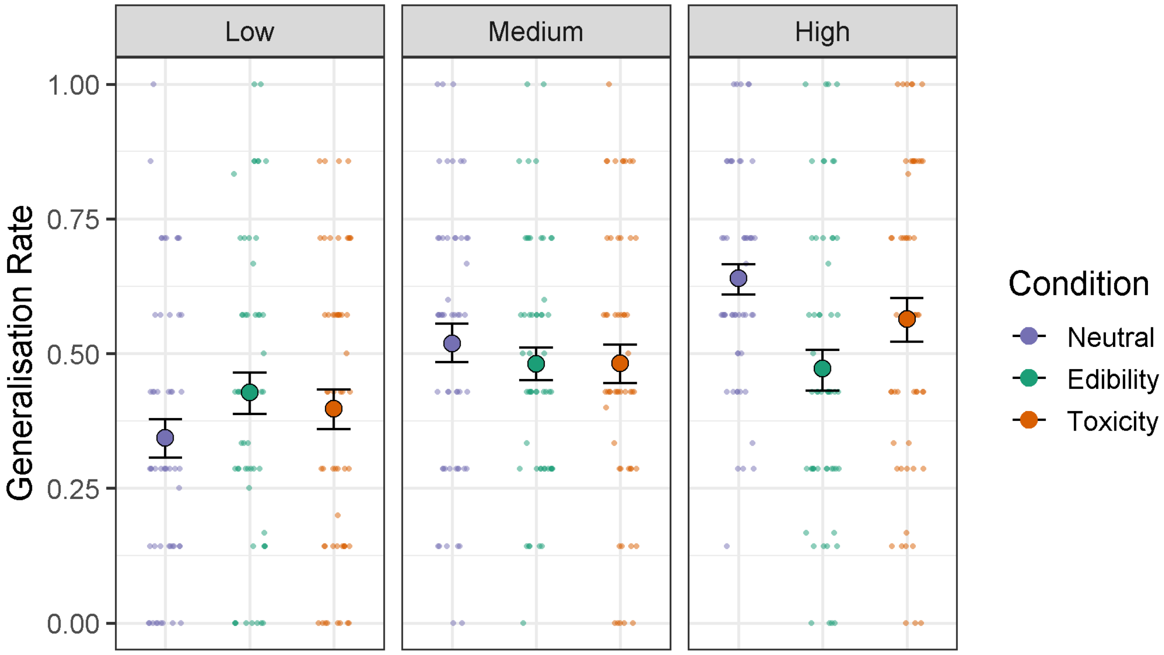
To test predictions 1 and 2— that toxicity information will be generalised at a higher rate and edibility information at a lower rate than control information, and that this effect will be greater under uncertainty—we examined the interaction between Occurrence and Condition further by conducting pairwise comparisons of Condition within each level of Occurrence. We found a statistically significant difference between Edibility and Neutral conditions within the High level of Occurrence (see Table 2; Figure 4). This offers some support for prediction 1 in that, at least in the High rate of Occurrence, edibility information appears to be generalised less than neutral information. However, we found no effect of toxicity information relative to neutral information at any level of Occurrence. We also found no evidence in support of prediction 2, with no effect of Edibility or Toxicity at the Medium level of Occurrence (where 50% of items had/did not have the property). These results indicate that, in contrast to the results Rioux, Russell & Wertz (2022; Chapter 2), the effects of information type on generalisation are not greater under higher uncertainty, and in particular, this effect is only present when the category from which participants are generalising predicts the property at a high rate.

Table 2. Pairwise comparison of generalisation rates between levels of "Condition" within each "Occurrence" (model predicted values)

Occurrence	Comparison (Condition)	Odds Ratio	SE	p-value
High	Neutral - Edible	2.06	0.39	**= .005**
	Neutral – Toxicity	1.50	0.29	= .477
	Edible - Toxicity	0.73	0.14	= .779
Medium	Neutral - Edible	1.18	0.22	= .994
	Neutral – Toxicity	1.30	0.25	= .915
	Edible - Toxicity	1.10	0.21	= .999
Low	Neutral - Edible	0.69	0.13	= .595
	Neutral – Toxicity	0.852	0.17	= .996
	Edible - Toxicity	1.23	0.24	= .976

Note: Subset of all condition:occurence pairwise comparisons. P-values adjusted using the Tukey method for a family of 9 estimates.

Figure 4. Generalisation rate by Occurrence (Low, Medium, High) and Condition.



Note: This figure presents raw mean generalisation rates by participant (small dots) and grouped by condition (large dots), within each level of rate.

Table 3. Pairwise comparison of generalisation rate between levels of "Occurrence" within each "Condition" (model predicted values)

Condition	Comparison (Occurrence)	Odds Ratio	SE	p-value
Neutral	High - Med	1.68	0.09	**= .027**
	Med - Low	2.15	0.34	**< .001**
	Low - High	0.28	0.04	**< .001**
Edibility	High - Med	0.96	0.16	= 1
	Med - Low	1.26	0.20	= .857
	Low - High	0.83	0.13	= .950
Toxicity	High - Med	1.45	0.11	= .282
	Med - Low	1.42	0.22	= .370
	Low - High	0.48	0.06	**< .001**

Note Subset of all condition:occurence pairwise comparisons. P-values adjusted using the Tukey method for a family of 9 estimates.

Pairwise differences between Occurrence within each level of Condition showed some significant effects (see Table 3). In the Neutral condition, significant pairwise differences were observed between all three levels of Occurrence, indicating that in this condition participants' generalisation rate differed reflecting the rate at which the colour category predicted the property (25%, 50%, or 75%) in the presentation phase. In contrast, this was not the case for Edibility and Toxicity conditions. No difference was found in generalisation rates between the different levels of Occurrence in the Edibility condition, suggesting that when generalising edibility information, the rate at which the feature occurred does not have a significant influence. In the Toxicity condition, whilst a statistically significant difference was observed between the High and Low levels of Occurrence, no effect was found between Medium and Low or Medium and High levels of Occurrence. This would suggest that for information where generalisation errors are more costly such as about edibility and toxicity, participants show minimal or no sensitivity to the rate at which a property is present in a category.

To examine the interaction between Condition and Occurrence further, we compared participants generalisation rate for each level of Condition at to the rate at which they observed the property occurring (i.e., we compared the rate at which participants generalised to the rate at which they observed that property occurring in the presentation phase; 75% in the "High" Occurrence level, 50% in "Medium" Occurrence, and 25% in "Low" Occurrence). Due to non-normality this was done using Wilcoxon signed rank tests, comparing generalisation rate in each condition within each level of Occurrence to the rate at which participants had seen the property occur (see Table 4). For High and Low Occurrence participants' generalisation differed significantly from the presentation occurrence in all conditions, being lower than 75% and higher than 25% respectively. Suggesting an overall overestimation for items from the Low Occurrence, and underestimation for items from the

High Occurrence, irrespective of Condition. In the Medium rate generalisation did not differ from the rate in any condition, with generalisation being not different from chance rate in all conditions. This is in contrast with prediction 2, and conflicts with the findings from Chapter 2.

Table 4. comparison of median generalisation within each level of Occurrence and Condition to presentation rate.

Occurrence	Condition	V	p-value
High (0.75)	Neutral	324.5	**= 0.001**
	Edibility	134	**= 0.001**
	Toxicity	300	**= 0.001**
Medium (0.5)	Neutral	728.5	= 0.911
	Edibility	553	= 0.214
	Toxicity	588.5	= 0.261
Low (0.25)	Neutral	919	**= 0.036**
	Edibility	1183	**< 0.001**
	Toxicity	1136	**< 0.001**

Note: Wilcoxon signed rank tests used due to normality assumptions being violated in certain rows.

Given the binary response nature of the task we ran additional analysis to compare generalisation in each level of Occurrence and Condition to chance performance, using the same analysis methods noted above (see Table 5.). We found that in the Low Occurrence generalisation differed from chance in all levels of Conditions, being below chance in all instances, suggesting participants were sensitive to the lower presentation Occurrence. However, in the High Occurrence only generalisation in the Neutral Condition differed from chance. The Medium rate predicted chance performance and as such is an identical analysis to than noted in the previous paragraph. This corresponded to an overall generalisation rate (across levels of Occurrence) being significantly below chance rate (0.5) in the Edibility Condition (V = 4821, *p* = .006) but not the Toxicity (5459.5, *p* = .094) or Neutral conditions (V = 5746, *p* = .503). Together these findings suggest that for edibility and toxicity conditions participants will reduce their generalisation when faced with indication that the property presence in a category is below chance, but will not correspondingly increase their likelihood of generalisation when faced with evidence that a category has a property at a rate above chance, whereas in the neutral condition participants would increase their generalisation accordingly.

Table 5. Comparison of median generalisation within each level of Occurrence and Condition to chance rate.

Occurrence	Condition	V	p-value
High	Neutral	1014.5	**< 0.001**
	Edibility	599	= 0.216
	Toxicity	877.5	= 0.245
Low	Neutral	262	**< 0.001**
	Edibility	482.5	**= 0.025**
	Toxicity	385	**= 0.003**

Note: Wilcoxon signed rank tests used due to normality assumptions being violated in certain rows. See Table 4 "Medium" for chance rate.

Finally, we ran an additional ANOVA analysis to examine the role of Condition and Occurrence on participants explicit judgement of occurrence. That is, what percentage of the food items of each colour they thought had the property. This analysis revealed a significant main effect of Occurrence (F (2) = 12.99, p < .001), but no main effect of Condition (F (2) = .37, *p* = .692), or a Condition*Occurrence interaction Occurrence Condition (F (4) = 1.69, *p* = .151). Given that participants generalisation rates were sensitive to Occurrence (see Table

1.), but explicit judgements were not in all cases and no effect of condition was observed on these, suggests that participants implicit judgements of a category's predictive power appear to be more strongly influenced by Occurrence and Condition. Moreover, we found a significant correlation between participants explicit judgements (what percentage of items in a colour category they thought had the property), and their generalisation (r = .55, *p* < .001*)*

Table 6. Pairwise comparison of participants' explicit estimates of the rate at which a colour category had the property, by Occurrence

Comparison (Occurrence)	t (df)	SE	p
High - Med	5.48	2.53	= .078
Med -Low	7.04	2.53	**= .016**
Low - High	-12.52	2.53	**<. 001**

Note. P-values were adjusted using the Tukey method for a family of 3 estimates

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3.2. Recall

3.2.1. Accuracy.

As with generalisation we ran Binomial GLMMs to examine whether experimental condition affected recall accuracy (correct/ incorrect). We used the same model selection approach as for generalisation—hypothesis testing comparing full models including the hypothesised terms of interest to a simpler nested model (Bolker et al., 2009). We compared a baseline model including demographic variables (Age, Sex) and possible nuisance variables (Colour, Response Time, Presentation Time, Hunger) as fixed effects, along with Participant and Stimulus Item as random effects, to an experimental model also including the fixed effects of Occurrence and Condition and their interaction. This allowed us to test prediction 3, and also allowed use to examine whether observed rate of occurrence has an effect on recall, as we observed in generalisation. As with the generalisation analyses above, the experimental model including Occurrence and Condition offered significant model improvement compared to the baseline model (χ^2 (8) = 21.51, p = .006). We also compared models including Food Neophobia, Emotionality, and Trait Anxiety to examine prediction 5, and found that the model including Food Neophobia offered significant model improvement (χ^2 (9) = 26.65, p = .002). This resulted in a final model comprised of the baselined model plus Condition, Occurrence and Food Neophobia, along with their interaction.

Within this final model, we found significant main effects of Occurrence (χ^2(2) = 8.38, p = .015), Food Neophobia (χ^2 (1) = 7.64, p = .006), stimulus Presentation Time (χ^2 (1) = 25.52, $p < .001$, and an interaction between Occurrence and Food Neophobia (χ^2(2) = 8.50, p = .014). However, contradicting prediction 3, no main effect of Condition (χ^2(1) = 1.95, p = .378), or interaction between Condition and Food Neophobia was found (χ^2(2) = 1.09, p = .581). Specifically, we found no support for the prediction that there would be greater recall of edibility and toxicity information. Also, in contrast to generalisation we found no significant interaction effect on recall accuracy for Occurrence and Condition (χ^2(4) = 8.19, p = .084). Finally, the fixed effect estimate for Presentation Time was 0.23 ($p < .001$), indicating a positive association between Presentation Time and recall accuracy. These results indicate that whilst there appears to be some influence of Food Neophobia on recall accuracy in the food domain, there is no strong evidence for an interaction with condition and as such contradicts prediction 5, that effects of information type on recall accuracy would be greater for participants higher on anxiety measures. The absence of an overall effect of condition also contradicts prediction 3, with type of information appearing to have no significant influence on recall accuracy in the present study.

In order to examine the effect of Occurrence rate on recall accuracy further, we again ran pairwise comparisons using the *emmeans* package in R (Lenth, 2021). These pairwise comparisons showed significant differences between the Medium and Low occurrence rate (OR = .83, *p* = .005), indicating that in the Low occurrence there was significantly higher mean recall accuracy, than the Medium rate. No difference was observed between the Low and High occurrence rate (OR = 1.10, *p* = .242), or Medium and High occurrence rates (OR =.92, *p* = .288).

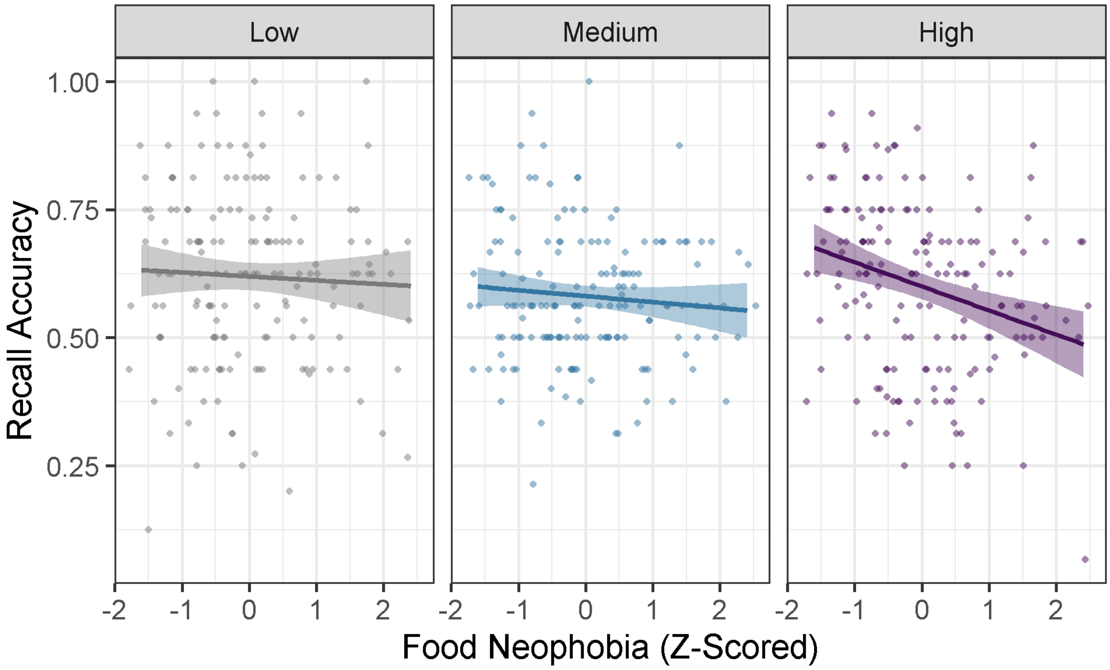
Post-hoc analyses also revealed differences in the effect of neophobia across the levels of Occurrence. The slope of neophobia is significant in the High rate (*p* < .001), but not in the Medium or Low occurrence rates (see Table 7). Pairwise comparisons of the effect of Food Neophobia between the both the High and Low occurrence rates (OR = .90, *p* = .004) and the High and Medium occurrence rates (*p* = .028), but not between the Medium and Low occurrence rates (*p* = .781). It therefore seems Food Neophobia has a negative effect on recall accuracy, but only in the High occurrence rate (see Figure 5). This suggests that that rather than increasing risk minimising patterns in recall, Food Neophobia results in risker recall, being associated with reduced recall for all information types including for that information which is pertinent to survival.

Table 7. Neophobia slopes within between levels of "Occurrence" (model predicted values)

Occurrence	Slope	SE	z	p -value
Low	-.02	.05	-.33	= .742
Med	-.06	.05	-1.14	= .255
High	-.22	.05	-4.18	**< .001**

Note. P-values were adjusted using the Tukey method for a family of 3 estimates.

Figure 5. Recall accuracy by Neophobia and condition.



Note: This figure presents raw mean recall accuracy rates by participant (small dots) and trend, within each level of occurrence. Neophobia grand mean centred and standardised by standard deviation.

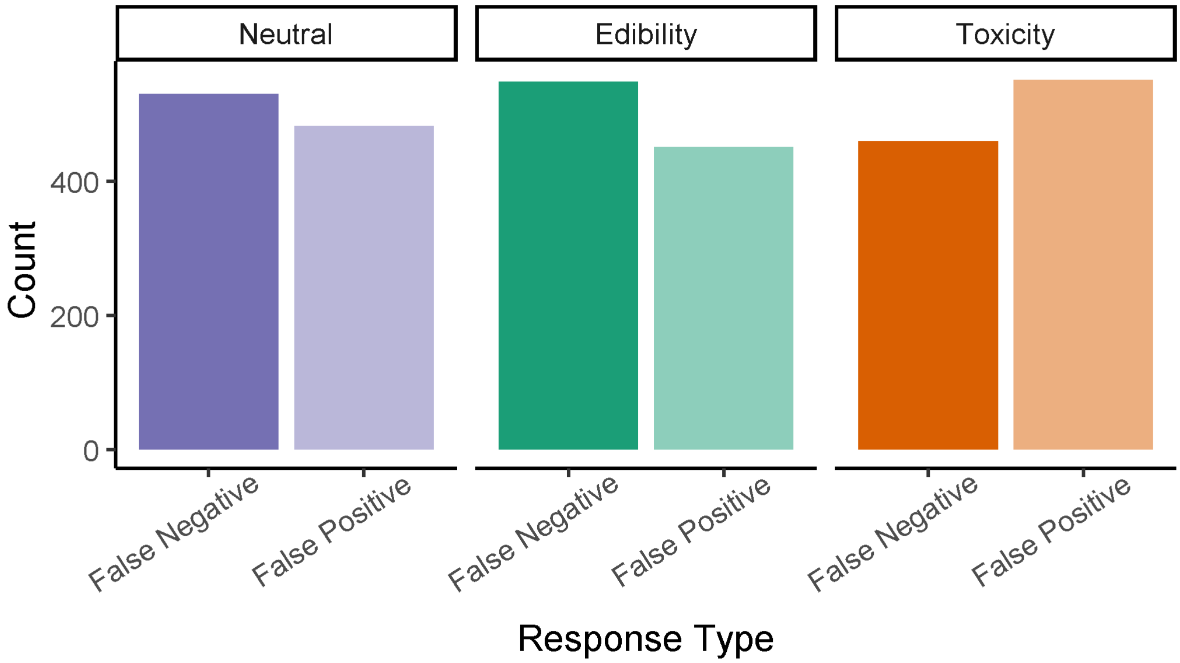
3.2.2 Error type.

We reasoned, following from principles of Error Management Theory, that there may be differences in the recall accuracy for different kinds of information. However, a core principle of EMT is that evolution has shaped cognitive systems to minimise costly mistakes, as such, and following Broesch et al., (2014) we also looked at the kinds of recall errors made, and whether these reflect the relative costs of errors.

Firstly, we examined whether the false positive to false negative rate differed across conditions. We again ran Binomial GLMMs, this time on Error Type (false positive or false negative, where the binary response variable is either false positive (coded as 1) or false negative (coded as 0). Again, we compared a baseline model including the fixed effects of Colour, Age, Sex, Response and Presentation Time, and Hunger, along with the random effects of participant and stimuli item, to experimental models also including condition and anxiety measures. Occurrence was not included in these models due to its inherent imbalance of error-types (e.g., in the Low Occurrence 4 of 16 items had the property, resulting in only 4 opportunities for true positives, but 12 for false positives, with the inverse being true for the High rate). The inclusion of Condition did not significantly improve the model relative to the baseline model (χ^2 (2) = 5.19, $p < .074$). As with the generalisation and recall models above, we also compared models including anxiety measures (STAI, Emotionality, Food Neophobia) and found a significant model improvement for the model including Trait Anxiety and Condition, relative to the baseline model ($\chi^2(5) = 14.525$, $p = .012$).

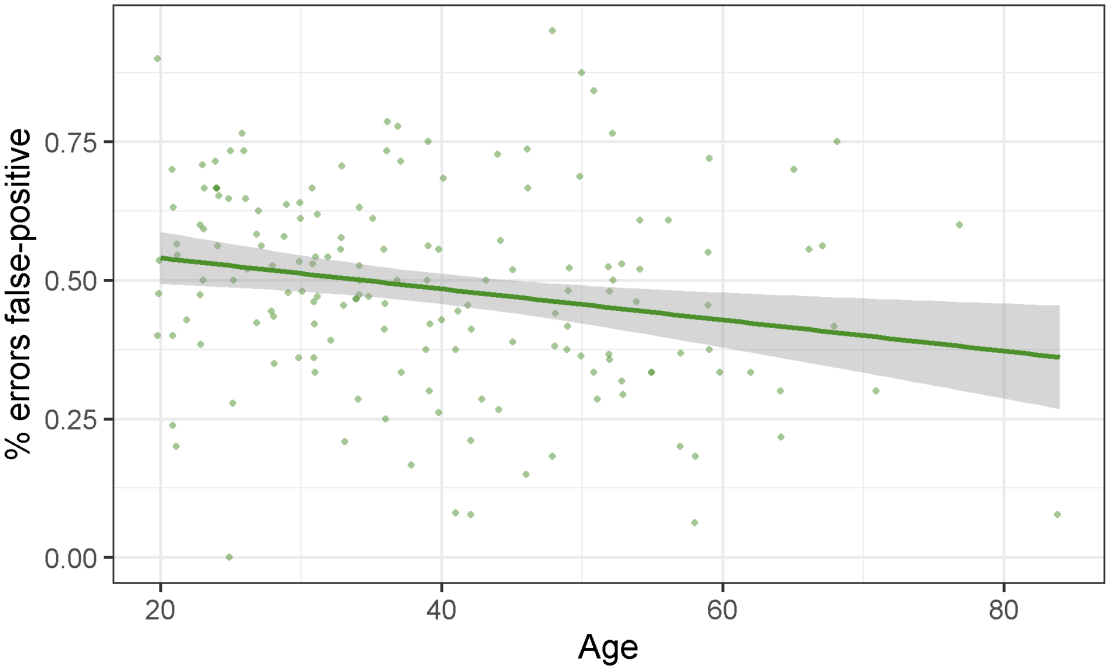
This final model included a significant main effect of age ($\chi^2(1) = 7.91$, $p = .005$), and a significant interaction between condition and Trait Anxiety ($\chi^2(2) = 9.57$, $p = .008$). We found no main effect of Trait Anxiety ($\chi2$ (2) = 0.02, $p = .900$), and whilst there did appear to be a difference in error type between conditions (see Figure 6), this was not significant ($\chi^2(2) = 5.50$, $p = .064$). This offers some limited evidence against prediction 4, indicating that relative rate of false positive to false-negative errors does not vary by condition. Moreover, there appears to be a significant effect of age, with a fixed effect estimate of -.18 ($p < .001$; see Figure 7.)

Figure 6. Raw count data for error type, separated by condition



Note. The false positive to false negative rate was significantly different from chance rate in the toxicity condition, but not the edibility or neutral conditions.

Figure 7. Percentage of errors that were false positives, by age



Note. No mean age differences were found between conditions (F (2), p = .051), with a mean age of 39, 43 and 37 for Neutral, Edibility and Toxicity conditions, respectively.

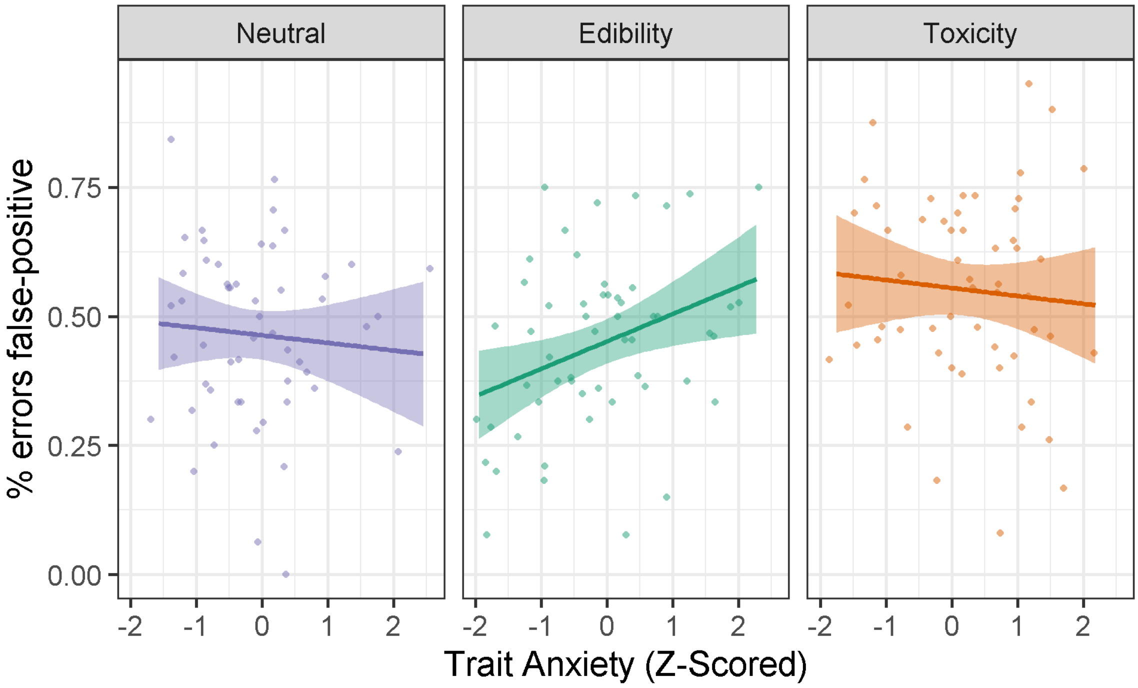
Post-hoc analysis of the Trait Anxiety Condition interaction revealed a significant effect of Trait Anxiety in the Edibility condition, but not the Toxicity or Neutral conditions (see Table 8). Whilst no effect of was found for trait anxiety, it should be noted that trait anxiety differed between conditions, being significantly greater in the toxicity condition than edibility (p < .001), and neutral conditions (p < .001). Pairwise comparisons of the slopes revealed a significant difference between the effect of Trait Anxiety in the Edibility condition and both the Neutral condition (z = -2.51, p = .032) and Toxicity condition (z = 2.722, p = .018), but not between the Neutral and Toxicity conditions (z = 0.151, p = 0.998). This indicates that whilst there is no difference between conditions in the relative rate of errors, there is a difference in how anxiety influences these errors, with greater Trait Anxiety being associated with a higher false positive rate. This challenges the notion of anxiety being a defence mechanism concerned with minimising costly mistakes, as for the edibility domain a false positive is the more costly error.

Table 8. False positive rate by condition and trait anxiety

Condition	Slope	SE	z	p-value
Neutral	- 0.14	0.10	-1.36	= .175
Edibility	-0.20	0.09	2.26	**= .024**
Toxicity	-0.17	0.10	-1.62	= .106

Note. P-values were adjusted using the Tukey method for a family of 3 estimates.

Figure 3. Percentage of errors which were false positive (relative to false negative) by condition and trait anxiety.



Note: This figure presents raw false-positive rates within errors by participant (small dots) and trend, within each level of condition. Trait anxiety grand mean centred and standardised by standard deviation.

In order to directly test prediction 4—that participants in the toxicity condition will show a greater number of false positives relative to false negatives and participants in the edibility condition would show the opposite pattern— we conducted a further analysis comparing False Positive-False Negative rate ***within*** each condition. We compared this rate to what one would expect if there was no difference in error-type (0.5, representing 50% of errors being false positive with 50% therefore being false negative). This analysis showed a significant difference in the toxicity condition (V = 6476, *p* = .030), but not edibility (V = 4551.5, *p* = .065), or Neutral conditions (V = 4145.5, *p* = .077). Wilcoxon signed rank tests were used due to non-normality. That the false positive rate for the Toxicity condition is significantly above chance lends some support to prediction 4 and corresponds with participants minimising costly errors. In the Toxicity condition the false negative is the more costly error, and a false-negative rate significantly below chance is indicative of an error-minimising strategy. However, the above GLMM on response type finding no significant difference between conditions suggests this finding should be taken with caution and requires further investigation.

3.2.3 Yes bias.

It is possible that the finding of a rate of false positives in the toxicity condition reflects an overall bias towards saying an item is toxic irrespective of whether this was a false positive or true positive. Indeed, Broesch et al. (2014) observed that both adults and children showed a tendency to say an animal was dangerous, regardless of whether they had been given information about it. It may be the case that the finding of increased false positives reflects such a tendency here.

To examine whether the error-type reflects overall response patterns we analysed overall responses irrespective of whether they were correct or not. Running identical analysis to the error type analysis run above we found similar effects. Again, the model including a Condition*Trait Anxiety interaction offered significant improvement compared to the model without. ($\chi2$ (2) = 8.681, p = .013). However, no main effect of Age was found ($\chi2$ (1) = 3.15, p = .076) and a significant main effect for Colour ($\chi2$ (2) = 28.69, $p < .001$)[2] was found. We observed the same post-hoc patterns of significance in the Trait Anxiety condition interaction, with the only significant effect of Trait Anxiety being in the Edibility condition (z = 2.28, p = .023), and significant pairwise comparisons found between Edibility and Neutral (z = 2.37, p = .047), and between Edible and Toxicity (z = 2.61, p = .025), but not between Neutral and Edibility (z = 0.108, p = .993).

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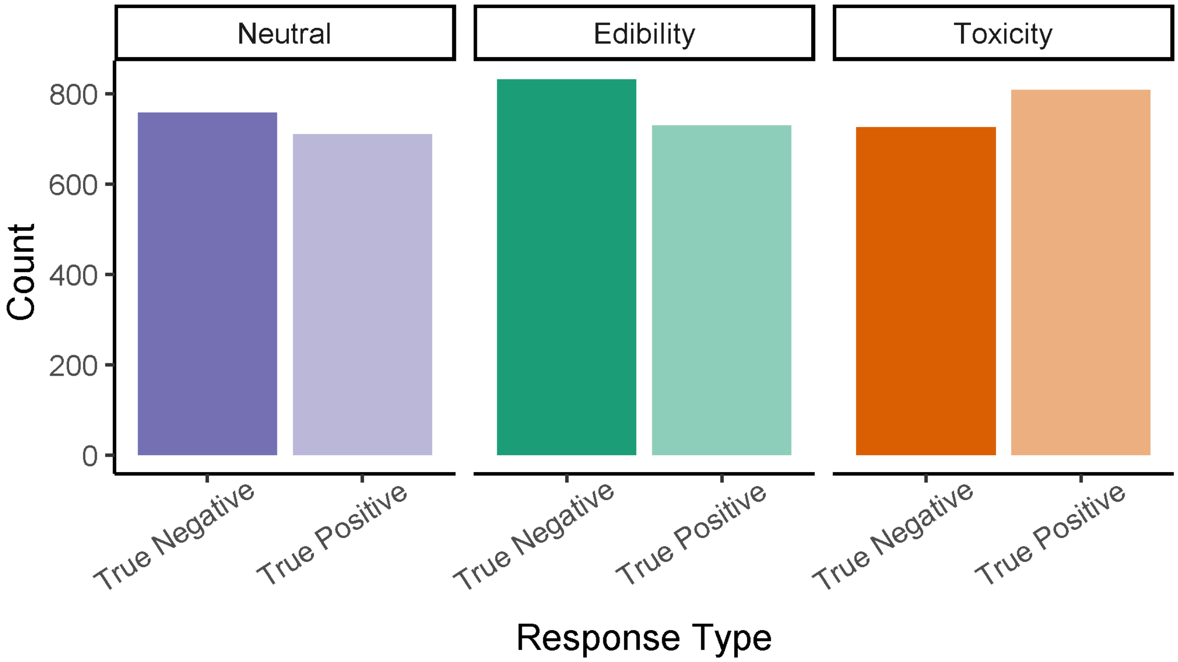
[2] A significant difference was found between yellow and green, and yellow and red in overall response. This was controlled for statistically in the model due to the inclusion of colour as a fixed effect, and item as a random effect. It was experimentally controlled for by counterbalancing across rates, and equal representation across conditions.

Above we noted the relative rate of false-positives to false-negatives in the toxicity condition (see Figure 6) differed significantly from chance, with a greater number of false positives than false-negatives. In order to examine whether this pattern reflects an overall response bias towards stating items are toxic, we ran the same analysis on correct data (true positives, true negatives, see Figure 8). We ran the same analysis, comparing the rate of true-positives (relative to true-negatives) in each condition to the rate one would expect should there be no difference between the error types (0.5). No difference was found in the Toxicity condition (V = 6403, *p* = .350), the Edibility (V = 5272, p = .210), or Neutral conditions (V = 5524, *p* = .424). This would suggest that the observation that false positives occur above chance rate in the toxicity condition is not a function of an overall response bias towards saying items are toxic, lending further support to prediction 4 and the notion that human learning has been shaped to minimise costly mistakes.

Figure 8. Raw count data correct response type, separated by condition.



Note.. No significant difference was found between the true positive to true negative rate and chance in any condition.

4. Discussion

4.1. Selectivity in Generalisation

We looked to examine, in line with predictions based on Error Management Theory and the findings of Rioux, Russell & Wertz (2022, Chapter 2), whether there were content differences in generalisation of edibility information and toxicity information and control information. We did this by conducting a generalisation task where, after seeing images of a number of possible foods from three different colour categories and being told these either had or did not have a property (dependent on condition), participants were asked whether these novel foods of each colour also had the property. Specifically, we predicted greater generalisation of toxicity information, and lower generalisation of edibility information relative to control information (prediction 1). Each colour category predicted the property to occur at a different rate (e.g., 25% of red items may be edible/toxic, 75% not edible/toxic), and we predicted greater effects of information type when the colour category less clearly predicted the property i.e., when 50% of items of that colour had the property, and 50% did not (prediction 2).

We found limited support for prediction 1, that there would be greater generalisation in the toxicity condition, and less in the edibility condition, relative to the control, with the only significant comparison being between the edibility and control conditions within the High occurrence rate. This finding is in the predicted direction, with participants generalising edibility information at a lower rate than control information. Indeed, this seems to reflect an overall more cautious generalisation strategy for edibility information, with this information type demonstrating an overall generalisation rate below chance, and a more limited sensitivity to the observed property occurrence rate than the toxicity and neutral conditions.

However, that we only observed an effect of information type in the High but not Medium (most uncertain) occurrence rate contradicts prediction 2 that the effects would be greatest under uncertainty, that is, when the colour category does not clearly predict the presence or absence of the property.

In all levels of occurrence rate, participants in the edibility and toxicity conditions generalised at chance or below chance (see Tables S2, S3 in the SI). This suggests that even when participants see evidence that a colour predicts items within that colour category having a property at a high rate (e.g., 75% of red items), participants in the edibility and toxicity conditions were still reluctant to generalise this to other members of that category (e.g., other red items), generalising at a rate no different from chance, whilst participants in the control condition (i.e., grows in summer) did generalise at a higher rate than chance. However, participants in the edibility and toxicity conditions reduce their generalisation rates when there is evidence that items in a colour category have a property at a low rate (e.g., 25% of the green items were toxic in the presentation phase). Taken together, these findings suggest an overall conservative approach in these conditions, with participants in the toxicity conditions reducing their generalisations when generalising from a category that predicts the property at a low rate, but not increasing them when the colour category predicts the property at a higher rate, where for neutral information generalisation is adjusted in accordance with the rate a category predicts a property. One plausible explanation for this could be an overall conservative threshold for information use where generalisation mistakes are costly (edibility, generalisation), with greater degree of evidence needed to generalise differently from chance for these information types. This is consistent with predictions and an error minimizing strategy for edibility, where false negatives are costly, but not for toxicity, where false negatives are the more costly error and would predict the opposite pattern. Finally, whilst not the primary examination here, these findings demonstrate that the predictive power of a category for a property directly relates to the generalisation of that property to novel category members, at least for neutral information.

This pattern of generalisation observed here is consistent with our hypothesis and the findings of Rioux, Russell & Wertz (2022., Chapter 2) that edibility information should be conservatively generalized, however, it directly contradicts the prediction of greater generalisation of toxicity information. Moreover, it challenges the finding of Russell, Rioux, & Wertz (in prep., Chapter 2) finding greater generalisation of toxicity, and less generalisation of edibility information under uncertainty, neither of which were found here. Instead, we see a pattern of generalisation which suggests conservative generalisation of evolutionarily relevant information, irrespective of the assumed asymmetry in the cost of errors.

4.2 Selectivity in Learning

We also looked to test further the finding that humans have biases in memory for evolutionarily relevant information and associations. This was done through a recall task where participants saw a series of images of possible foods along with whether these items had or did not have a property (edibility, toxicity, or neutral), and then saw these items again in a recall phase and asked whether they had or did not have said property. Based upon the principles of Error Management, and research indicating preferential learning for evolutionarily relevant information (Barrett & Broesch, 2012; Broesch et al., 2014; Nairne et al., 2009; Stubbersfield et al., 2015), we predicted greater recall for edibility and toxicity information relative to control information, and a different pattern of mistakes for each information type, with more false positives than false negatives in toxicity, more false negatives than false positives in edibility, and no difference for control information.

In direct contradiction to our predictions, we found no clear effect of content on recall accuracy. Contrary to evidence showing greater recall for danger information in children (Barrett et al., 2016; Barrett & Broesch, 2012; Broesch et al., 2014), and for threat and survival relevant information in adults (Leding, 2019; Nairne et al., 2007; Nairne & Pandeirada, 2008; Stubbersfield et al., 2015), we found no preferential retention of danger information about foods in adults, consistent with Broesch et al. (2014)'s similar finding for adults learning about dangerous animals. We also found no preferential recall of edibility information. This finding raises questions as to why selective learning has been found in adults for some kinds of threat and survival relevant kinds of information, but not for danger information or edibility information. All of the information types outlined above are *prima facie* important for survival and have costly mistakes. As such further work should compare these information types directly. One possible methodological distinction is that work finding an effect for threatening and survival related information in adulthood used word base recall tasks (e.g., Leding, 2019; Nairne et al., 2007), where the present study and that of Broesch et al. (2014) used an image-based task. It may be the case that different kinds of stimuli elicit different informational effects for adults, and further work should examine survival information advantages with image-based stimuli, and danger information with text stimuli.

In addition to increased recall accuracy for edibility and toxicity information (prediction 3), we also predicted that there would be a difference in kinds of mistakes made for the different kinds of information (prediction 4). Specifically, we predicted a greater number of false positives than false negatives in the toxicity condition, and the reverse pattern in the edibility condition, with no difference between false positives and false negatives in the control condition. Whilst condition was not a significant predictor of the kinds of mistakes made in our primary models, when looking within each condition we did find a difference between false-positives and false-negatives in the toxicity condition. This offers partial support for the prediction that errors in recall would reflect cost asymmetries, with this appearing to be the case for toxicity but not edibility information. Specifically, the greater number of false-positives relative to false negatives in the recall of toxicity information is consistent with a cost minimising strategy, with a reduced rate of the costly false negative in this domain supporting the Error Management Theory derived prediction of learning systems shaped to minimise costly errors.

However, where Broesch et al. (2014) observed an overall response bias towards saying something is poisonous or dangerous, irrespective of information provided, we did not observe this effect. We found an inflation of saying the property is present, but only when participants made errors (i.e., a bias for false-positives relative to false negatives), but not when correct responses were made (no bias for true-positives relative to true-negatives). This provides evidence that there is not a general response bias for saying a food item is toxic— if this were the case, we would expect an inflation of “this is toxic” in overall responses, irrespective of whether a mistake was made or not.

Finally, given we did not see greater generalisation of toxicity information (see section 4.2.1) this may suggests differing strategies for risk minimisation where a participant does not know the answer for an item they have seen before, vs a novel item. Indeed, we observe error minimising strategy of favouring false positives is present when participants do not know the correct answer for familiar items (greater false positives in recall errors), but not unfamiliar items (no greater generalisation of toxicity information).

4.3. Individual Differences

In addition to the hypothesised effects of information type on generalisation and recall, we predicted that anxiety would predict greater effects in both cases. That is, for generalisation we predicted higher anxiety to correspond to greater generalisation of toxicity information and less generalisation of edibility information. And in recall we predicted higher anxiety to be associated with greater recall accuracy of edibility and toxicity information. No effect of anxiety was found in generalisation for any of our measures (Trait Anxiety, Food Neophobia or Emotionality). This contradicts the prediction of increased anxiety corresponding to greater error management in the generalisation of evolutionarily relevant information.

Anxiety also did not appear to affect how different kinds of information were generalised. Anxiety related traits also only showed minimal effects on recall accuracy, with Food Neophobia being the only trait yielding significant effects. Participants higher on food neophobia showed reduced recall accuracy, but only for the colour category that predicted the property at a high rate in the presentation phase. Whilst contradicting the prediction of greater recall for danger and edibility in information for those high on anxiety, this pattern could indicate a cautionary strategy, with participants higher on neophobia reporting items as not having a property, even when presented with evidence of that category of item having the property at a high rate. Whilst to our knowledge food neophobia has not previously been linked with poorer recall accuracy, this finding is consistent with Rioux, Leglaye, et al. (2018), who observed food neophobia to be associated with poorer inducive reasoning, and further research demonstrating anxiety to be linked with poorer recall performance (e.g., Andreoletti et al., 2007; Cassady, 2004). This Food Neophobia effect also challenges the notion of anxiety being a function of a spuriously activated defence system as has been implied by Nesse (2001, 2005), as such a defence system should favour the recall of evolutionarily relevant information, and this should be greater in anxiety related traits such as Food Neophobia, where our results indicate the opposite.

Similarly, we observed an effect of anxiety on the type of recall errors observed. Specifically, we see an interaction between trait anxiety and information type, with trait anxiety being positively correlated with false-positive rate in the edibility condition. This means that individuals who score more highly on anxiety were *more* likely to make the costly error of a false positives (recalling something as edible when it is not) than those low on anxiety. This counterintuitive finding again challenges the role of anxiety as spurious activation of a cautionary principle. Such a principle would favour error minimisation which in the case of edibility should manifest as reduced false positives relative to false negatives, as the cost of a false positive (saying something that is not edible is edible) is greater than the cost of a false negative (saying something that is edible is not), with anxiety eliciting greater effects. As with the effect of neophobia on recall accuracy we see the opposite pattern suggesting that, relative to the goal of minimising errors, higher anxiety predict worse performance.

4.4. Limitations and Future Directions

The present project is limited by a number of factors for which further work develop to shed further light on the role of information type on learning and generalisation. First amongst these is the use of colour categories. Colour has been shown to be a core feature of food categorisation (Hayakawa et al., 2011; Macario, 1991; Rioux et al., 2016), and as such was used in the present study to elicit the categories to which rate was mapped. Indeed, we found that participants' generalisations were sensitive to rate, indicating colour functioned successfully for this purpose in the present study. However, it is plausible that colour has an influence on learning and generalisation outside of this. We found a colour difference between yellow and red and yellow and green in overall response bias in the recall task, with participants more likely to recall yellow items at having a property, regardless of whether this was correct. Whilst colour was controlled for statistically, and methodologically via counterbalancing, the role of colour was not the primary aim of the present work, and that we found a colour effect here could suggest further work is needed investigating its role more directly. Indeed, in non-human animals certain colours have been found to elicit faster learning (Rönkä et al., 2018), and to be perceived as threat signals (Ninnes et al., 2015; Ninnes & Andersson, 2014), factors which should be further investigated in humans. For example, building upon work such as that demonstrating selective associations of fear with certain stimuli (e.g. DeLoache & LoBue, 2009; see Öhman & Mineka, 2001 for review), further work could test whether certain colours are more readily associated with certain properties in the food domain, or building on the effect observed in the present study, whether certain colours elicit an overall liberal tendency towards property attribution in the food domain, as observed here for yellow.

An additional, related, limitation of the present study Is the multidimensionality of food. That is, foods can differ along multiple dimensions, and whilst colour is important in food categories (Macario, 1991), so too is shape (Rioux et al., 2016). In order to use real foods, the present study used colour as a categorising dimension. However where natural foods were used in the present study to allow a greater degree of external validity, this meant that other dimensions of their visual appearance was not controlled. Future work should look to investigate the role of different dimensions in food generalisation further, this would reduce uncertainty about the dimensions on which participants categorised, moreover it would help make clearer the debate around the role of colour and shape in food categorisation (Macario, 1991; Rioux et al., 2016), along with other possibly defining features such as texture. Indeed, the present dissertation had begun testing such a study, examining the role of colour and shape in food property generalisation in infancy, however this was unfortunately cancelled do the onset Covid-19 pandemic.

Finally, whilst the present study looked to examine generalisation, alternative explanation for performance could exist. In particular, the distinction between a false memory and generalisation. It is possible that items in the recall phase were not recognised as having been seen before, and as such decisions were generalisation based. Inversely, it could be the case that participants in the generalisation trials incorrectly thought they recognised an item, and as such responded according to a false memory. Indeed, in the field of false memory research it has shown emotion to have an influence on false memory, with differences for positive and negative valance (Bookbinder & Brainerd, 2016; Kaplan et al., 2015; Pesta et al., 2001). In the present study we have no means to examine whether responses for novel food items were a function of generalisation, as intended, or false-memories. Further research can examine the role of these two possibilities by testing the false memory for information pertaining to edibility and toxicity of foods, for example by asking participants in explicitly whether they recognise an item as having been seen before, or by using methods used in false memory research (Coane et al., 2007; Pesta et al., 2001; Roediger & McDermott, 1995).

4.5. Conclusions

The present study looked to test whether generalisation and recall of learned information is influenced by the type of information learned (edibility, toxicity, neutral) to reflect evolutionary recurring asymmetries in the cost of mistakes for these kinds of information. We also looked to test the role of uncertainty in the generalisation of different kinds of information, in particular, the role of a category’s predictive power for a property on how that property is generalised to novel category members. Finally, we investigated how individual differences, specifically anxiety and food neophobia, on how these different types of information are learned and generalised.

Overall we found evidence of an error minimising strategy for the generalisation of edibility information, with participants generalising this information at a lower rate overall. This is consistent with Error Management Theory predictions, with false positives being the more costly mistake and therefore greater generalisation of edibility could prove costly. However we did not observed differences in generalisation between information type, except when a category had high predictive power, wherein a difference was observed between edibility and neutral information. Again this supports the notion of an error minimising strategy for generalisation of edibility information, yet, we did not observe the predicted similar approach in the generalisation of toxicity information, with no increased generalisation being observed.

We found that where participants generalisation of neutral information differed to reflect the rate at which a category predicted the property, this was not the case for evolutionarily relevant properties (edibility, toxicity). Relative to the medium rate participants would not generalise these properties less for colour categories that were shown to have the property at a low rate, nor show increased generalisation when the property was predicted at a higher rate. When generalising this kind of information where mistakes may provide costly, it appears participants show *less* sensitivity to the predictive value of a category for that information, than they do for neutral information.

No differences were found on recall accuracy for different information types, however our analyses did reveal that, when mistakes were made, participants in the toxicity condition made more false positives than false negatives, reflecting the relative costs of these mistakes. This offers some support to the notion of a learning system calibrated to minimise costly mistakes. That this kind of effect was not observed in the edibility condition suggests a limited scope to this effect and requires further investigation.

Contrary to our predictions, we found no evidence of anxiety being a protective system and therefore increasing error management biases. Generalisation did not appear to be affected by anxiety, yet we did see an effect of Food Neophobia on recall accuracy, and of Trait Anxiety on error type. Participants higher on Food Neophobia showed reduced recall for information, irrespective of condition, for items in the colour category that predicted the property at a high rate in the presentation phase. This challenges the notion of anxiety enhancing risk minimisation in learning, rather, shows food neophobia to increase rather than decrease accuracy. Whilst this is not consistent with error minimisation, it could be the case that the avoidance of novel foods that characterises food neophobia could extend to learning about information, a possible outcome that warrants further investigation. Moreover, it was observed that Trait Anxiety offered a significant effect on false positive rate in the recall of edibility information. People higher in trait anxiety showed a higher false positive rate, a strategy which, like the effect of Food Neophobia on recall, contravenes error minimising principle. These findings indicate that anxiety and related traits are not an overactivation of defence mechanisms, and show anxiety to increase not decrease risk-increasing responses.

In conjunction these findings offer support for a generalisation system that is biased to reflect costly errors, however this seems only to be the case for edibility information. Moreover, where previous research has demonstrated shown a learning bias towards certain information types we did not observe similar effects, raising questions as to possible domain differences in learning biases. Finally, where it was predicted that anxiety would increase risk minimising behaviours, Trait Anxiety and the anxiety related Food Neophobia both decreased what could be considered risk minimising strategies, challenging about the notion of anxiety as a risk minimising system.

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Chapter 4: Selective Edibility of Plants: A Replication of Wertz & Wynn (2014)

1. Introduction

For humans and non-human species successful food acquisition is of vital importance for survival. Organisms must manage the need for resources with the possible risks of gathering such resources. In addition to the obvious risk of predation posed by threatening animals (Barrett, 2015), gathering from plants also poses risks to animals and humans alike, in the form of physical defences and toxic compounds (Belovsky & Schmitz, 2006; Keeler & Tu, 1983; Manners, 1996; Mithöfer & Boland, 2012; Wertz, 2019; Wertz & Wynn, 2014b; Włodarczyk et al., 2018). One way to safely navigate these risks is to learn what in one's environment is dangerous. However, an issue any learning organism faces is identifying what to learn. Out of the variety of associations, and interactions an organism faces, its learning machinery must decide what is important to retain. For example, there are a great many things one could learn about a fruit: its texture, its smell, how it looks, how juicy it is, whether it has seeds, what time of year it grows, whether it has medicinal or functional uses, if it is edible, if it needs to be prepared. All of this information may be valuable, but some might be more valuable than others, for instance knowing something is highly toxic may have more survival value than knowing it is firm. Of the swathes of different objects and situations one encounters, the mind must solve the complex problem of what to retain. One possible solution to this problem is for some associations or information to be learned more readily than others, specifically information of ecological importance such as food risks (see Gallistel, 2000; Gallistel et al., 1991; Seligman, 1970; Seligman & Hager, 1972).

One example of such selectivity in how learned associations are made is research on food aversion. Seminal research by (Garcia & Koelling, 1966) demonstrated that, in rats, a shock would be readily associated with an audio-visual stimulus, but not a gustatory one, and nausea would be readily associated with the gustatory but not audio-visual stimuli. Importantly, these associations also appear to emerge even after time delays between stimulus and response (Kalat & Rozin, 1973; Revusky, 1968) wherein one might have expected the association to be less clear and thereby less easily made, and even when rats are anaesthetised (Bermudez-Rattoni et al., 1988). Another example of possible preparedness in the domain for food comes from Shettleworth (1973, 1975), who observed that in Golden Hamsters food was an effective reinforcer for certain food relevant behaviours (e.g., scratching/digging), but not food irrelevant behaviour (e.g. grooming). Evidence also exists for selective food aversion learning in humans, with both children and adults learning specific food aversions following chemotherapy or other medical treatments (Bernstein, 1978; Mattes et al., 1987; see Bernstein,1994 for review). Moreover, selective learning of fear has also been demonstrated in humans, with studies having demonstrated preferential learning of fear associations with fear-relevant stimuli such as snakes and spiders(e.g. DeLoache & LoBue, 2009; Öhman & Mineka, 2003; Tomarken et al., 1989), blood (Pury & Mineka, 1997) and guns (Hugdahl & Johnsen, 1989; see also Mineka & Öhman, 2002; Öhman & Mineka, 2001 for reviews).

Yet individual learning is a costly endeavour and learning about the wide variety of possible food sources in one’s environment a not insignificant task. Humans inhabit all continents and, as an omnivorous species who also process a wide range of food, have an enormous ecological environment from which we gather resources, and therefore about which we have to learn. Evolutionary models have suggested that in cases where individual learning is costly, social learning is an adaptive strategy (Boyd et al., 2011; Boyd &

Richerson, 1985; Feldman et al., 1996; Kendal et al., 2018; Oña et al., 2019). Humans are social learners, we can learn from our conspecifics, an ability which has also been observed in non-human species (Avarguès-Weber et al., 2013; Galef & Laland, 2005; Heyes, 1994; Laland, 2004; Laland et al., 1996). The use of social transmitted information about food and foraging has been demonstrated in extensive research across different species (see Galef & Giraldeau, 2001 for review), including rodents (Galef, 2012), birds (Slagsvold & Wiebe, 2011), non-human primates (Gustafsson et al., 2014; Rapaport & Brown, 2008; Schuppli et al., 2016; van de Waal et al., 2013). For example, foraging locations in bumblebees (Dawson & Chittka, 2014), and lobtail feeding innovations in Humpback Whales (Allen et al., 2013). The importance of social influence on food behaviour has also been shown in human children and infants (DeJesus et al., 2018; Hamlin & Wynn, 2012; Shutts et al., 2009, 2013). Indeed, it has been argued that human social transmission too might also be biased towards the transmission of certain information, termed content bias (Henrich et al., 2008; Henrich & McElreath, 2003; Richerson & Boyd, 2005). Indeed, recent research has suggested that in both WEIRD (Western, Educated, Industrialised, Rich and Demographic; Henrich et al., 2010) and comparatively non-WEIRD cultures, human children show greater recall for socially transmitted information about dangerous animals (Barrett et al., 2016; Barrett & Broesch, 2012; Broesch et al., 2014), with Broesch et al. (2014) finding a similar effect for toxicity information.

In addition to children preferentially learning danger information, it has been shown that human adults will preferentially associate fear and certain stimuli (Ohman & Dimberg, 1978; Ohman et al., 1976), and have a learning bias for the preferential retention of survival-relevant information (Nairne et al., 2007, 2009; Nairne & Pandeirada, 2008) and threatening stimuli (Leding, 2019). Moreover, it appears that disgust in particular is the subject of preferential learning, with disgusting images being recalled more than other images, even when those images are also unpleasant (frightening) images (e.g., Chapman et al., 2012; Croucher et al., 2011; Moeck et al., 2021). Previous work has also shown greater retention of contaminated objects (Fernandes et al., 2017), disgusting words (Charash & McKay, 2002), and for the source memory (context) for disgusting behaviour (Bell & Buchner, 2010). This sensitivity to disgust has been argued to serve the function of pathogen and disease avoidance (Curtis et al., 2011; Curtis & de Barra, 2018; Oaten et al., 2009; Tybur et al., 2013)

As part of a broader research program examining the influence of plants on human cognition in general and social learning specifically (see Wertz, 2019), Wertz & Wynn, (2014) applied a similar logic to the domain of plants. Given the importance of plants as a food source for humans, the lack of reliable morphological predictors of plant edibility or toxicity and the cost of individual learning under such circumstances, they predicted that human infants may have specialised social learning strategy to quickly learn about plant edibility. To test this, they conducted a series of experiments testing the hypothesis that infants would more readily associate edibility with plant stimuli than non-plant stimuli. This was done in 6- and 18-month-old infants, using two established methods from cognitive development research: a choice task, where infants are asked explicitly to indicate a preference (e.g., Cheries et al., 2008; Hamlin et al., 2007) and a violation expectation paradigm. The violation of expectation paradigm is based on classic work demonstrating that infants will exhibit longer looking time for novel as opposed to familiar stimuli (Fantz, 1964), and this method has been used to measure infants expectations in a variety of domains such as physics (e.g. Baillargeon, 2016; Baillargeon et al., 1985), theory of mind (Gergely et al., 1995; Oniski & Baillargeon, 2005), social evaluations (Hamlin et al., 2007), and social dominance (Thomsen et al., 2011).

Wertz and Wynn (2014) found than 18-month-old infants would identify fruit taken from a plant stimuli as edible at a higher rate than a fruit from a non-plant stimuli, that is, they would select the fruit taken from the plant at a significantly higher rate than the fruit taken from the non-plant when asked which one they could eat. They also found that 6-month-olds exhibited demonstrated longer looking time for a fruit being taken to the mouth from a non-plant, indicating surprise and therefore that they associate the fruit less with the non-plant than plant stimuli. These findings were taken as evidence that infants selectively associate plants with edibility, and the finding in 6-month-olds has since been replicated (Rioux & Wertz, 2022)

The initial aim of the present project was to replicate and extend the finding observed in 18-month-olds, and examine whether infants also selectively associate plant foods with inedibility. As outlined above, evidence in non-humans suggests that certain stimuli are more readily associated with certain negative outcomes (e.g. Garcia & Koelling, 1966), and similar effects have been observed for snakes and fear in human infants (DeLoache & LoBue, 2009), with some indication that infants are also sensitive to observing others' fear responses (e.g. Hoehl et al., 2008; Hoehl & Pauen, 2017). Building upon Wertz & Wynn (2014)'s finding that infants selectively associate edibility with plants, we reasoned that due to their possibly carrying dangerous toxins or pathogens plants may also be preferentially associated with cues that they are *not* edible. Indeed, in addition to physical threats and toxins (Manners, 1996; Mithöfer & Boland, 2012), it has more recently been argued that plant pathogens may pose a threat to humans (Kim et al., 2020). Previous research has noted that human psychology does seem to be sensitive to the threats posed by plants, with specialised psychological mechanisms, such as behavioural avoidance, helping minimise such threats (Rioux & Wertz, 2021; Wertz & Wynn, 2014b; Włodarczyk et al., 2018). Given disgust has been proposed as a disease avoidance mechanism (e.g., Oaten et al., 2009), and observations that disgusting cues will elicit avoidance behaviours (Ammann et al., 2020), we reasoned infants would selectively associate disgust or distaste, as a cue of inedibility, with plants. Using the same choice procedure used by Wertz & Wynn (2014) we aimed to test whether after seeing a cue of disgust for both items, and being then asked which they prefer, infants would selectively avoid a food from a plant at a higher rate than one from an artifact. That is, would they associate the plant food with toxicity at a higher rate than the non-plant-based food.

Prior to this extension however, we looked to replicate the finding from Wertz & Wynn (2014) of selective social learning of plant edibility in 18- month -olds. Over recent years growing amounts of data support the existence of what has been termed the *replication crisis* in psychology, with a number of large-scale research projects demonstrating a substantial proportion of findings in psychology fail to replicate (Camerer et al., 2018; Open Science Collaboration, 2015; see Shrout & Rodgers, 2018 for a review). Whilst a large focus has been on social psychology (Schimmack, 2020) due to controversies in this field, the systemic problems facing psychology have also been noted in other fields such as clinical psychology (Hengartner, 2018), and importantly for the present study, infant research (Davis-Kean & Ellis, 2019; Frank et al., 2017). As such, we conducted a replication study of Study 1 from Wertz & Wynn (2014), using the same methods and stimuli as the original study. We predicted that, like the original, infants would preferentially associate plants with edibility and therefore choose a fruit from a plant at a higher rate than a fruit from a non-plant, in a force choice task.

2. Study 1: Choice Task Replication

How does one learn what one can and should eat? This is a fundamental problem faced by all species, as if you get it wrong the consequences may be dire. Previous work in animals has shown that certain associations are more easily made than others (e.g., Cook & Mineka, 1990; Garcia & Koelling, 1966), and it has been argued that such selective associations offer fitness benefits by making learning about evolutionarily relevant information, such as food toxicity, more efficient (Seligman, 1970). Wertz & Wynn (2014) looked to examine a similar principle in humans, testing whether infants would preferentially associate plants with edibility. Indeed, in a series of experiments across two age groups and using different methods, they found this to be the case. However, given psychology is facing a replication crisis (Shrout & Rodgers, 2018), and infant methods have come under scrutiny (Peterson, 2016), we looked to replicate this finding prior to developing it further.

Specifically, the present study looks to replicate study 4 of Wertz & Wynn, wherein they observed infants to selectively choose a fruit from a plant object compared to a non-plant object after witnessing edibility cues of both. If, as Wertz &Wynn (2014a) observed, infants selectively associate plants with edibility we predict that after witnessing edibility cues for fruits taken from both a plant and a non-plant stimuli infants would select the fruit from the plant at a higher rate.

This study was pre-registered on the Open Science Framework: https://osf.io/sn73r. The present work diverges from the pre-registration in that the initial condition failed to replicate. As such rather than running the additional pre-registered conditions, we ran additional replication conditions to examine possible causes of the non-replication.

2.1. Method

2.1.1 Participants

The initial replication study consisted of two versions each with 20 infants, resulting in 40 participants. Infants were aged 18 months (, M_{Days} = 20; Female = 21). This sample size of 20 infants per group was determined by a power analysis using G*Power 3.1 (Faul et al., 2007) and was a larger sample than the original study, N = 16 for the condition being replicated. This power analysis was conducted for a two-tailed binomial test, comparing proportion rates found in (Wertz & Wynn, 2014) to the chance rate (for a binary choice) of 50%, and giving 80% power at an alpha level of 5%. Infants were recruited through a participant database, and as in the original study, only full-term infants who heard the language in which they were being tested (i.e., German) spoken more than 50% of the time, were included. Participants are recruited from the area of Berlin and tested in the BabyLab at the Max Planck Institute for Human Development. This study was approved by the institute's ethics committee. The parents of participants provided written consent and were compensated 10 Euros. In the first replication study, Study 1a hereafter, an additional 19 participants were tested but excluded for making no choice (9), or fussiness (10). In Study 1b, an additional 6 participants were tested and excluded for fussiness (4), or making no choice (2).

2.1.2 Materials

The stimuli used in both Studies 1a and 1b were the same realistic-looking artificial plant, and a non-plant control artefact used in both Wertz & Wynn (2014) and the replication by (Rioux & Wertz, 2022), each with four fruits attached (see Figure 1). These fruits were either dried plums or apricots. The plant was approximately 25cm high and 25cm wide and was constructed to resemble a realistic plant in both shape and size. It comprised of artificial stems with dark green artificial leaves attached, four green wires on which the fruit were attached, in a plant pot topped with faux dirt fabric. The artifact stimuli were designed to have similar features to the plant stimuli, but a different configuration. It comprised of a glass cylinder in which sat a smaller foam cylinder at the base, above this were the same type of artificial leaves used for the plant object, but painted silver, along with silver wires to which the fruit were attached. The artifact stimuli measured approximately 24.5cm high and 15cm in diameter.

Figure 1: Plant stimuli (left), non-plant stimuli (right). See Figure 2 below for scale.

Participants parents would also complete The Plant Experience Questionnaire (Wertz & Wynn, 2014a, 2014b; see Rioux & Wertz, 2021 for validation), a questionnaire asking parents about their infants' interactions with plants. Specifically, it is comprised of 4 subscales regarding how often infants (i) interact with indoor plants, (ii) interact with outdoor plants, (iii) eat from plants, and (iv) are prevented from interacting with plants (Rioux & Wertz, 2021). For the present study this included two additional questions asking about the infants' experience with apricots and plums.

2.1.3 Procedure

The method used was closely adapted from that used in the original Wertz & Wynn (2014) paper, with close assistance from the lead author, although some details differed, and these are discussed below. Prior to completing the test session parents were asked to complete the consent forms along with a questionnaire on their child's previous experience with plants and the fruits used in the study. The procedure was comprised of a show phase and a choice phase. For the show phase, infants were sat on their parents’ lap, at one end of a stage facing a closed curtain. E1 was sat at the other end of the stage behind the curtain. In front and to each side of E1 were the two stimuli, one with plums attached and the other apricots. Between these was a dark grey board (approx. 50 x 40 cm) with two white squares upon it. In the first part of the show the curtain was raised and E1 leans forward and says ``hello" (in German, “hallo”) to the infant, while smiling. E1 would then break eye contact and return to being upright. The curtain was then lowered. The curtain was then raised again and the E1 again said hello to the infant, before breaking eye contact again. E1 then turned to one of the objects, removed a fruit and moved the fruit into his mouth making a ‘hmmm’ sound as if considering the food item (see Figure 2., below). The curtain was then lowered at the end of this vocalisation. This was then repeated for the other object. The curtain was then raised a final time and after once again saying hello to the infant, E1 turns to one of the objects and transfers the remaining three fruit to the board in front of him, he then turned and repeated this for the other object without a curtain break in between. The curtain then drops for the final time, ending the show phase.

Which fruit was on which stimuli object was counterbalanced across participants, with some participants seeing the plum on the plant-stimuli and the apricot on the non-plant, and others vice-versa. Which stimuli item was on which side of the experimenter was also counterbalanced across participants, as was which object was interacted with first, and which item was plated first.

Following the show phase, a second experimenter (E2), who was blind to which fruit had been on which stimuli item, presented the participant with a choice between the two fruit types. Whilst their parents were filling in the questionnaire at the beginning of the study E2 interacted with the infant so that they were familiar with them for the choice phase. For this phase, the parent was turned so they were facing away from the stage and asked to ensure the infant is sat upright on the end of their knee, they were also asked to close their eyes. E2 then knelt in front of the infant with the board from the show, on which were the two fruit types. The board was initially out of the infants reach. E2 then asked the infant "do you see these?" (in German, as is all spoken parts), and followed the infant’s gaze to ensure they looked at both fruit options on the board. If the infant only looked at one of the fruits E2 tapped behind the other fruit with their finger to draw attention to it. Whenever this is required E2 also tapped the other fruit afterwards. Once the infant had looked at both fruits E2 re-centres the infants gaze upon them by saying "look at me", this was followed by "which one can you eat? can you show me? which one can you eat? [*in German: “Welches kannst du essen? Kannst du mir zeigen? Welches kannst du essen? “*]. On the second ``which one can you eat?" the board was moved within range of the infant for them to make a choice. A choice was considered made when the infant reached and touched the fruit or white square beneath it, whilst also looking at it. If an infant did not make a choice within 60 seconds the trial was ended.

Two versions of this procedure were run. An initial version of the study was run using a grey stage and curtain set-up, and the default lighting in the Babylab at the Max Planck Institute (Study 1a hereafter). However, as noted above, during this version a high proportion of participants were excluded for fussiness (N = 10) or made no choice (N = 9) out of a total of 39 infants tested. Fussiness refers to being distressed or crying so the study is ended, or fussy behaviours that mean the participant do not observe the event (e.g., turning and hiding their head on their caregiver, getting off their parent's lap). This was much greater than the fuss-out/no choice rate noted in Wertz and Wynn (2014), which was 1 and 5 respectively, out of a total sample size of 32 .Given this increase in drop-out rate and the results found, we developed the procedure further to examine whether possible methodological factors were leading to this as this dropout rate. Firstly we adapted the lighting and colour conditions to be more similar to those used by Wertz & Wynn. Specifically, where we had been using a brightly lit room with a grey set up in study 1a (see Figure 2), we refitted the stage area to be black, with lighting focusing on the stage for Study 1b. It is plausible that our initial set up did not focus the infants' attention enough causing restlessness. Additionally, it is well established that infants are sensitive to social cues such as facial expressions (e.g., Hoehl, Palumbo, et al., 2008; Hoehl, Wiese, et al., 2008; Ruba & Repacholi, 2019), with evidence also showing a sensitivity to vocal expression (Kim et al., 2010; Mumme et al., 1996; Vaish & Striano, 2004). Where in Study 1a multiple different experimenters had filled the second experimenter role, the final sample of Study 1b used only one experimenter in this role, which may facilitate less inter-experimenter variation in these social cues during the choice phase. Finally, it is possible that one reason for a high "no choice" rate is infants' distractibility. It is known that even much younger infants than our sample exhibit anticipatory looking behaviour (e.g., Johnson et al., 1991; Träuble et al., 2010), we therefore raised the curtain again after the final show phase, and prior to the choice, to reveal an empty stage and minimise infants' possible distraction by the anticipation of further show events. Indeed these three changes led to a reduced dropout rate for Study 1b, with 4 participants fussing out, and 2 infants providing no choice.

Figure 2: Example show trials from Study 1a, Study 1b, Study 2

Study 1a.

Study 1b.

Study 2.

2.1.4 Reliability Coding

Both the experimenters' interaction with the stimuli, and the infants' choice was coded for reliability from video recorded data. Experimenter 1's interactions were blind coded for valence, in Study 1a internal coder consistency, that is how often they rated trials with the same valence, across participants, was above 90%, and in Study 1b it was 100%, indicating the valence of the experimenter's interaction was consistent across trials. The time the experimenter interacted with the fruit from each stimuli object was also coded, from the removal of the fruit object until the end of the vocalisation, with no significant difference between experimenter interaction times for the plant and non-plant stimuli in either Study 1a (t(17) = -.57, p = .578), or study 1b (t(18) = .02, p = .983).

Infants' choices were also blind coded by an additional experimenter based on video recordings. In both Study 1a and 1b the live coding only differed from reliability coding in 1 instance in each case. In these cases an additional coder determined the final choice.

2.2. Results and Discussion

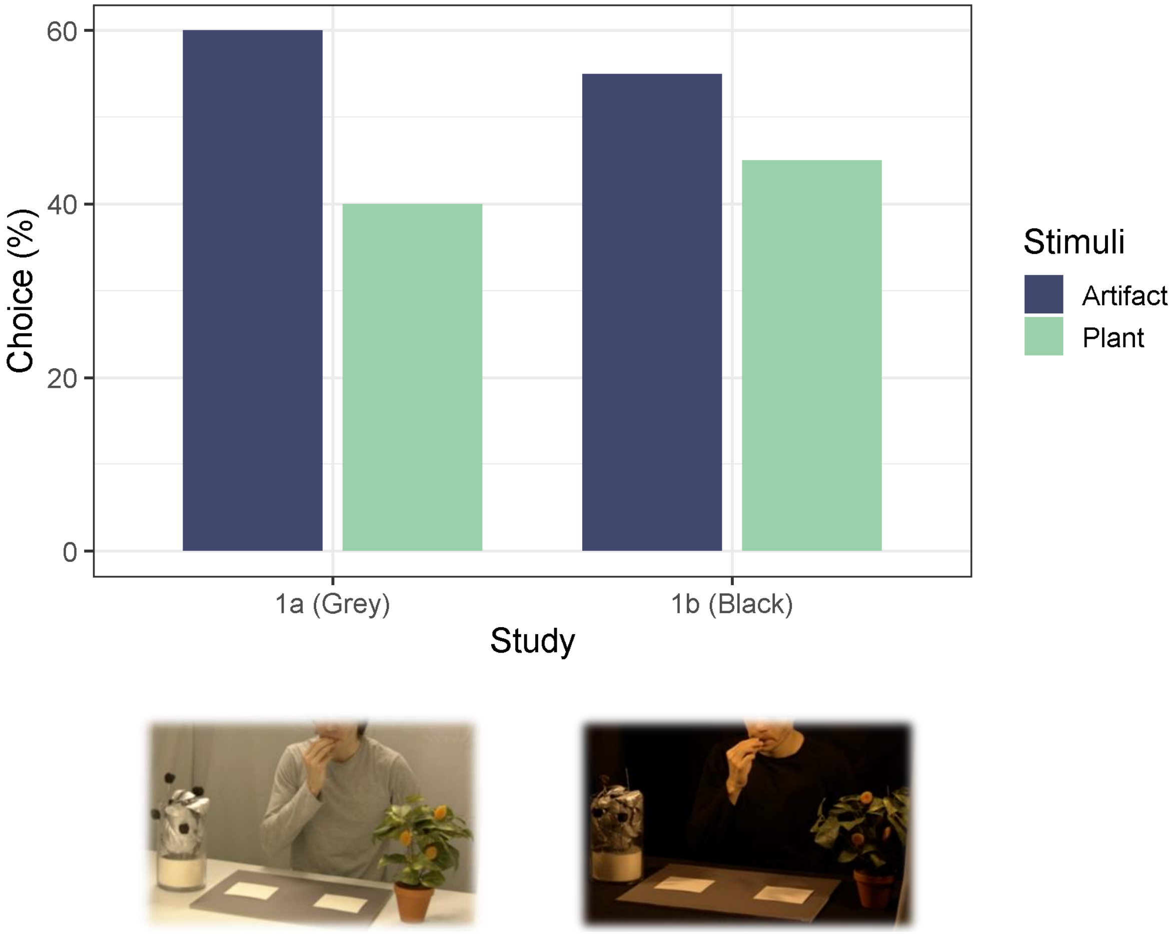
2.2.1 Study 1a

It was predicted that, as with Wertz & Wynn (2014), infants would select the fruit from the plant-stimuli as edible at a higher rate compared to fruit taken from the non-plant stimuli. Following Wertz & Wynn (2014a), the choice data was analysed using a binomial test to compare choice rates for each fruit to random for a binary choice (p = 0.5). An Exact Binomial Test revealed that infants did not select the fruit from the plant at a rate significantly different from chance (8/20, Binomial P = 0.4 [0.19 -0.64], p = .503). This would suggest that infants do not preferentially associate plants with edibility, challenging the finding of Wertz and Wynn (2014). Participants also did not demonstrate a choice rate different from chance for the colour of the fruit chosen, with 14 out of 20 selecting the plum (Binomial P = 0.7, *p* = .115), meaning the null effect is not a function of a fruit preference biasing the results. As there has been some indication of a side preference in choice studies (e.g. Nighbor et al., 2017), we also tested whether there was a preference for the fruit from a particular side, but found no effect, with 12 out of 20 participants selecting the fruit that had been from the stimuli on the left (Binomial P = 0.6, *p* = .503).

2.2.2 Study 1b

As with the findings of Study 1a, the rate at which infants selected the fruit from the plant stimuli did not differ significantly from chance (9/20, Binomial P = 0.45 [0.23 -0.68], *p* = .824), again indicating the participants did not preferentially associate the fruit from the plant stimuli with edibility. As in Study 1a we ran further analysis to examine whether infants preferred one colour fruit over the other or if there was a side preference. Neither colour choice or side choice rate differed significantly from chance, selecting the orange fruit in 11 out of 20 instances (Binomial P = 0.55 [0.32 -0.76], *p* = .824), and the fruit from the stimuli item on the right in 11 out of 20 instances (Binomial P = 0.55 [0.32 -0.76], *p* = .824).

Figure 3. Choice percentage for each object type in Study 1a (left), and Study 1b (right)



2.2.3 Discussion

Both attempts to replicate the finding of selective associations of plant edibility in 18-month-olds from Wertz & Wynn (2014) using a choice paradigm were unsuccessful. Instead, infants chose the fruit from the plant and non-plant stimuli at a rate no different from chance in both Study 1a and Study 1b. It is plausible that the current finding indicates a false positive in the original Wertz & Wynn (2014a) study- that infants do not selectively associate edibility with plant stimuli over non-plant stimuli. Should this prove to be the case it would raise questions as to the underlying theory regarding selectivity in human learning, at least for the domain of plants. Indeed, the changes made between Study 1a and 1b substantially reduced the dropout rate and as such we can have more confidence in this null finding. However, several factors should encourage caution when drawing this conclusion from the present findings. Firstly, the non-replicated study was only one of a number of studies conducted by Wertz & Wynn (2014). Specifically, the corresponding finding in 6-month-old infants was not tested here. Moreover, this finding from Wertz & Wynn (2014a) suggesting selective associations between plants and edibility in 6-month-olds has since been replicated in other work (Rioux & Wertz, 2022.) It is therefore prudent to consider possible methodological reasons for non-replication.

One methodological avenue to examine would be the robustness of the choice task used. Salvadori et al (2015), failed to replicate Hamlin & Wynn (2011)'s study, indicating infants prefer helpers to hinderers, using similar methods, and concluded that methodological variation may have caused this, and that further understanding of the requisite methodological details for success in use of this choice method was required. Indeed, further research has also demonstrated issues in replicating this task (Cruz-Khalili et al., 2019; Nighbor et al., 2017). However, whilst there have been issues replicating this finding using the choice method, research using EEG methods has demonstrated a sensitivity to helpers and hinderers using this method (Gredebäck et al., 2015; Tan & Hamlin, 2022). Moreover, a recent meta-analysis has demonstrated a preference for helpers over hinderers (Margoni & Surian, 2018), though it should be noted the authors also raise the issues of a file drawer problem (unpublished work), publication bias, and laboratory effects wherein studies from the original authors demonstrate greater effect sizes. As such it appears that there may be reliability issues with the choice method used in Wertz & Wynn (2014) more broadly.

Whilst the present work attempted to conduct the study true to the original, a number of factors did in fact vary. In addition to the set-up differences noted above, the country of the samples and therefore language and cultural norms differed between the present study and the original, moreover there may be as yet unidentified factors which influence infants' performance on this task The relevance of the cultural differences may be of specific note here. Previous research has demonstrated some differences in caregiver-toddler interactions, and how this relates to temperament, in the US and Germany (Kirchoff et al., 2019). Indeed it has also been found that German adults are especially sensitive to social norms, relative to those in the US (Hareli et al., 2015), a cultural difference which may be also be reflected in infants' social interactions. It is possible that cultural differences make a social task such as the choice task suitable or effective method in the North American sample used in Wertz & Wynn (2014), but not in the present German sample. Moreover, the non-replications by Salvadori et al. (2015) and Schlingloff et al. (2020) noted above were also an attempt to replicate a study originally conducted in the US in a European sample. It is therefore plausible that the choice method is contingent on US caregiver-child interaction norms.

3. Study 2: Looking time

We noted above the possibility of methodological issues being the cause of the non-replication in Study 1a and 1b. We therefore looked to examine whether infants selectively associate plants with edibility using a different method. Using an alternative method to examine the same question allows us to examine whether the non-replication in Study 1a and 1b was a function of the method. If this is indeed the case, then one would expect an alternative method to demonstrate an effect, if on the other hand we fail to find a selective plant edibility effect in 18-month-olds using an alternative method this would serve as further evidence against the existence of a selectivity effect in this age group, or indicate other methodological factors are at play. Specifically we will look to test whether edibility is selectively associated with plants using the looking time method, used in the other studies of Wertz and Wynn (2014) with 6-month- olds, demonstrating such selectivity.

The looking time method was based on that used by Wertz & Wynn (2014) in their experiments with 6-month-old infants, and more recently in a replication of this finding by Rioux & Wertz (2022). These studies used a violation of expectation paradigm common in cognitive development research (Baillargeon et al., 1985; Hamlin et al., 2007). Wertz & Wynn (2014a) reasoned that if infants preferentially associate plants with edibility, they would be more surprised, and therefore look longer, at an experimenter eating fruit from a control stimuli than the plant stimuli, and indeed this is what was observed in Study 4 of Wertz & Wynn (2014), and in a the recent replication of Rioux & Wertz (2022). Given these findings we predicted that, if the non-replications observed in studies 1a and 1b are a function of the choice method used, and 18-month-olds do preferentially associate edibility with plants, infants would exhibit longer looking time for events where the experimenter ate fruit from the non-plant stimuli relative to the plant stimuli.

3.1. Method

3.1.1 Participants

Final participants were 17 infants aged 18 months (18 months, M_{Days}= 15; Female = 9). This was from a planned sample size of 20 based by Rioux & Wertz (2022), who conducted power analyses based on the effect size reported in Wertz and Wynn (2014), however testing ended prematurely due to the Covid-19 pandemic. An additional 6 infants were tested but excluded for fussiness. As in Studies 1a and 1b participants were recruited through a participant database. Only full-term infants who heard German spoken more than

50% of the time, were recruited. Participants are recruited from the area of Berlin and tested in the BabyLab at the Max Planck Institute for Human Development. This study was approved by the institute's ethics committee. The parents of participants provided written consent and were compensated 10 Euros.

3.1.2. Procedure

The method in Study 2 is very similar to that of Study 1 and is based upon that used with 6-month-olds by Wertz & Wynn (2014). As in Study 1 infants were sat on a parent's lap in front of a stage with a curtain. The curtain began closed and then rose, and an experimenter was present with the same stimuli as in Study 1, a plant and non-plant artefact, one of which is apricots, the other, plums, however the board that was present in Study 1 was no longer present. The experimenter leaned forward and said "hallo [in German]" to the infant, before breaking eye contact and returning to a normal posture. The curtain then closed. The curtain then rose again, and the experimenter said hello, before turning to one of the objects. As in Study 1 the experimenter then takes the object, moves it into their mouth and makes a 'hmmm' sound as if considering the fruit (see Figure 2., above). However, unlike Study 1, the experimenter then remained in position with the fruit in mouth. A trained second experimenter, hidden from view from the infant, coded the amount of time they are looking at the event using jHab (Casstevens, 2007). The experimenter remained still with the fruit in mouth for 30s, or until the second experimenter coded the infant looking away for 2s, after which the curtain was lowered and the trial ended. The curtain was then raised again, and the procedure repeated for the other stimuli item. This was repeated two more times for each stimuli item, so the participants saw three incidences of interacting with each stimuli type. As in Study 1, which fruit was on which stimuli, which item was interacted with first, and which item was on the experimenters right/left, were counterbalanced across participants.

3.1.3. Reliability coding

As with Studies 1a and 1b the experimenter's interaction with the objects was coded for reliability. Reliability coders coded the amount of time the experimenter interacted with each object. Two trial pairs were removed due to an experimenter interaction difference between the objects being greater than 2.5 SD above or below the mean. Despite this, a small but significant difference was observed in the experimenter's interaction between the two object types, with the experimenter interacting with the plant for an average of 286.67ms (t (50) = 2.08, $p = .04$), with a mean interaction time of 5377ms for the plant stimuli, and 5090ms for the non-plant stimuli, according to the primary coder. A second coder coded 50% of trials and found no significant difference in the experimenter's interaction time between the object types. In addition to interaction time Coders also coded the valence of the interactions. The primary coder recorded an internal consistency of 100%, that is for 100% of trials they rated valence to be the same, and the second coder 89%, suggesting a high degree of consistency in the experimenter's vocalisations across trials and participants. Coders also examined the infant's attention during the show, coding whether the infant was looking at the show for: (i) the fruit being removed from the object, (ii) fruit being moved to the mouth, and (iii) the experimenter placing the fruit in their mouth. The infant was only considered to be paying attention if all three criteria were met. Two coders coded all events with 65% agreement, with the differences coded by a third coder. The final coding data showed no trials where the participant was not paying attention, resulting in no trials being excluded. Finally, looking time was also reliability coded. Where there was a discrepancy (difference of greater than 2s) between the live coding and the reliability coding a third person coded those trials (52% of trials), and the recorded looking time of the live coder or reliability coder that was closest to that of the third coder was used in the final data set.

3.2. Results and discussion

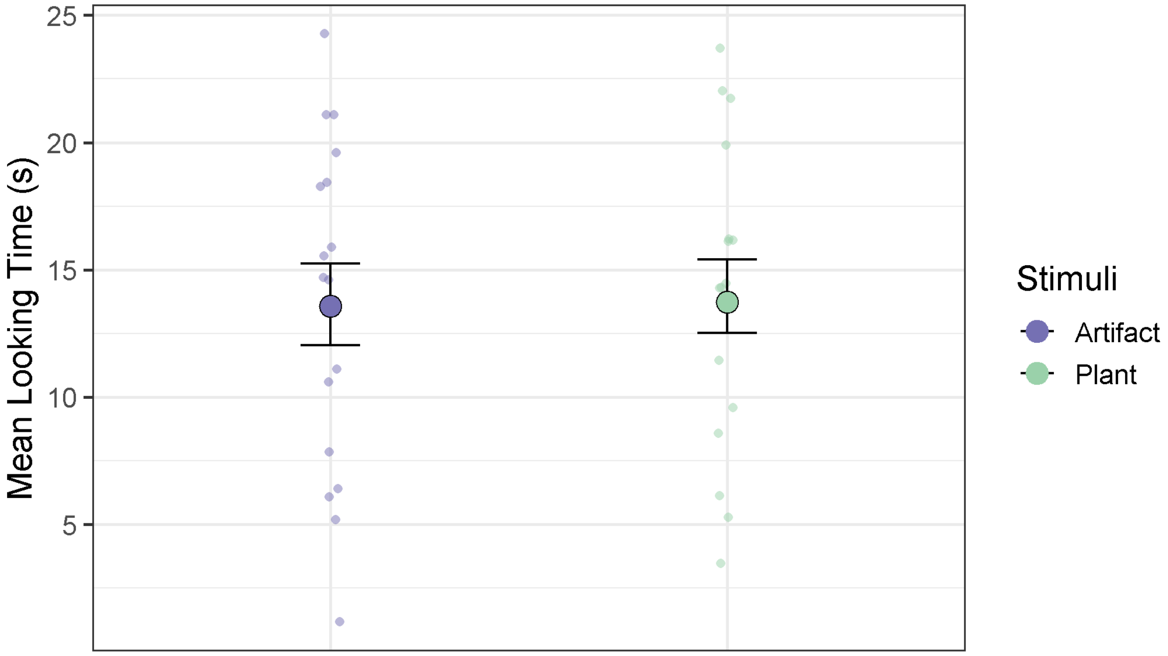
3.2.1. Results

Based upon the looking time results found in Study 4 of Wertz & Wynn (2014), and the results of the more recent replication by Rioux & Wertz (2022) we predicted that, if infants selectively associate plants with edibility, they would look longer at the event where the experimenter ate from the non-plant stimuli compared to the plant stimuli. Following Wertz & Wynn (2014a) and other studies of looking time (e.g., Aguiar & Baillargeon, 2003), differences in looking time between the plant and non-plant events were compared using t-tests.

Consistent with Wertz & Wynn (2014) we set a ±2.5 SD threshold for looking time outliers, and as no trials fell outside of this threshold no outliers were removed. As the differences between pairs were normally distributed ($W = 0.97$, $p = .201$), we were able to use t-tests. We found no statistically significant difference in looking time between plant ($M = 13.75$ s, $SD = 9.32$s), and non-plant ($M = 13.56$s, $SD = 9.37$s) events ($t = -.119$, $p = .906$), and can therefore not reject the null hypothesis of no effect of object type on looking time.

As a measure of violation of expectation, we would expect infants' looking time to decrease over trials, as such and following previous research utilising looking time measures (e.g., Olineck & Poulin-Dubois, 2009; Powell et al., 2018), we also examined the first trial only. That is, we compared looking time in the first trial between those who saw the plant first against those who saw the artifact first. As only a participant's first trial is analysed and that the item seen first was counterbalanced across participants, this analysis is between groups, and due to non-normality was conducted using Wilcoxon rank sum tests. As with the full looking time data we found no significance between plant (*Median = 23.80, SD =9.57*) and non-plant (*Median = 22.06, SD = 7.32*) events (W = 33, *p = .918*).

Figure 4. Looking time across condition.



Note: This figure presents mean looking time by participant (small dots) and grouped by condition (large dots) for each stimuli type. No significant difference was observed between conditions

Finally we looked at the correlation between the Plant Experience Questionnaire (PEQ; (Rioux & Wertz, 202; Wertz & Wynn, 2014b) and looking time for the two object types. We conducted correlation analysis between each subscale of the subscales for the PEQ and found no significant correlations.

Table 1. Correlations between PEQ subscales and looking time for each object time.

Frequency of…	Plant Looking Time	Artifact Looking Time
Outdoor interaction with plants	-.15	-.22
Indoor interaction with plants	-.13	-.17
Eating from plants	.01	.28
Being stopped from touching plant	.001	.16

Note: No significant correlations were found.at the Bonferroni adjusted alpha level of 0.0125.

3.2.2. Discussion

In Studies 1a and 1b we were unable to replicate the original finding from Wertz and Wynn (2014a) that infants selectively associate plants with edibility, preferentially selecting a fruit from a plant stimuli rather than from a non-plant stimuli. Rather, in both Study1a and Study 1b observed no difference in infants' choices. Given that the choice method has been shown to be non-replicable in other instances (Cruz-Khalili et al., 2019; Nighbor et al., 2017; Salvadori et al., 2015), we looked to test whether the non-replications observed in Studies 1a and 1b were due to problems with the choice methods. We therefore ran a live looking time study, following that of Wertz & Wynn, (2014a) with 6-month-olds and in the replication of this finding by Rioux & Wertz (2022), and again found no evidence for the selective association between plants and edibility in 18-month-olds. Again, however the use of the black stage set up and new lighting resulted in a lower dropout rate t

One reason for this finding could be methodological problems with this method, too. Indeed, like the choice method used in Study 1a and Study 1b live looking time measures have also been shown to be unreliable (Peterson, 2016; Rubio-Fernández, 2019; Schlingloff et al., 2020). As Peterson (2016) notes, these methods are subject to a degree of human flexibility, indeed, the reliability coding in the present study indicated a divergence between two coders on a number of trials, indicating variation even in trained coders. Such a critique is consistent with recent research noting differences between live coded looking time and eye tracking data using electronic eye trackers (Henny Yeung et al., 2016; Venker et al., 2020). Whilst it has been a valuable tool in developing knowledge of cognitive development, it has recently been suggested that the violation of expectation method should no longer be used in future research (Paulus, 2022), although work elsewhere has indicated way to improve rather than discard the method (Rubio-Fernández, 2019). Whilst the future of the method is unclear, one point is not, conclusions about infant cognition require converging evidence using multiple methods. Indeed, the present work looked to examine the reliability of this looking time method further, and refine the choice method used in Studies 1a and 1b, however this was not possible due to the Covid-19 pandemic (see section 4.1.1 below).

4. General Discussion

In the present work we looked to examine, following the findings of Wertz and Wynn (2014a), whether infants selectively associate plants with edibility. In Study 1a we conducted pre-registered replication of Wertz & Wynn (2014a)'s finding that 18-month-olds would choose a fruit taken from a plant object at a higher rate than from a non-plant object, when presented with cues of edibility for both objects. This initial replication attempt did not find the same effect, observing no differences in infants' choices between the fruit from the plant and non-plant objects. However, due to a high dropout rate (9 infants excluded for making no choice, 10 for fussiness), and certain methodological divergences from the original study, we ran a further replication, Study 1b, to examine whether methodological factors resulted in the non-replication. Study 1b adapted the replication to be closer to the original study, namely by altering the lighting and colour scheme of the testing environment, and whilst a decrease in dropout rate was observed (2 infants were excluded for making no choice, 4 for fussiness), we again found no difference in infants' choices between the fruit from the plant and non-plant objects. Finally, it has been observed elsewhere that there appears to be problems replicating studies using the choice method (e.g., Cruz-Khalili et al., 2019; Nighbor et al., 2017; Salvadori et al., 2015). Given this Study 2 looked to examine whether 18-month-old infants selectively associate plants with edibility by using an alternative method, the violation of expectation paradigm, used in the original study with 6-month-olds, and in a more recent replication (Rioux & Wertz, 2022; Wertz & Wynn, 2014a). As with Study 1a and 1b we did not find infants to selectively associate plants with edibility, with no significant difference in looking time observed between events where infants saw an actor eat from a plant object and from non-plant object. These findings have implications both for the research topic— selective learning— and for infant research methods more broadly.

4.1. Infant research methods

The field of psychology has, over the past decade, found itself in what has been termed the *replication crisis*. This stems from evidence demonstrating a large number of research findings to be non-replicable (e.g., Open Science Collaboration, 2015). This has served to illustrate broader problems in psychology, such as a file drawer problem wherein a large amount of work, particularly null results go unpublished (Lishner, 2022; Rosenthal, 1979), questionable research practices (John et al., 2012), undisclosed flexibility in data collection and analyses (Simmons et al., 2011), publication bias (Francis, 2012; Franco et al., 2014) and incentive structures that favour a literature that is biased and low quality (Smaldino & McElreath, 2016).

This state of affairs in psychology more broadly has led to an analysis of the problems facing developmental research, including replicability issues in this field (Davis-Kean & Ellis, 2019). Indeed, both of the methods used in the present study, infant choice methods and the violation of expectation paradigm, have been shown, in some cases, to be non-replicable or unreliable (Peterson, 2016; Rubio-Fernández, 2019; Schlingloff et al., 2020), and subject to laboratory effects where certain researchers or labs find greater effects than others (e.g. Margoni & Surian, 2018).Moreover, Ethnographic research has demonstrated a number of challenges towards psychological rigour in infant research labs, such as flexible stopping of data collection (Peterson, 2016). In fact, awareness of such issues has led to calls for improvement in methods and transparency within the field (e.g., Byers-Heinlein et al., 2021; Eason et al., 2017; Kominsky, 2022). Findings such as those in the present work demonstrate the importance for transparency in infant research to help shed light on why findings are replicated in some instances but not others. Indeed, the present thesis looked to engage with these issues in infant psychology through pre-registration, basing sample sizes on power analysis, and transparent reporting of methods.

One area on which the present work sheds particular light is the underreporting of methodological detail in psychology experiments. We noted above that there was a substantial decline in dropouts between Study 1a and Studies 1b and 2, after what were ostensibly minor methodological adjustments that may not traditionally be included in methods sections. Whilst high, a dropout rate such as that observed in Study 1a is not unusual, in fact, in one analysis of infant vision studies with 12-montholds it was observed that the dropout rate in studies of infant vision due to fussiness ranged from 0-62%, a substantial range. (Slaughter & Suddendorf, 2007). That, as observed in the present work, minor changes to methods can yield substantial differences highlights the importance of reporting such detail in manuscripts. Indeed, it is noted by Scheel (2022) that limited detail on methods make statistical inferences difficult to evaluate. And, for example, an increased size of method sections to allow greater detail is one change made in *Psychological Science* in a series of changes to improve psychological papers in that journal (Lindsay, 2015). The observation here that small changes may yield significant experimental differences also raised important questions about scientific outcomes. In their meta-analysis of infants' social evaluations Margoni & Surian (2018) note a substantial laboratory effect, that is, a difference in the size of effects between laboratories. Whilst many labs within a field may use the methods, small variations in test procedure or set up, as noted here, may yield different effects. That this effected drop out rate in the present study demonstrates the effects these can have on infant participants, and may therefore also be an important factor in observed effect sizes. Again this highlights the importance of detailed methods reporting in infant research.

4.1.1. Planned Extensions

One difference between the original work by Wertz & Wynn (2014a) Study 1a and Study 1b is the sample difference between these studies (testing German infants) and Wertz & Wynn (2014a) who tested US infants. Above we noted that social interaction norms may differ between the US and Germany, as observed by Kirchoff et al. (2019), and that in some cases developmental findings from the United States which involve such social interactions have not replicated in European samples (e.g.,Salvadori et al., 2015). In using a looking time method in Study 2 possible effects of social interaction were removed from the response phase of the study. However, in both Study 1 and Study 2, participants observed a live actor, who greeted and acted in front of them. It may well be the case that this social interaction is received differently in our German sample relative to the sample in Wertz & Wynn (2014). In the choice task used in Studies 1a and 1b, and by Wertz & Wynn (2014a), infants observed a live actor and were then presented with the choice by an experimenter, two interactions where social interaction may influence the outcome to a greater degree than intended. Moreover, it is well established that infants are sensitive to social cues (e.g., in fear responses; Hoehl et al., 2008; Hoehl & Pauen, 2017), and in the domain of plants in particular infants have been shown to exhibit increased social referencing relative to other objects

(Elsner & Wertz, 2019). Indeed, it is of note that the successful replication by Rioux & Wertz (2022) infants observed a video of the experimenter, rather than a live demonstration.

In order to rule out extraneous influence from such social interactions, it would be valuable to further examine selective edibility of plants in 18-month-olds with minimal social interaction. The present project looked to do this by use of an automated choice task—wherein infants would be presented with the two food items, without the interaction with an experimenter thereby removing social interaction during the response phase. Unfortunately owing to the Covid-19 pandemic it was not possible to run this version and it remains an open question to be investigated in the future.

Another related methodological issue to examine would be the role of age in the present non-replication. In all of Study 1a, Study 1b and Study 2 participants were 18-month-olds and in all instances selective edibility of plants was not observed. Yet, Rioux & Wertz (2022) did replicate this effect in 6-month-olds. It is possible that the finding of selective edibility is robust in a younger age group, but not in 18-month-old infants, and it may indeed be the case that this is a function of cultural differences noted above, however this warrants testing. It is also plausible that the looking time method is problematic with this age group. Whilst the violation of expectation method was selected due to it successfully being used by both Wertz & Wynn (2014a) and Rioux & Wertz (2022) with 6-month-olds, the method is primarily used with younger infants (e.g. Gao et al., 2000; Hamlin et al., 2007; Jin et al., 2018; Kuhlmeier et al., 2004; Simon et al., 1995; Spelke et al., 1995). To examine these possible age effects we looked to test selective edibility of plants in 11-12-month-olds using a violation expectation measure, an age where it has been found to be viable (Gergely et al., 1995). This would allow us to test two things. Firstly, whether the non-replication in Studies 1a, 1b, and 2 were a function of the age group tested, and moreover whether in 11-12-month-old infants selectively associate plants with edibility.

4.2. Selectivity in learning

Whilst the present non-replication may be a function of methodology, and the outstanding questions above warrant investigation, it is also plausible that the original finding by Wertz & Wynn (2014a) was a false positive. A possible theoretical reason for the present non-replication is the valence of edibility. A large amount of existing work showing learning biases show preferential learning or associations examines information that is negative or costly such as danger (Barrett et al., 2016; Barrett & Broesch, 2012; Broesch et al., 2014), fear (e.g. DeLoache & LoBue, 2009; Öhman & Mineka, 2003; Tomarken et al., 1989), and disgust (e.g. Chapman et al., 2012; Croucher et al., 2011; Moeck et al., 2021). Indeed, as has been noted in previous chapters, it has been widely observed that humans demonstrate a negativity bias, even in infancy (Hamlin & Baron, 2014; Hamlin et al., 2010; Morewedge, 2009; Rozin & Royzman, 2001; Vaish et al., 2008). Future research should therefore examine whether there is selective learning in the plant domain for negative information such as disgust, as was initially planned here, allowing for an examination of both negativity and plant effects on association formation in infancy. Finally, the present findings, if true, challenge the notion of a specialised learning system for plants, though it should be noted that other elements of the specialised psychological mechanisms for the avoidance of plant dangers proposed by Wertz (2019), namely behavioural avoidance, has converging evidence over a number of studies (Rioux & Wertz, 2021; Wertz & Wynn, 2014b; Włodarczyk et al., 2018).

4.3. Conclusions

Overall the present work found evidence challenging the finding of Wertz & Wynn (2014) that 18-month-old infants selectively associate edibility with plants compared to non-plant stimuli. In Study 1a this was tested using a choice task, and in Study 1b a choice task was again used after refining the set up to minimise variation between the present work and the original study. In Study 2 this question was examined with an alternative method, the violation of expectation paradigm. No evidence for the selective edibility of plants was observed in any of the three studies. This raised important questions about those methods used, and directs future research in this regard. Moreover, whilst absence of evidence is not necessarily evidence of absence, the present findings raise questions as to the presence of specialised plant learning in infancy.

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Chapter 5: General Discussion

This dissertation looked to replicate and build upon previous research demonstrating learning biases for evolutionarily relevant information by investigating whether humans preferentially learn about danger and edibility information about foods, and further, looked to test whether similar biases were also present in generalisation systems. These questions were investigated by examining learning and generalisation of edibility and toxicity information about foods across the lifespan. Chapters 2 and 3 looked to test, for the first time, whether there are differences in the degree to which different kinds of information are generalised, in children and adults. Chapter 3 looked to build upon this further by investigating the role of uncertainty and how individual differences in anxiety influence how people generalise edibility and toxicity information. Chapter 3 also looked to build upon previous work showing learning biases for certain kinds of information such as danger (e.g., Barrett et al., 2016, disgust, survival relevant information), by examining possible learning biases for information about the edibility and toxicity of foods. Finally, Chapter 4 attempted to replicate and extend Wertz & Wynn's (2014a) finding that infants selectively associate edibility with plants, relative to control artifacts.

The findings in Chapter 2 demonstrate that there does appear to be selectivity in generalisation for information about edibility and danger in adulthood, with information about the toxicity of food generalised at a greater rate, and information about the edibility of foods at a lesser rate. Interestingly, this effect was only observed in cases where the category of the item was most uncertain, that is, when it bore 50% similarity to both an item that had the feature (e.g., This is edible), and 50% similarity to an item that did not (e.g. This is not edible). These results are consistent with predictions of Error Management Theory (Haselton & Nettle, 2006), that cognitive systems are shaped over evolutionary time to minimise the more costly mistakes— overgeneralising toxicity, and undergeneralising edibility are the lesser mistakes in these domains. However, where previous research has demonstrated learning biases for danger in childhood (e.g., Barrett et al., 2016), we only observed an effect of information type on generalisation in adults, but not children.

Chapter 3 presented results demonstrating some further support for the notion that generalisation differs for different information types. In Chapter 2 we found that this effect was only present under the highest degree of categorical uncertainty. Yet, results in Chapter 3 show that when uncertainty is about the predictive power of a category (i.e., how well a category predicts an item having a property), effects of information type are only present under high levels of certainty. Specifically, participants generalised edibility information at a rate significantly lower than control information but only when a category predicted a property at a high rate, a finding consistent with the principle of minimising costly errors. This was reflected in an overall generalisation rate less than chance for edibility information, but no heightened generalisation was observed for toxicity information, contra our predictions. Chapter 3 also presented results showing no preferential recall of edibility or toxicity information about plant-based foods, challenging existing literature demonstrating a learning advantage for survival relevant information (e.g., Stubbersfield et al., 2015). However, we also report that participants have a greater number of false positives (the less costly mistake) than false negatives (the more costly mistake) in the recall of toxicity information, a finding consistent with a learning system shaped to minimise the costly mistakes. Finally, effects of anxiety related traits were observed for both recall and error type. Recall accuracy was observed to decline with Food Neophobia, but only when there is high certainty about a category's predictive power. And, the rate of false-positive errors increased with Trait Anxiety, but only for information about edibility. These results would indicate that, contrary to increasing risk minimising strategies as per predictions, anxiety may increase risk taking strategies, with Food Neophobia reducing the recall of possibly useful information, and Trait Anxiety increasing more costly recall errors, at least in certain contexts.

Chapter 4 reports results failing to replicate those of Wertz & Wynn (2014), who, in one study, found that 18-month-old infants selectively associate edibility with a plant, relative to a control stimulus. However, as Wertz & Wynn (2014) included multiple experiments and their findings with younger 6-month-old infants have been replicated elsewhere (Rioux & Wertz, 2022), we ran follow up experiments to examine reasons for non-replication. Follwing the initial non-replication we ran an additional experiment with methodological changes to the initial attempt to examine whether said non-replication was a function of differences in the set up between the replication and original study. This also showed no preferential association between plants and edibility, yet demonstrated the roll of methodological factors on outcomes in infant research. We then attempted to replicate using an alternative method, infant looking time, to test whether the non-replication in the first two cases was due to problems with the experimental paradigm used. Yet, this study also failed to find an effect using a looking-time method. Further studies planned to develop this analysis by testing possible methodological factors, namely age and experimenter interactions, but these were cancelled due to the Covid-19 pandemic.

1.1. How to Generalise

This dissertation looked to build upon work demonstrating that humans exhibit preferential attention for threatening stimuli such as animals (e.g. Lipp & Derakshan, 2005; Maratos et al., 2008; Öhman et al., 2001) and faces (e.g. Maratos et al., 2008; Mather & Knight, 2006), and learning biases for dangerous or survival relevant information (e.g. Barrett et al., 2016; Nairne et al., 2007; Stubbersfield et al., 2015), by examining whether similar biases were present in generalisation. Error Management Theory posits that where there is an asymmetry in the costs of mistakes, and these costs are recurrent, that cognitive systems may be shaped to minimise the more costly errors (Haselton & Nettle, 2006). Generalisation of information about the edibility and toxicity of foods appear to be a prototypical example of this, where EMT would clearly predict such biases. For toxicity information one can generalise incorrectly in two ways, generalise toxicity information when one shouldn't, or not generalise when one should. Imagine you have learned that an orange fruit is toxic and come across another similar orange fruit. If you don't generalise that toxicity information and it turns out you should have, that is a possible fatally costly error, by contrast, if you do generalise when you ought not to have, you have only missed out on a potentially nutritious fruit. The inverse pattern is true for edibility, one could make the mistake of not generalising when one should, and miss out on a meal, or generalise when one should not, and again potentially ingest something toxic (see Chapter 3, Section 1.3, Figures 2a & 2b). We therefore predicted that human generalisation systems would be shaped accordingly, with greater generalisation of toxicity information and less generalisation of edibility information, to reduce the rate of these costly errors.

In Chapter 2 we present evidence that humans do generalise different kinds of information differently, with greater generalisation of toxicity information and less generalisation of edibility information. Indeed, it seems to be the case that under uncertainty, generalisation systems reflect the relative costs of errors of generalisation in the food domain, consistent with an Error Management approach (Haselton & Nettle, 2006). Less generalisation of edibility information would minimise the possibly costly mistake of incorrectly generalising edibility information, and more generalisation of toxicity information would reduce the chance of incorrectly *not* generalising toxicity information. Results presented in Chapter 3 also demonstrate a similar sensitivity to information type, with reduced generalisation of edibility information observed, yet with no effects observed for toxicity information.

This effect is also consistent with literature demonstrating negativity bias, that is, a greater weighting of negative information than positive (Bebbington et al., 2017; Ito et al., 1998; Vaish et al., 2008), and also loss aversion, an element of prospect theory (Kahneman & Tversky, 1979) arguing that decision makers are more sensitive to losses than equivalent gains (e.g. Tom et al., 2007). Indeed, from a survival standpoint, ingestion of inedible or toxic foods are certainly a loss. Whilst the role of negativity for toxicity is clear, being negatively valanced, and associated with the possible costs of illness, reduced generalisation of edibility is also consistent. Indeed, the observation of reduced generalisation of edibility information could be a function of *increased* generalisation of its inverse, inedibility. Where edibility is a possible gain, inedibility is a possible cost. Due to the methods used, where participants have a binary choice between "is edible" and "is not edible", this distinction cannot be clarified and is an important area for further study.

Chapter 2 also presented results examining the role of negativity effects directly, demonstrating that whilst similar patterns of generalisation were present for both negative/positive information and toxicity/edibility information, there is some indication that these effects are greater for toxicity and edibility information. This would indicate that the effects observed cannot solely be a function of negativity effects. That this effect does not seem to be fully explainable by broader negativity effects offers further support for a biased, or selective, generalisation system more sensitive to certain kinds of information, similar to those observed in learning where certain stimuli are more associated with others such as snakes and fear (e.g. DeLoache & LoBue, 2009), and certain information more readily learned (e.g. disgust; Chapman et al., 2012; Croucher et al., 2011; Moeck et al., 2021). Future research should consider generalisation in other domains where negativity bias is present, such as disgust, and compare this to other neutral and negative information to delineate those domains showing biases that are specialised and those which are a function of more general loss aversion or negativity bias.

In Chapter 2 it was observed that the effect of information type on generalisation was only observed under the highest degree of uncertainty about the item's identity. Yet results from Chapter 3 demonstrate that the role of categorical uncertainty is less clear. Where experiments in Chapter 2 examined cases where an item's identity was unclear (is it A or B) but there was no uncertainty as to whether each of those options had a property or not, Chapter 3 examined category-based induction, specifically cases where categorical membership was clear, but the predictive power of that category was more or less certain. In contrast to results from Chapter 2, higher uncertainty did not predict greater effects of content type on generalisation. In fact, the only effect of information type on generalisation was observed at the higher level of certainty about the category's predictive power, and even then only for edibility information. This could indicate that content effects only appear when the item or category from which one is generalising has a high degree of predictive power –100% in the experiments in Chapter 2, and 75% in the high occurrence rate of Chapter 3 where the effect was observed. Indeed, whilst literature on this question appears scarce, this is consistent with findings suggesting causality, like similarity, is important for generalisation (Hayes & Thompson, 2007; Rehder, 2006, 2009), that is, the degree to which a property is seen to cause another.

Modern humans, especially those in wealthy industrialised societies (like participants in Chapter 2 and 3), have access to a staggering amount of information about different possible foods, either directly or through media. This may cause scepticism regarding the power of any particular feature of foods to predict other features that individuals who lived with more limited exposure, as is the case for most of human history, may not develop. There is evidence in Chapter 3 that participants did use category-based induction— their generalisation rates differ according to the rate at which a category has a property—it may therefore be the case that prior exposure to diverse foods in our sample reduced participants perceptions of predictive validity of categories based on visual similarity (in our case, colour).

Finally, one outstanding question is age differences in generalisation biases. Work on learning has shown that children preferentially learn information about danger (Barrett et al., 2016; Barrett & Broesch, 2012; Broesch et al., 2014), and in Chapter 4 we present findings supporting the observation of Broesch et al., (2014) that this is not the case in adults. However, in Chapter 3 we observe the inverse age pattern for generalisation. This would suggest differing developmental trajectories for informational biases in these mechanisms. A possible explanation for these differences is a strategy change during development. In childhood you have less knowledge, and the acquisition of such is vitally important, indeed, evidence shows that in certain domains children are better learners than adults (Gopnik et al., 2017; Gualtieri & Finn, 2022; Lucas et al., 2014), and childhood is noted as a key period in learning about one's environment (Joffe, 1997; Muthukrishna et al., 2018). Conversely, in adulthood you have more knowledge and have had opportunities to learn how to learn, and as such may need to rely on learning biases less. Yet the opposite may be the case for generalisation, having less value during childhood when one's catalogue of category concepts is still developing. Indeed, in childhood systems of induction themselves are developing (Feeney & Heit, 2007; Fisher & Sloutsky, 2005; López et al., 1992), whereas in adulthood generalisation systems are more developed and one has more information on which to draw.

Finally, the present dissertation initially planned to examine generalisation biases in infancy as well as in adulthood, with initial testing having begun shortly before the Covid-19, and this question remains an open one which warrants future investigation.

1.2. What to Learn?

The present work builds upon existing literature that shows that learning systems appear to be biased towards certain evolutionarily relevant kinds of information. It has been observed that there appear to be biases for learning information about danger (Barrett et al., 2016; Barrett & Broesch, 2012; Broesch et al., 2014), for threatening individuals and situations (Baltazar et al., 2012; Kinzler & Shutts, 2008), disgusting images and contaminate objects (Chapman et al., 2012; Croucher et al., 2011; Fernandes et al., 2017; Moeck et al., 2021), for cheaters (Mealey, 1996), and for survival information more broadly (Nairne & Pandeirada, 2008, 2010; Stubbersfield et al., 2015). It has also been argued that human psychological systems may also have been shaped by the threats posed by plants (Wertz, 2019), with infants appearing to selectively associate plants with edibility (Rioux & Wertz, 2021; Wertz & Wynn, 2014a). As opposed to animate threats such as humans and animals, the inanimacy of plants means the threat posed by them is due to error on the part of the agent— they cannot hunt you, threats posed by them are through ingestion or contact (Włodarczyk et al., 2018). As such successful learning about plant-based foods could help successfully mitigate many of the threats posed by them. The present dissertation therefore looked to examine whether there is a learning advantage for information about edibility and toxicity of plant based foods, similar to that observed in other domains. However, whilst learning systems seem to be sensitive to learning about threatening individuals (Kinzler & Shutts, 2008) and animals (e.g. Barrett & Broesch, 2012), results presented in Chapter 3 show no learning advantage for information about the toxicity of plant based foods, nor did we observe a learning advantage for information about the edibility of plant foods.

This begs the question as to why, specifically given the observed generalisation effects. One possible reason is the nature of the threat. As noted, plants are inanimate and thereby inaction towards them does not pose a threat to an individual. Any risks posed to an individual come from mistakes in interacting with plants, and thereby can be mitigated through avoidance. Correspondingly, infants appear to show behavioural avoidance strategies towards plants and plant foods (Rioux & Wertz, 2021; Wertz & Wynn, 2014b; Włodarczyk et al., 2018). In contrast the threats posed by animals and other humans cannot be mitigated by behavioural avoidance strategies to the same degree, indeed it seems that where infants demonstrate behavioural avoidance for plants, infants and young children do not show such a strategy for animals, engaging more and also actively seeking information (Lobue et al., 2013). It could therefore be the case that the risk minimization strategies differ for kinds of naturalistic threats, with greater information seeking and advantaged learning being found in the animal domain, and behavioural avoidance strategies being favoured in the domain of plants and plant-based foods. Indeed, the generalisation findings of Chapters 2 and 3 would support this notion, with effects of information being found in generalisation of greater toxicity and reduced edibility generalisation facilitating behavioural avoidance.

The results of the present dissertation would suggest that learning systems are not specialised for the retention of information about the edibility or toxicity of foods. However, it does appear to be the case that they are shaped to minimise errors, with results from Chapter 3 demonstrating a difference in the kinds of errors made when recalling toxicity information. One explanation for the presence of cognitive biases, made under the auspices of Error Management Theory, is that cognitive systems have been shaped over evolutionary time to minimise costly errors (e.g., Haselton & Nettle, 2006). Indeed, findings from Chapter 3 support the notion of a learning system designed to minimise costly errors. It was observed that recall mistakes for toxicity information were asymmetric, directly reflecting the relative costs of these mistakes, with a higher rate of false positives (saying something is toxic when it is not), the less costly error, than false negatives (saying something is not toxic when it is), the more costly error. Interestingly, whilst there appears to be the inverse pattern for edibility information, this is not significant, with a significant difference between the kinds of mistakes only found in the toxicity condition.

As with the generalisation effects noted above, an increased false positive rate in toxicity recall also corresponds to literature demonstrating negativity bias, that is a greater weighting of negative information than positive (Bebbington et al., 2017; Ito et al., 1998; Vaish et al., 2008), and also loss aversion, an element of prospect theory (Kahneman & Tversky, 1979) arguing that decision makers are more sensitive to losses than equivalent gains (e.g. Tom et al., 2007). If "is toxic" is perceived as more negative, or a greater loss than the corresponding "not edible", it could explain the presence of error-minimising effects in toxicity but not edibility information. This raises the further question however, of whether minimising costs in the present context is better conceptualised as minimising losses, or avoidance of negative outcomes.

It is also of interest that we found an effect of age on error type. Loss aversion has been observed to increase with age (Gächter et al., 2022; Mrkva et al., 2020), which could explain the age effects on error-type and yes-bias observed in Chapter 2. Yet, interestingly, it is also well established that negativity bias *decreases* with age (Carstensen & DeLiema, 2018; Kisley et al., 2007; Wood & Kisley, 2006). That we observed an increase in error type with age, and loss aversion but not negativity sensitivity has been shown to increase with age, could suggest that error-management in recall is more a function of minimising perceived losses than sensitivity to negatively valanced information. Understanding the mechanisms underlying error-management in recall is of great interest and warrants further investigation, may shed light on discrepancies in findings, and is a logical next step in understanding error management in this domain.

We observed in Chapter 3 that there were significant effects of Trait Anxiety on the kinds of mistake made for edibility information, but not for toxicity or neutral information. Interestingly, participants lower on anxiety performed more in line with what one would predict based upon error management principles, that is, participants low on anxiety exhibited more false negatives (the less costly error) and participants higher on anxiety showed more false-negatives. This challenges the notion of anxiety increasing risk aversion (Hartley & Phelps, 2012), or as spurious activation of defence (Johnson et al., 2013) mechanisms, as in this instance anxiety seems to decrease error minimisation.

1.3. Replication(s)

In addition to the theoretical findings outlined above, the present dissertation highlights the importance of replication in psychology. Over the past decade it has become clear that psychology is in a replication crisis (Earp & Trafimow, 2015; Open Science Collaboration, 2015; Schimmack, 2020; Shrout & Rodgers, 2018), with this reducing trust in the field (Wingen et al., 2019). As such the present dissertation looked to replicate existing work on which it was built. In addition to a pre-registered replication attempt of Wertz and Wynn (2014) in Chapter 4, in Chapter 3 it looked to conceptually replicate work demonstrating a learning advantage for dangerous and survival relevant information (e.g. Barrett et al., 2016; Stubbersfield et al., 2015), specifically we replicated Broesch et al. (2014)s null finding that adults did not preferentially learn danger information. Finally, in Chapter 3 we looked to test again our own finding of greater generalisation of toxicity, and reduced generalisation of edibility information (Rioux et al., 2022; Chapter 2), finding converging evidence that this is the case for edibility, but not toxicity.

Results presented in Chapter 4 failed to replicate those observed by Wertz & Wynn (2014a) wherein infants preferentially associate plants with edibility. Whilst Rioux & Wertz

(2021) successfully replicating the finding in 6-month olds, we were unable to replicate this finding in 18-month-olds across three experiments using two different methodologies. The initial two non-replications using the original methods in other domains of developmental psychology also failed to replicate using this method (Cruz-Khalili et al., 2019; Nighbor et al., 2017; Salvadori et al., 2015). We therefore used alternative methods for the third replication attempt, namely, live looking time measures which were used by Wertz & Wynn (2014) in their initial finding with 6-month-olds and in Rioux & Wertz' (2022) replication of this, again we found no evidence that infants selectively associate plants with edibility. It is possible, therefore, that these non-replications indicate that the original findings by Wertz and Wynn (2014) are a false positive. However, it also appears to be the case that studies using the method used in the second replication, live looking time coding, have also failed to replicate effects in other domains (Peterson, 2016; Rubio-Fernández, 2019; Schlingloff et al., 2020). Therefore, in order to rule out further possible explanations for the present non-replications additional replications were planned. Namely, one major concern with the choice method used by Wertz & Wynn (2014) is that it is a social method contingent on social interaction, we therefore looked to examine a non-social choice method. Additionally, given that Rioux & Wertz (2022) successfully replicated the looking time finding with 6-month-olds, and we did not find an effect with 18-month-olds, we aimed to examine whether age effects may exist, planning to run a looking time study with 12-month-olds. Unfortunately these studies were prevented by the onset of the Covid-19 pandemic, and as such these questions remain open for further work.

1.4. Conclusions

Modern food acquisition relying on industrial and processed foods is the exception, with risky hunting and gathering being the norm historically and for many societies today.

The present dissertation looked to examine how these risks have shaped human cognitive systems, specifically learning and generalisation. Evidence presented here offers the first evidence that human generalisation systems are biased to minimise costly mistakes. Specifically, in adults but not children it appears that generalisation is biased towards generalising edibility at a lower rate than other information, with less clear evidence that toxicity is generalised to a greater extent. Further, the present body of research offers some indication that learning systems too are similarly shaped, with the kinds of mistakes made in the recall of toxicity information reflecting their relative costs, with a greater number of false positives than false negatives. However, questions are also raised about the degree to which human learning has been shaped to be more accurate for these kinds of information as, contrary to literature, there was no enhanced learning for information about toxicity in the food domain, and the finding that plants are selectively associated with edibility in infancy was not replicated. Together this sheds light on interesting open questions, in particular, further investigations of the respective roles of learning and generalisation across different age groups are required to shed light on these effects across the lifespan.

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German Summary

Während viele Gesellschaften sich heute auf industriell verarbeitete Nahrung verlassen, ist dies im Vergleich zu anderen Gesellschaften in der Welt und in der Geschichte untypisch. Die Beschaffung von Nahrung durch Jagen oder Sammeln birgt Risiken, die eine Person gegen die Abhängigkeit von diesen Mitteln zum Überleben abwägen muss. Eine Strategie zur Minimierung dieser Risiken besteht darin, sich über die Bedrohungen in seiner Umgebung zu informieren, und es scheint, dass die Lernsysteme darauf spezialisiert sind, wobei bestimmte Informationen leichter erlernt werden können als andere. Frühere Untersuchungen deuten darauf hin, dass Säuglinge in Bezug auf die Essbarkeit von Pflanzen selektiv lernen, und allgemein haben Studien gezeigt, dass Kinder und Erwachsene dazu neigen, überlebenswichtige Informationen bevorzugt zu lernen (z. B. Gefahr, Bedrohung). Eine Erklärung für die Entstehung solcher Präferenzen („biases") ist die Fehlermanagement-Theorie (Error Management Theory), die besagt, dass in Fällen, in denen bestimmte Fehler kostspieliger sind als andere, kognitive Präfenzen („biases") entstehen, um die kostspieligeren Fehler zu minimieren. Die vorliegende Dissertation argumentiert, dass diese Logik auch auf Generalisierungsprozesse angewendet werden kann, und untersucht, inwiefern verschiedene Arten von Informationen unterschiedlich verallgemeinert werden und wie sich dies über den Lebensverlauf hinweg unterscheidet. Außerdem wird selektives Lernen („learning biases") gegenüber bestimmten Arten von Informationen weiter untersucht.

In Kapitel 2 (Rioux, Russell & Wertz, 2022) wird untersucht, ob Generalisierungssysteme in Bezug auf bestimmte Arten von Informationen voreingenommen sind, indem geprüft wird, ob die Generalisierung von Informationen durch Erwachsene und Kinder über Genießbarkeit und Toxizität die relativen Kosten von Generalisierungsfehlern für diese Arten von Informationen widerspiegelt. Wir stellen fest, dass dies der Fall ist: Erwachsene verallgemeinern Informationen zur Toxizität stärker und Informationen zur Genießbarkeit weniger. Interessanterweise scheint dies nur bei dem höchsten Maß an Unsicherheit der Fall zu sein, und der Effekt wird bei Kindern nicht beobachtet. Darüber hinaus finden wir Hinweise darauf, dass es einen allgemeinen Negativitätseffekt auf die Generalisierung zu geben scheint, der jedoch die Unterschiede bei der Generalisierung von Informationen über Genießbarkeit und Toxizität nicht vollständig erklären kann. Diese Ergebnisse liefern den ersten Hinweis darauf, dass bei Menschen die Generalisierung die relativen Kosten möglicher Generalisierungsfehler widerspiegelt, und unterstützen die Auffassung eines Generalisierungssystems, das so gestaltet ist, dass kostspielige Generalisierungsfehler minimiert werden.

In Kapitel 3 untersuchen wir die Auswirkungen der Art der Information auf die Generalisierung mit einer anderen Methode, gehen näher auf die Rolle von Unsicherheit ein und untersuchen die Rolle, die individuelle Unterschiede, insbesondere Angst, bei der Generalisierung spielen. Wir haben auch versucht, auf bestehenden Arbeiten aufzubauen, die zeigen, dass das Lernen für bestimmte Arten von Informationen (z. B. Bedrohung, Gefahr) spezialisiert ist, indem wir selektives Lernen („learning biases") in Bezug auf Informationen über Gefahr und Genießbarkeit im Bereich der Nahrung untersucht haben. Wir fanden eine begrenzte Auswirkung der Art der Information auf die Generalisierung bei Erwachsenen, konnten aber im Gegensatz zu Kapitel 1 nicht feststellen, dass dieser Effekt bei Unsicherheit größer ist. Darüber hinaus fanden wir zwar nicht den vorhergesagten Effekt des Informationstyps auf die Erinnerungsgenauigkeit, der in früheren Untersuchungen beobachtet wurde, aber es wurde festgestellt, dass der Informationstyp die Art der gemachten Fehler beeinflusste, wobei die Teilnehmer mehr falsch-positive Fehler im Vergleich zu den kostspieligeren falsch-negativen Fehlern bei Toxizitätsinformationen machten. Schließlich konnten wir nachweisen, dass entgegen den Vorhersagen individuelle Unterschiede nicht zu risikominimierendem Verhalten führen, sondern dass unter bestimmten Umständen größere Angst zu risikoerhöhendem Verhalten führen kann.

In Kapitel 4 versuchten wir, ein Ergebnis von Wertz & Wynn (2014) zu replizieren, die beobachteten, dass 18 Monate alte Säuglinge Pflanzen selektiv mit Essbarkeit assoziierten und nicht mit einem Kontroll-Artefakt. Wir konnten diesen Befund nicht replizieren. Daraufhin testeten wir den Effekt mit einer alternativen Methode, um mögliche methodische Gründe für unsere Ergebnisse zu untersuchen, und konnten erneut keinen Effekt beobachten.

Insgesamt belegen die in dieser Dissertation vorgestellten Ergebnisse, dass die Generalisierung, nicht aber das Lernen, von der Art der verallgemeinerten Informationen abhängig zu sein scheint. In Übereinstimmung mit den Vorhersagen der Fehlermanagement-Theorie (Error Management Theory) scheinen Generalisierungssysteme darauf ausgerichtet zu sein, die kostspieligeren Fehler zu reduzieren, allerdings nur unter bestimmten Umständen. Dies erfordert weitere Untersuchungen, um die moderierenden Faktoren für die Generalisierung potenziell kostspieliger Informationen zu klären, sowie weitere Replikationen bei der Untersuchung von selektiven Lernprozessen.

Declaration of authorship / Eidesstattliche Erklärung

I hereby declare in lieu of oath

- that I have written this dissertation independently and without unauthorized assistance,
- that I have not submitted this dissertation to any other university and that I do not hold a doctoral degree in the subject of psychology, and
- that I am aware of the doctoral regulations for the degree of Dr. Phil./Ph. D. in the Department of Education and Psychology at the Freie Universität Berlin dated December 2, 2008 (FU-Mitteilungen 60/2008)

Hiermit erkläre ich an Eides statt,

- dass ich die vorliegende Arbeit selbstständig und ohne unerlaubte Hilfe verfasst habe,
- dass ich die Dissertation an keiner anderen Universität eingereicht habe und keinen Doktorgrad in dem Promotionsfach Psychologie besitze und,
- dass mir die Promotionsordnung zum Dr. Phil ./Ph. D. des Fachbereichs Erziehungswissenschaft und Psychologie der Freien Universität Berlin vom 2. Dezember 2008 (FU-Mitteilungen 60/2008) bekannt ist.

Berlin, 2022

Connair Russell