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Food shopping under risk and uncertainty

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ABSTRACT

During the 2020 Covid-19 pandemic panic buying of food was reported by the media. Panic buying has received little attention within behavioural science. In this paper we suggest that optimality models of foraging under risk and uncertainty would be a fruitful place to begin developing useful and testable hypotheses about this behaviour. In making this case we relate panic buying to a general increase in foraging effort, which we characterize as an increase in purchasing and spending. We note two risks during the pandemic – that of food security and that of predation, where predation is understood as a perceived threat to life due to infection risk. Food security was effectively solved early on in the pandemic, whilst perceived threat to life has remained but diminished to some limited extent. We relate panic buying to food caching as a method of buffering risk and make six predictions about how this behaviour should present under food insecurity and perceived threat to life.

1. Introduction

In this paper we discuss the phenomena of panic buying and increased purchasing during disasters. At the time of writing we are undergoing a global pandemic caused by the emergence of a novel coronavirus (SARS-CoV-2), which leads to a respiratory illness called Covid-19. This virus was first detected in the city of Wuhan in China in late 2019 and rapidly spread around the globe (Nextstrain.org, 2020, Hadfield et al., 2018). According to the Worldometer statistics website, on 8 June 2020 there were just over 7.1 million cases of Covid-19 worldwide which had led to 406,474 deaths and just over 3.4 million recoveries (Worldometers.info, 2020).

In response, many governments introduced emergency measures intended to reduce loss of life and strain on health care systems. These included closing all non-essential businesses and controlling access to grocery stores and other essential services. At the beginning of the pandemic, many countries reported a relative increase in the amount of food and related goods purchased at these outlets, and in some early cases, stocks of particular items were rapidly depleted (Bekiempis, 2020; Lufkin, 2020). Such rapid depletion in response to an on-going or impending disaster is often referred to as panic buying or panic purchasing (Stevenson, 2010).

Whilst panic buying is not a novel behavioural pattern, there is very little formal discussion about it within the behavioural sciences. In order to remedy this situation we suggest that optimality approaches developed within behavioural ecology (Parker, 2006) should be of relevance, with special focus upon foraging under risk and uncertainty. Following the introduction of psychological accounts of panic buying, we will draw out key themes and relate them to foraging under risk and uncertainty. This discussion will be followed by an analysis of developed world shopping as a foraging ecology and various predictions will be made about what a human forager might do when risk and uncertainty become a factor in that ecology, with particular reference to the 2020 viral pandemic. We conclude with remarks about how to test the ideas presented. We believe this approach can relate panic buying, as an extreme

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response, to considerations of foraging efforts more generally. Moreover, we can encompass panic buying and increased purchasing during a disaster within one explanatory framework and make some predictions about who may or who may not be more susceptible to behaviours of these kinds.

2. Psychological accounts of panic buying

Panic buying is a well-documented but not well-explained phenomenon. A Google Scholar search, conducted on 8 June 2020, using the search term <"panic buying" OR "panic purchasing"> revealed 2800 publications on this topic since 2010. These articles came from multiple disciplines including economics, business, marketing studies, disaster and supply chain management. Of those articles, 1680 contained some reference to psychology and behaviour (assayed by adding < AND "psychology" OR "behavior" OR "behaviour"> to the original search term). But there is only a small direct contribution to this literature from the behavioural sciences.

Bacon and Corr investigated relevant psychological factors for behaviour change interventions in light of the recent Covid-19 pandemic using reinforcement sensitivity theory, which assumes that personality traits are underpinned by a biological motivational system (Bacon & Corr, 2020). They discuss hoarding and panic buying as approach behaviours that might help to ameliorate anxiety caused by uncertainty and relate this to the concept of self-efficacy (2001, Bandura, 1989). Sim et al. have also argued that panic-buying during the Covid-19 pandemic might be related to anxiety reduction in the face of uncertainty (Sim, Chua, Vieta, & Fernandez, 2020). Specifically, they see panic buying as a possible attempt to maintain normal lifestyles for as long as possible across predicted shortages. But Sim et al. also relate panic buying to simple coping and a response to loss of control. Arafat et al. note that panic buying, whilst much observed across history, has so far not been systematically explained by psychologists (Arafat et al., 2020). As with the previous authors, they suggest panic buying is often a method to deal with a feeling of loss of control, something that they directly relate to perceived scarcity of resources during a disaster and uncertainty over the nature and duration of the situation.

Panic buying is a form of stockpiling and will lead to hoarding, if only in the short term. The clinical literature on dysfunctional hoarding has noted that poor quality of life (QOL) measures are directly related to compulsive hoarding. Saxena et al. have shown that:

(C)ompulsive hoarders had significantly lower scores than non-hoarding OCD (obsessive compulsive disorder) patients in two major domains of QOL: safety and living situation. Hoarders felt less safe in their own neighborhoods, were less satisfied with their protection against attack or robbery, and were more often the victims of crime. Hoarders were also much less satisfied with their living arrangements than non-hoarding OCD patients. ((Saxena et al., 2011) p.478, parentheses added).

This list again speaks to some notion of uncertainty triggering hoarding behaviour. This is in keeping with the site-security hypothesis of hoarding, which sees the accumulation of items in hoarding individuals as the acquisition of capital to buffer against future uncertainty (Kellett, 2007). Items are gathered, stored at a site, and protected. Within clinical populations we might anticipate unusual cue sensitivity and a heightened sense of danger and uncertainty. Within non-clinical populations, similar behaviours may be evoked when real danger and uncertainty are present.

Arafat et al. (2020) also introduce social learning considerations, suggesting that there may be an imitative element to panic buying that causes it to spread within a population, and this in turn magnifies the effects of uncertainty and loss of control. As the authors also note, media reporting of these behaviours can further intensify the signal that a population faces jeopardy.

Whilst these accounts do not present formal models of panic buying they clearly focus on similar issues: danger, uncertainty, a role for resource storage and a specific psychology of anxiety and perceived sense of control. These problems are not species specific and would benefit from a broader and more generalized perspective in order to gain explanatory traction. Kellett's (2007) hoarding thesis comes close to delivering this by directly drawing upon literature in animal behaviour and likens the capacity to maintain site-security to resource holding potential. In keeping with that work, we believe that panic buying can be directly related to models of animal foraging and especially those of foraging under risk and uncertainty.

3. Foraging

3.1. Foraging models

Optimality models emerged in behavioural ecology with the introduction of microeconomic paradigms. Behaviours were seen as strategies that might maximize average lifetime inclusive fitness (Grafen, 1984). Inclusive fitness is the sum of direct and indirect fitness, which are the outcomes of the reproductive efforts of an organism and its genetic relatives respectively (West & Gardner, 2013). In foraging scenarios (food search), calorie return can be used as a proxy for fitness (Stephens, Brown, & Ydenberg, 2007). Thus, the prediction from optimality theory is that less profitable items will either be consumed or they will not, there will be no mixed strategy of some less profitable and some more profitable items in a diet.

It should be noted that the disciplinary assumption is not that nature will supply a perfect rendition of optimal outcomes. Rather, empirical data can be measured against those models and the mismatch (or error) can be pursued through hypothesis development and further work. This much should be obvious from the use of calories as a proxy for fitness given that food also supplies nutrition. Optimal energy gain may not be the only component of fitness. More precisely one cannot assume that the rank ordering of calorific pay-offs precisely matches the rank ordering of true fitness pay-offs. What is assumed is that there is a utility that is maximized through choices, and that this maps perhaps in a non-linear way onto fitness (Caraco, Martindale, & Whittam, 1980; Kacelnik & El Mouden, 2013).

Foraging models can be roughly segregated into those focused upon individual animal foraging strategies, and those focused upon foraging within groups. Table 1 summarizes some of the principal models in both categories discussed in this paper.

Table 1
Some examples of individual and social foraging models with key references.

Model type	Model	Principal effect	Key papers
Individual	Prey choice	Prey items are evaluated in terms of their calories and their individual handling costs such that individual outcomes will enable a rank ordering of available prey items. This preference structure is dependent upon the encounter rate with more profitable items.	(Davies, Krebs, & West, 2011)
Individual	Patch	The marginal value theorem states that an animal should leave a depleting patch, incurring travel costs to move to another patch, only when the rate of return in the first patch falls below the mean rate of return of all background patches.	(Charnov, 1976a; Nonacs, 2001)
Individual	Diet choice – generalism versus specialism	Search time (relative abundance) of high value prey items can be offset by more readily available lower value items, such that an animal will either eat both low and high value items when encountered, or only high value items when they drop below a search time threshold.	(Charnov, 1976b; Krebs, Erichsen, Webber, & Charnov, 1977)
Social	Producer-scrounger	A certain proportion of a population will actively find (produce) food, whilst the remainder of the population will instead scrounge food from those producers. Effectively producers have to share a proportion of their yield with scroungers. Scrounging can amount to following producers and harvesting a portion of the found food before the producer can, or to consuming by-catch (e.g. the fragments beneath a bird feeder caused by the production activity of a bird above), through to direct theft of food items once extracted. Scroungers can do well with relatively few producers in the population, but when producers increase scroungers are often beaten to resource.	(Barnard & Sibly, 1981; Hamilton, 2002)

3.2. Foraging under uncertainty and risk

There is a distinction to be drawn between risk and uncertainty. Risk refers to a known probability, which can be interpreted as a chance of something happening within a set of things or as an expectation of a unique event. Uncertainty implies an unknown probability. Risk data is hard won, and perhaps always imperfect in the natural world (Kacelnik & El Mouden, 2013). But living under uncertainty should be common especially for foraging animals that must deal with various vicissitudes of life including weather conditions, calorific and nutritional pay-off, predation threat, and the behaviour of their prey items.

When food reward is unpredictable in foraging scenarios, animals will resort to fat deposition or food caching (hoarding) or both. Fat deposition can be caused by consuming more food or by changes in metabolism under unpredictable conditions but, irrespective of mechanism, foraging activity also increases (Anselme & Gunturkun, 2019). These outcomes look like adaptations for buffering animals against uncertainty, buying them time to successfully forage in later bouts. Anselme and Gunturkin describe this as an enhanced response to food uncertainty and note that within psychology, a common finding is that a conditioned stimulus (CS) is responded to more when followed by an unpredictable food reward. This kind of approach behaviour is like that described by reinforcement sensitivity theory, and applied directly to responses to the recent Covid-19 pandemic where hoarding and panic buying are approach behaviours to anxiety caused by uncertainty (Bacon & Corr, 2020).

Within the foraging under risk literature there has been great interest in what determines a decision to forage in patches with high outcome variance (risky) as opposed to low outcome variance (not risky). This dates back to a classic study by Caraco and colleagues that looked at foraging choices in Yellow Eyed Juncos (*Junco phaeonotus*). Birds were presented with a consistent reward or a variable reward, but the mean pay-offs over time were equal, and birds were either starved prior to the experiment or not. The basic finding was that hungry birds were risk prone and opted for the variable food reward, whereas non-hungry birds were risk averse and took the consistent pay-off option (Caraco et al., 1980).

Caraco et al. was the first empirical demonstration of risk sensitive foraging and the paper has received much attention, although with poor levels of replication (Kacelnik & El Mouden, 2013). None the less, the finding can be accounted for in fitness terms by arguing that under starvation the potential gains made by a large pay-off are worth pursuing, and they can only be achieved under the variable food reward condition. This is referred to as **the budget rule**, which more precisely claims that an animal should be risk averse when the fixed (or low variance) options are sufficient to meet fitness gains, and risk prone when those options are not sufficient (Kacelnik & Bateson, 1997).

The budget rule is a needs-based approach to predicting risk prone foraging behaviour. It is also possible that animals that are in good condition and can afford to forage under risk are more likely to do so based on ability instead of need. These abilities will include being in good condition making animals either robust enough to weather losses up to a point; more likely to succeed under risk; or, are in better condition which can increase the pay-off relative to that for an individual in poor condition (Barclay, Mishra, & Sparks, 2018). Barclay et al. have captured these routes to foraging under risk in a **state-based model**, where the organism's state is a function of its embodied capital (including its physical state and social capital) and situational factors (which are those environmental variables that mediate embodied capital effects). Thus, an organism's state value is a measure of its relative advantage within a given environment.

One's state in turn influences four key parameters that determine the costs and benefits of risk-taking in any given circumstance: (i) the probability of successful versus unsuccessful risk-taking; (ii) the expected value (payoff) of successful risk- taking; (iii) the expected value (payoff) of unsuccessful risk-taking; and (iv) the expected value (payoff) of the non- risky or 'safer' option. Importantly, one's state can be relative to one's circumstances, relative to alternate states within the same individual or relative to others. A starving

Table 2
Supermarket sales increases (%) in the UK per week in 2020 compared to the same week of 2019, for the weeks ending 29 February and March 7 (Nielsen Scantrack, 2020b), 14 March (Nielsen Scantrack 2020, as cited by Southey, 2020), and 21 March (Nielsen Scantrack, 2020a).

	29 February	7 March	14 March	21 March
Meat substitute	54			
Soup	35	61	118	206
Baking	35			
Canned meat	30	73	147	200
UHT milk		91	181	
Pasta/noodles		74	168	167
Canned pasta		60	148	226
Canned fish				164
Pot noodles				150
Adult analgesics	36	103	170	168
Children's medicine	35	124	228	182
Disinfectant	28			
Cough/cold/flu meds	27	79	155	231
Facial tissues	16	91	154	153
House-cleaning	14		141	
Shower/bath (includes hand d.)		96	152	156
Toilet paper		88	140	
Throat care				224
Tobacco				18
Alcohol				58

individual, for example, is disadvantaged compared to that same individual with a full belly, and is more disadvantaged in food-poor environments than in food-rich environments. Anyone engaging in social conflict is advantaged when they are healthy and have allies, relative to that same individual injured or alone. In other words, 'state' can refer to a competitive (dis)advantage within direct competition, but can also apply to situations far removed from direct competition or comparison to rivals (Barclay et al., 2018, pp 2-3).

Barclay et al. formally modelled this approach and found that risk taking was more likely to be favoured for individuals capable of proximately calibrating their state against key environmental factors.

It has been demonstrated that previously hungry animals that fed from a source with delay or yielding a lesser amount will later opt for that source, even when another with less delay or a larger amount is available. In the great scheme of things, finding food when at starvation is more important than finding it when satiated; in effect this is an asymmetric risk. Thus, monitoring internal state can focus learning of food CSs, such that pairing with unconditioned stimuli (USs) under starvation will create robust learning; in effect the US has greater informational value under these conditions (Kacelnik & Bateson, 1997). This outcome has been formally modelled (McNamara, Trimmer, & Houston, 2012) and relates to earlier work implying that optimal learning in a changeable environment is perhaps not possible (McNamara & Houston, 1985). Inclusive fitness could be increased by learning about reliable food sources under starvation – if they can be found in those conditions then they are more likely to be found under better ones.

4. Shops, foraging and panic buying

Panic buying is always discussed within the context of developed world shopping practices. The history of food retailing is a one of increasing diversity of offer, and increasing certainty of choice (Munson, Tiropanis, & Lowe, 2017; Stanton, 2018). These modern practices are at the end of a relatively short history of human development that saw the emergence of pastoralism and agriculture leading to innovations in human social organization (Kaplan, Hooper, & Gurven, 2009). Humans have long cached food, and developments in domestic living, such as cool larders, ice rooms and eventually refrigeration and freezing, alongside the emergence of preserving technologies attest to this. These behaviours and innovations are long-term management solutions to uncertainty that have removed humans from wild foraging and enabled the acquisition of crucial capital (food) with clear fitness pay-offs. We see similar behaviours in other species, for example insects that cultivate fungus for food, rather than directly foraging for it (Dall, 2010).

4.1. Shops as patches

Modern shopping might best be characterized as a managed patch solution to foraging, where the patches never really deplete or vary meaningfully and are therefore relatively stable with regard to fitness outcomes. Moreover shopping in conjunction with domestic technologies has expanded human caching capacity with many people buying food for a week or some similar period (Achón, Serrano, García-González, Alonso-Aperte, & Varela-Moreiras, 2017).

Food shopping is a well-defined foraging task in an ecological niche that offers an increasing diversity and certainty of choice. Since many supermarkets stock the same kinds of produce, they spend much time competing with one another on price or quality in order to attract more foragers by offering particular cost-benefit trade-offs. This competition effectively stratifies supermarkets, as different socioeconomic groupings respond to different trade-offs with specific kinds of food choice limitations resulting within each group (Camden et al., 2018). Given this, one assumption might be that foragers face a patch choice problem, and more or less solve it as a prey choice problem. The prey choice model predicts that different prey items are ranked from most to least profitable in terms of their

calories and handling costs, so that the most profitable currently available prey are selected (see Table 1).

4.2. Panic buying, increased purchasing and caching

The panic buying and increased purchasing seen at the start of the current Covid-19 pandemic is a form of increased caching behaviour. Increases in purchasing and spending can be regarded as increases in foraging effort, relative to comparable periods of time in the past (Table 2). The general population had been given good reason to suppose that access to food resource would change for the worse (for numerous reasons including disruptions to the food supply chain as workers fell ill, and the need to limit visits to shops in order to enact infection control measures). It was also clear that the length of any disruption was unknown and the solutions to disruption were undetermined. Buffering a hiatus in normal availability of essential items would appear to be a rational management decision; and, whilst the popular media made much of specific runs on odd items like toilet paper and dry pasta (specifically labelled as panic buying), Table 2 indicates a more measured approach to food security at the population level in line with the site-security view of hoarding (Kellett, 2007). Indeed, many of the food items are non-perishable or have long shelf lives.

It is possible that the specific runs are related to producer-scrounger (P–S) foraging. The P–S model suggests that a population consists of producers who actively forage (or produce) food, and scroungers who exploit the producers, for instance by following them and taking a portion of the producers' food for themselves (see Table 1). PS-models are closely related to innovator-imitator models in which a few members of a population can solve problems, whilst the majority copy their solutions (Lehmann & Feldman, 2009). This is the difference between adopting an effortful individual learning strategy or a cheaper social one, and is related to the suggestion from Arafat and colleagues that social learning is involved in panic buying (Arafat et al., 2020). It is possible that people may be prone to imitation under uncertainty as they look to social clues for quick solutions rather than investing in extensive data collection, which may not pay off due to time constraints.

Food caching relies on the ability to find sufficient food, handle it and store it to a good degree of success. Socioeconomic variables, as a measure of individual state, should differentiate here. Poorer individuals are less likely to have capacity to buy large amounts of food in one hit, and will more likely have less capacity to store lots of items in their homes. This does not mean that they will not increase purchasing relative to their own baselines where they can, but it does mean that there should be partitioned variance in caching across socioeconomic groups.

Socioeconomic position, whilst closely related to absolute income, is a function of many parameters including education, neighbourhood effects and access to opportunities. In effect it is a broader conception of resource than income alone. Broadly speaking we see declining socioeconomic status as co-varying with increasing exposure to stochastic risk and reduced ability to plan long-term management solutions. These effects have been well documented in related literatures (Nettle, Coall, & Dickins, 2011; Nettle, Dickins, Coall, & de Mornay Davies, 2013; Smith & Elander, 2006). We predict that the likelihood and extent of increased purchasing will differ between socioeconomic groups. A German panel survey asked 1000 participants whether they had increased their purchases during the pandemic compared to their previous shopping behaviour. Increased purchasing was more common in people who either attended university or had obtained a high school diploma allowing for university enrolment than in those who had not. Increased purchasing was less common in households with a monthly income below €1,500, but equally common in all other income grades (The Nielsen Company, 2020). This will likely be due to limited possibilities of increasing purchases in the lowest income grade. Data from the other income groups does not suggest that household income had an effect on panic buying likelihood, although their relative increase of purchasing is unknown.

A corollary effect of socioeconomic status might relate to the kind of food purchased during the pandemic. Low socioeconomic status in developed world countries is strongly and positively associated with higher rates of obesity (J. C. K. Wells, 2016). For women, at least, this is possibly a fat deposition strategy to deal with food uncertainty (Nettle, Andrews, & Bateson, 2017). In keeping with this, a higher percentage of body fat in both sexes, but not hunger, has been related to a preference for impulsive food decisions rather than delay for a better reward (Rasmussen, Lawyer, & Reilly, 2010). High calorie foods might be preferred during a pandemic, especially during early stages of food uncertainty, including by those who are unable to cache (§4.3).

4.3. Caching and predation

Panic buying and increased purchasing may also be a response to foraging under fear of predation. The SARS-CoV-2 virus that causes Covid-19 directly threatens health and mortality. Whilst the virus is not a predator, but rather a parasite, the public health response to the pandemic has been directed at social behaviours making clear that risk of morbidity and mortality is increased by social contact. To some interesting extent this should increase vigilance around other people, not dissimilar to increases in vigilance seen in animal foraging under predation (Brown & Kotler, 2007) as other people might become associated with a perceived threat to life. Thus, we might expect an effort to reduce exposure to infection over time in much the same way as animals attempt to reduce exposure to predation.

Small passerine birds have high metabolic demands but cannot afford to store too much fat as it impedes flight, making predator evasion less successful. They constantly balance starvation against predation risk. Two hypotheses exist. The first is that diurnal foraging effort is bimodal with a peak in activity in the morning to stave off overnight starvation and survive into the day, and a second peak before sunset to store enough food to survive the night. In the middle portion birds seek cover to reduce predation. The second is that birds spread the risk across the day prioritizing reducing starvation when they face significant predation risks (Bonter, Zuckerberg, Sedgwick, & Hochachka, 2013). Bonter and colleagues found empirical support for the risk-spreading hypothesis in four species of free-living passerines but did note bimodal distributions had been recorded in some other species in the absence of predation pressure.

In passing they also noted that many of these species, in both cases, may be relying on food caches for example during the morning to gain enough energy to commence foraging.

In the bird studies quoted a key factor was the state of the individual bird, this time in terms of its energetic capacity (Houston, McNamara, & Hutchinson, 1993). The mortality risk associated with starvation appears too high to discount in favour of predator avoidance. During the early stages of the pandemic two threats were present: food insecurity (uncertainty of finding food) and perceived threat to life (infection). In the later stages of the pandemic food insecurity was reduced as wholesalers and retailers made it clear that supply chains were robust. Panic buying under food insecurity, perhaps driven by innovator-imitator dynamics, would largely ignore perceived threat to life and see foragers enter uncontrolled (prior to the introduction of public health measures) patches with relatively high risks of predation in order to secure food. When food security was assured this left only the perceived threat to life (somewhat reduced due to public health measures). With low outcome variance food resources now re-established we might predict regular foraging trips to shops to also resume.

Modern shoppers are probably not best described as diurnal foragers: their metabolic margins are very far from those of small passerines, and they seem to rely upon food caches in normal times. Given this, it is possible that when food security was resumed foragers might have maintained increased foraging effort (purchasing) in order to increase inter-foraging delay to reduce exposure to infection. This relates to the concept of a landscape of fear, which describes the areas foraging animals will underexploit when there is significant predation threat (Brown & Kotler, 2007). Where patch foragers might generally move to less predator rich areas, all patches in the case of the current pandemic carry some perceived threat to life due to infection.

There is some limited evidence that modern foraging in the developed world is influenced by a landscape of fear. For example, Dennis and colleagues found that adolescents preferred to buy food from unhealthy fast food outlets, as opposed to healthier options, because the healthier shops were located in areas that they found threatening (Dennis, Gaulocher, Carpiano, & Brown, 2009). Also, a number of studies have found support for the watching-eyes effect when posters depicting watching eyes have been used to drive down anti-social behaviour, including theft (Dear, Dutton, & Fox, 2019). Theft is a form of foraging behaviour subject to costly social sanctions, which again is a form of predation. The association between watching eyes and being caught and punished is thought to be very strong. These interventions create a landscape of fear for criminals.

Our precise prediction here is that food insecurity should lead to a greater increase in caching behaviour than predation (or infection) threat alone. If one's food supply fails then buying time to resolve new resource is important. When that is resolved, a constant and novel perceived threat to life that is approximately equal across all low outcome variance patches may lead to a continued increase in foraging effort, but not necessarily to the same level. The level may be reduced due to costs associated with increasing caching, including expenditure within a monthly pay packet and limitation on choice, as more long-lasting foods may have to be selected.

4.4. State based considerations

The precise risk of death due to infection is hard to calculate, although readily available data in broadcast, online and print media makes clear categories of higher risk. Those who are elderly, or have underlying conditions that make respiratory disease a danger, or whose access to medical care is restricted will necessarily feel more vulnerable and potentially more fearful. Again, this will be socioeconomically distributed (Pickett & Wilkinson, 2015). It is possible that these vulnerabilities, again seen as state-based variables, might impact upon perceived threat to life such that a further prediction would be that the general increased purchasing should occur in those who are less vulnerable or perceive themselves as such. This is in line with survey data from Germany, where increased purchasing was less common in people who considered themselves to be vulnerable, and less common in those with standard medical insurance as opposed to those with private medical insurance (The Nielsen Company, 2020). In essence, the less vulnerable a person is, the better equipped they are to deal with infection threat and they can afford to increase foraging effort, which will mean that inter-foraging intervals might return to normal once food uncertainty is removed, regardless of perceived threat to life. Indeed, we might expect bold foragers in this context to exploit more diverse foraging niches to maximize prey choice, just so long as risk was not too high (Mella, Ward, Banks, & McArthur, 2015; Wat, Herath, Rus, Banks, & McArthur, 2020). However, vulnerable individuals should still reduce the time spent in supermarkets and could either move their purchasing online, or recruit a third party to forage for them.

As Brown and Kotler note, in high risk environments animals should be more fearful; but also if the animal has more to lose in fitness terms it should be more fearful; and, if the gains from any unit of energy are less they should be more fearful than an animal with more to gain from that same unit (Brown & Kotler, 2007). Thus, not everyone should be expected to resume normal foraging when threat has been attenuated by public health interventions. Note that risk, here, should be seen as an opportunity cost of foraging.

5. Drawing hypotheses together

In §4 we explored panic buying and increased purchasing using the tools provided by foraging theory (Table 1 and §3). We sought to explain this behaviour as increased foraging effort for a normally caching species. In this case increased caching is hypothesized in order to buffer a period of food uncertainty, but we have also argued that exposure to predation (infection) risk may affect that effort and especially for vulnerable individuals. Socioeconomic status should differentiate people in terms of their engagement with increased foraging effort. We also suggested that panic buying, understood as a run on specific items, might be facilitated by producer-scrounger dynamics within the population that caused imitators to track social information about what might be most in need of caching during peak uncertainty.

Table 3
Six hypotheses about panic buying and increased purchasing during a disaster period. *Caching* refers to increased caching in humans, a species that already cache in modern populations. *Baseline* refers to purchasing comparisons between the same months in a disaster year and in previous non-disaster years, where purchasing is a measure of foraging effort.

	Hypothesis	Foraging considerations
1a	Socioeconomic status should be positively correlated with the likelihood of caching	State-based
1b	Low socioeconomic caching should have smaller percentage increases from baseline than higher socioeconomic status caching	State-based
2	Healthy food choices should reduce during caching, but more so in low socioeconomic status groupings	State-based
3	Panic buying (item runs) should be localized and short lived as imitative strategies	Producer-scrounger
4	Foraging effort under food uncertainty should be greater than under predation (perceived threat to life) alone	Risk and uncertainty
5	Those who are less vulnerable should be bolder and only increase foraging effort due to food uncertainty but not due to perceived threat to life.	State based and fear

We have pulled out our six key hypotheses and presented them in Table 3.

As we noted, panic buying is an underexplored area but those discussions that do exist, including some in the clinical hoarding literature, cohere around issues of risk and uncertainty. We have used optimal foraging literature and survey data to derive the preceding discussion and hypotheses.

Rapid survey assessments are a natural response during a crisis, and with due cautions around self-reported data and yes/no questions; they do give a useful sense of possible trends but without capturing true variance in behaviour. To this end, and in this case, they help to build hypotheses. But surveys like this are clearly blunt tools. Actual data on spending, and food choice would be extremely useful and may become available at some point after the pandemic (although some researchers note this is hard to access (Munson et al., 2017)). To really test the dynamic nature of our hypotheses we believe a combination of detailed observational data from similar, real pandemic situations, modelling and experimental work are required.

6. Conclusion and afterword

This paper is a contribution to a special issue of *Learning and Motivation*, published in honour and memoriam of James E. Wright, better known as Jim Wright.

Jim Wright's academic legacy is one of enduring intellectual scholarship, and a deep interest in behaviour. His focus upon both behaviourism and ethology, frameworks of learning and instinct respectively, give a sense of his breadth and also his willingness to engage in theoretical contemplation. Only an agile and congenial host would attempt to accommodate both camps. The first author (Dickins) was fortunate enough to benefit from Jim's intellectual hospitality during his formative years and as an emergent academic, having been introduced by his father, David W. Dickins, an almost exact contemporary and friend of Jim's. Those exposures had their influence. The sense of excitement around studying behaviour in the field and lab, but also through theoretical engagement, echo down the generations and across collaborations.

This paper results from the collaboration between academic generations and the kind of wide ranging conversation that Jim would engage in. We thank Jim for directly and indirectly exposing us to this, and in turn for educating us. We hope that this attempt to apply foraging theory to a contemporary problem is in keeping with Jim's intellectual spirit, but we also hope that we have convinced readers that marrying foraging theory with more pragmatic problems has the potential to bear fruit. The use of foraging theory as a framework for explanation within human concerns has been pursued before (Hantula, Brockman, & Smith, 2008; Pirolli & Card, 1999; Wells, 2012), so our only claim to novelty is to apply it to modern consumer behaviour during a crisis.

Author statement

TED and SS both contributed to the development of the arguments presented in this paper. TED wrote a full manuscript and SS added to subsequent drafts.

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