A scarcity mindset alters neural processing underlying consumer decision making

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Not having enough of what one needs has long been shown to have detrimental consequences for decision making. Recent work suggests that the experience of insufficient resources can create a "scarcity" mindset; increasing attention toward the scarce resource itself, but at the cost of attention for unrelated aspects. To investigate the effects of a scarcity mindset on consumer choice behavior, as well as its underlying neural mechanisms, we used an experimental manipulation to induce both a scarcity and an abundance mindset within participants and examined the effects of both mindsets on participants' willingness to pay for familiar food items while being scanned using fMRI. Results demonstrated that a scarcity mindset affects neural mechanisms related to consumer decision making. When in a scarcity mindset compared with an abundance mindset, participants had increased activity in the orbitofrontal cortex, a region often implicated in valuation processes. Moreover, again compared with abundance, a scarcity mindset decreased activity in dorsolateral prefrontal cortex, an area well known for its role in goal-directed choice. This effect was predominant in the group of participants who experienced scarcity following abundance, suggesting that the effects of scarcity are largest when they are compared with previous situations when resources were plentiful. More broadly, these data suggest a potential neural locus for a scarcity mindset and demonstrate how these changes in brain activity might underlie goal-directed decision making.

scarcity | consumer choice | fMRI

Lacking the resources to satisfy one's needs has a profound impact on decision making. In an attempt to alleviate their financial situation, people who live in circumstances of poverty often make decisions that may cause their situation to deteriorate. They take out loans at higher interest rates (1), save less (2), are more present biased in economic choice tasks (3), and they participate more often in lotteries (4). To help understand these phenomena, researchers have proposed a state-dependent account of scarcity: Shah, Mullainathan, and Shafir (5) posit that irrespective of the limited resource itself (money, time, food, etc.), the mere feeling of not having enough will elicit a scarcity mindset. This research shows that a scarcity mindset leads to greater engagement on decision problems that involve these scarce resources, at the expense of attention to other matters (5–7); however, see refs. 8 and 9. Here, we aim to add to this literature in two ways. Here, we develop a task compatible for fMRI experiments, to allow for the examination of how scarcity in a particular domain can impact decisions taken in another, unrelated context. We do this to investigate whether a scarcity mindset might influence brain processing when making everyday consumer decisions.

Investigating how a scarcity mindset plays a role in decision making in a laboratory setting is a challenging endeavor. Previous efforts include limiting personal resources, for example, limiting shots in an experimental shooting game (5), triggering thoughts about the past when resources were scarce (10), inducing hunger by food restriction (11, 12), current income level (7), or exposure to faux articles about economic recession (13) (for an extensive overview of different scarcity manipulations see ref. 14). However, such manipulations do not always rely on deciding about actual scarce resources in the present; they may be confounded by different life histories or be dependent on particular skills in the game participants are playing. Moreover, to our knowledge, no neuroimaging investigation on scarcity exists to date. In the current experiment, we aimed to isolate the effects of a scarcity mindset in an fMRI laboratory setting, while controlling both for behavioral outcome and the time spent on the task.

An important set of decisions we make on an everyday basis is concerning consumer choice. This type of decisions is especially interesting in the context of a scarcity mindset, given that in situations where assets are low, balancing needs and wants with resources is both imperative and difficult. The role of resource scarcity in consumer choice has received increasing attention (e.g., ref. 15); however, limited experimental work has been conducted to date. Here, we explore how the presence of a scarcity mindset can impact consumer choice, by employing a well-established and rigorous auction mechanism, namely the Becker–DeGroot–Marschak (BDM) task (16) to measure true valuation for each of a set of supermarket products we offered for sale to participants. In a previous series of studies, authors argue that a scarcity mindset might render people more deliberative and thus less susceptible to external influences when making decisions about resources (17). However, decision making under conditions of economic hardship is also known to be affected by influences unrelated to the

Significance

How poverty impacts decision making is a vitally important societal question. Recent influential theories proposed that altered decision making by the poor might be explained by a "scarcity" mindset. Here, we created an experimental manipulation which allowed us to investigate how consumer decisions and their neural processes are affected by scarcity, while circumventing potential confounds associated with comparing individuals with high and low income. Neuroimaging results suggest that a scarcity mindset affects neural mechanisms underlying goal-directed decision making, and that the effects of scarcity are largest when they are compared with previous situations when resources were abundant. The current findings contribute to a greater understanding of the mechanisms by which limited resources affect decision making.

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scarce resource; for example, poverty is associated with high caloric food intake (18, 19), and income inequality leads to increased consumption of higher-status or positional goods (20, 21). In addition, previous studies suggest that consumer choice might be dependent on different attributes of food products, for example, the distinction between the relative hedonic (pleasurable, e.g., candy) and utilitarian (nutritional, e.g., broccoli) aspects of foods (22). Therefore, here we examined the effects of scarcity on consumer decision making, in general, and additionally explored the effects of scarcity on participants' preferences for hedonic or utilitarian food types.

We place consumer choice in the cognitive framework of goal-directed decision making (23). Broadly, goal-directed decision making involves a value comparison process between different possible actions while taking both internal and external current states into consideration, and subsequently selecting the option with the highest subjective value. The orbitofrontal cortex (OFC) and dorsolateral prefrontal cortex (dlPFC) are crucial neural nodes for goal-directed decisions (23). Increased activation in OFC is consistently found to predict increased subjective value (24–27), and this region has also been shown to encode task-specific state space representations, a property that is essential for embedding task requirements and goals into the decision process (28). In parallel, the dlPFC is involved in a variety of cognitive processes that are implicated in goal-directed behavior, including organization of working memory and planning (29, 30). Additionally, the dlPFC has been involved specifically in purchasing decisions (24), representing higher order goals when making these choices. Overall, therefore, it is theorized that OFC operates as a "hub," taking input from other regions of the brain, such as the dlPFC, and integrates this information into stimulus value (26, 31). Given their involvement in goal-directed decision making, and previous findings that valuation processes are affected in scarcity (17, 20, 21), the OFC and dlPFC are important candidate regions for examining whether and how a scarcity mindset can impact consumer decision making.

We experimentally examined how consumer choice might be affected by a mindset of scarcity and their related neural processes. To do this, we created an experimental paradigm called the stage games by which we manipulated scarcity and abundance mindsets. Participants underwent fMRI scanning while completing this three-stage task. Each stage consisted of 30 trials of a simple cognitive/perceptual task: dot counting, shape matching, and dot comparison (Fig. 1). Participants could either win or lose a token on each trial. Importantly, participants were required to possess a positive balance of at least one token to progress to each following stage, and if they successfully completed all three stages they received a monetary bonus. Participants attempted the task twice—once after receiving an initial endowment of 1 token, and once after receiving an endowment of 10 tokens. Task feedback (i.e., wins and losses) was manipulated to ensure that there was an equal number of wins and losses across each stage of the task (*SI Appendix*, Fig. S1). Crucially, this ensured that in the single token endowment condition, participants consistently hovered around the one token threshold to continue, thus eliciting a scarcity mindset for this run. Alternatively, in the 10 token endowment condition, participants always lay comfortably above the threshold required to advance, thus creating an abundance mindset. Participants returned to the laboratory 1–2 wk later to assess their preferences for products independent of a scarcity or abundance mindset. At the end of each of the three stages, participants were directed to an unrelated task called the bidding task (Fig. 2), in which they bid for various food items with a separate experimental budget to assess the influence of the scarcity and abundance mindsets on consumer decision making.

To assess the influence of the two mindsets on choice and the associated neural activity, we compared both the behavioral and fMRI data of the bidding task embedded in the scarcity and the abundance mindset. Following ref. 5, we hypothesized that in a scarcity mindset, decision making is more consistent with subjective value. Therefore, we expected that bids made in the scarcity condition would show a stronger relation to willingness to pay for products as indicated by participants without a mindset manipulation. We furthermore expected that scarcity affected the neurobiological processes underlying goal-directed decision making, specifically in the OFC and dlPFC. Lastly, we investigated whether a scarcity mindset affects willingness to pay differentially for hedonic versus utilitarian consumer products.

Results

Behavioral Analyses. First, we investigated subjective differences between the mindset conditions via a short questionnaire following the scanning session. Participants were significantly affected by the scarcity mindset [$F(1,76) = 14.49$, $P < 0.001$]. In a scarcity mindset, participants reported that they felt less confident [M (abundance) = 7.21, M (scarcity) = 4.74, $t(38) = -7.69$, $P < 0.001$, Cohen's $d = 1.23$] and more stress [M (abundance) = 4.69, M (scarcity) = 2.67, $t(38) = 6.11$, $P < 0.001$, Cohen's $d = 0.98$], compared with the abundance mindset. Participants did not report feeling differentially motivated or excited between the two mindsets. Participants did not show any response time differences during the perceptual tasks of the stage games when comparing between the scarcity and abundance mindsets (*SI Appendix*).

To examine how participants made bids for the consumer products in this task, we first tested how individual ratings of hedonic, utilitarian, liking, frequency of buying the product, and retail price per product affected participants' bidding behavior (see *Methods* for full mixed-effects models). Results from this model showed that participants made higher bids for products that had higher retail prices [$F(1,139.54) = 115.97$, $P < 0.001$] that were rated higher in the hedonic scale [$F(1,68.91) = 38.71$, $P < 0.001$] and when the product was rated as more liked [$F(1,45.14) = 53.78$, $P < 0.001$]. How frequently participants bought the product and how utilitarian the products were rated did not affect bids (frequency: $P = 0.12$, utilitarian: $P = 0.74$).

Next, we tested whether participants were willing to pay more for consumer products in the scarcity mindset compared with the abundance mindset, and if this was dependent on product type (hedonic/utilitarian) or order of the mindsets [scarcity first, abundance second (SA)/abundance first, scarcity second (AS)]. There was no significant

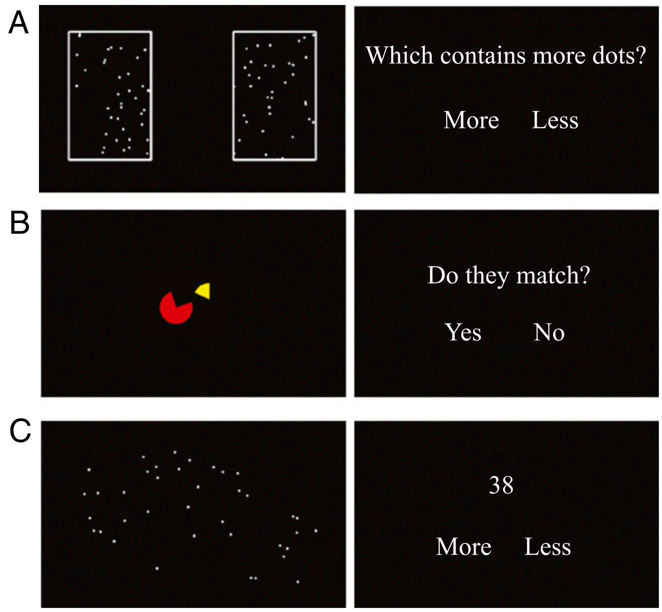

Fig. 1. The three cognitive/perceptual tasks of the stage game task. (*A*) Dot comparison task. We presented participants with the two rectangles filled with dots for 1 s. We asked to choose which rectangle contained more dots. In reality, both rectangles always contained an equal, random amount of 30–40 dots. (*B*) Shape matching task. Participants were presented with two shapes for 1 s and asked to indicate whether the shapes together comprised a perfect circle. In reality, none of the shapes fulfilled this criterion. (*C*) Dot counting task. A random amount of dots drawn from a uniform distribution of between 30 and 40 were presented on screen for 1 s. Participants' task was to estimate if the amount of dots appeared on screen was more or less than a presented number.

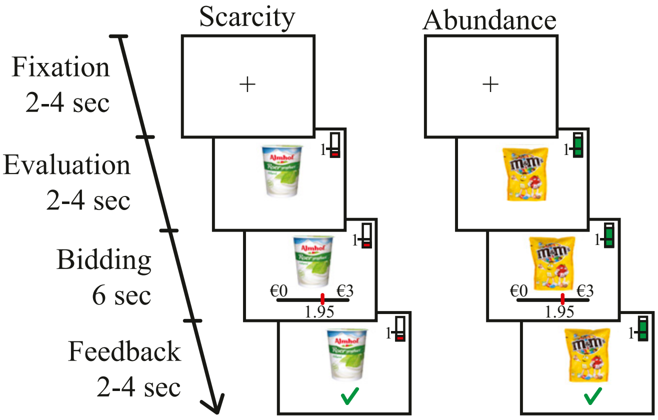

Fig. 2. Time structure of the bidding task. Participants could indicate their bid amount on a slider from €0 to €3, in increments of €0.05. The figure on the *Top Right* corner of the screen reminded participants of their performance in the stage game. The feedback screen indicates whether participants' bid was higher than the computer generated price. Products were never presented more than once.

main effect of mindset on bids [$F(1,41.04) = 1.47$, $P = 0.23$], with approximately equal average bids in the scarcity compared with as abundance mindset ($M =$ €1.23, $M =$ €1.19, respectively). Participants were willing to pay more for hedonic products [$F(1,41.01) = 5.47$, $P = 0.02$, M (hedonic) = €1.26, M (utilitarian) = €1.13]; however, there was no interaction with mindset ($P = 0.39$). Order of the mindsets did not affect participants' bids.

Then, we explored whether participants' valuation of products would be more in line with subjective value in a scarcity mindset compared with abundance. To test this, we examined whether rated willingness to pay for the products, as measured in the behavioral session 1–2 wk later, affected bidding behavior in the scarcity and abundance mindsets differently. Results showed that this willingness to pay measure significantly predicted higher bids during the scanning session [$F(1,41.14) = 191.67$, $P < 0.001$]. However, willingness to pay did not predict bids differently in the scarcity versus the abundance mindset; the interaction between mindset and willingness to pay for the products 1–2 wk later was not significantly different ($P = 0.83$).

As an exploratory analysis, we investigated how the actual value of the products, as assessed by their retail price, impacted bidding behavior as a function of mindset. Overall, participants' behavior was significantly affected by retail price [$\beta = 0.11$, $t(43) = 6.75$, $P < 0.001$]. The moderation of this effect by mindset was marginally significant. In scarcity, participants bid more in line with retail price than in abundance [$\beta = 0.06$, $F(1,119{,}99) = 2.70$, $P = 0.103$]. In a second model, the measures of hedonic, utilitarian, liking, and buying frequency were added as covariates to the model to control for individual differences, and this effect reached statistical significance [$\beta = 0.06$, $F(1,168.3) = 4.32$, $P = 0.029$].

fMRI Results. To examine how scarcity, compared with abundance, impacted the neural mechanisms of consumer choice, we divided the task into three phases (Fig. 2): First, the evaluation phase, in which participants are presented with the product; then the bidding phase, in which participants indicate the amount they would like to pay for the product; and finally the feedback phase, where participants learned whether or not they had won the auction item.

Evaluation phase. Consistent with our hypothesis, the contrast scarcity > abundance during the evaluation phase of the bidding task exhibited greater BOLD activity in the OFC (BA 11) [whole brain voxel $P < 0.001$ unc., $t(1,40) = 3.31$, cluster FWE corrected, $P = 0.001$, k = 152, see Fig. 3]. Subsequent ROI analysis on this functional cluster revealed that activity in the OFC was not different for hedonic or utilitarian products, and did not depend on order of presentation of the scarcity and abundance mindset.

Bidding phase. Across both mindsets and product types, we found that the parametric modulator of bid amount (i.e., willingness to pay) was positively associated with the right dlPFC activity (BA45/47), dorsal anterior cingulate cortex (dACC) activity (BA32/8), and left anterior insula (BA 47/48) [all clusters whole brain voxel $P < 0.001$ unc $t(1,40) = 3.31$, right dlPFC: p (FWE) = 0.001, k = 151, dACC: cluster p (FWE) = 0.002, k = 190, left anterior insula: cluster p (FWE) = 0.020, k = 120]. These effects were not significantly moderated by mindset, product type, order of the mindsets, or any of their interactions.

The contrast abundance > scarcity during the bidding phase showed increased neural activity in the left dlPFC (BA 46) and left angular gyrus (BA 39) in abundance compared with scarcity [dlPFC: whole brain voxel $P < 0.001$ unc, $t(1,40) = 3.31$, cluster FWE corrected $P = 0.064$, k = 51, angular gyrus: whole brain voxel $P < 0.001$ unc, $t(1,40) = 3.31$, cluster FWE corrected $P = 0.060$, k = 52, see Fig. 4]. Further ROI analyses revealed an order effect, with a significant interaction between mindset and order of presentation [$F(1,40) = 4.40$, $P = 0.042$, $\eta^2 = 0.10$], specifically in the dlPFC. Participants who were first presented with the abundance mindset showed a decrease in dlPFC activity in the scarcity mindset [$F(1,19) = 36.75$, $P < 001$, $\eta^2 = 0.66$]. However, the participants who started with the scarcity mindset showed no subsequent significant effect of mindset on activity in the left dlPFC [$F(1,21) = 1.23$, $P = 0.263$].

Feedback phase. Collapsed across mindsets, the contrast positive > negative feedback (i.e., winning the product vs. not winning) showed greater neural activity in the following regions: OFC (BA 11, cluster FWE $P < 0.001$, k = 117), left angular gyrus (BA 39, cluster FWE $P < 0.001$, k = 88), right caudate nucleus (BA 11, cluster FWE $P = 0.004$, k = 9), precuneus, BA 21, bilateral middle temporal gyrus, dACC (BA 32, cluster FWE $P = 0.001$, k = 18). Reverse contrast negative > positive feedback showed stronger neural responsivity in the bilateral posterior insula [left insula: $t(1,40) = 3.31$, cluster p (FWE) = 0.023, k = 94, right insula: $t(1,40) = 3.31$, cluster p (FWE) = 0.002, k = 181].

We observed a trend that suggests that activity in the vmPFC as a function of positive versus negative feedback, was different in the scarcity and abundance mindsets [$F(1,40) = 3.60$, $P = 0.065$, $\eta^2 = 0.08$]. The difference in responsivity of the vmPFC when receiving feedback, that is, positive minus negative feedback, is larger in scarcity than in abundance [$t(40) = 1.81$, $P = 0.078$, M (scarcity) = 0.35, M (abundance) = 0.20]. Activity in the caudate nucleus was not significantly affected by mindset.

Discussion

This study investigates the impact of a scarcity mindset on the neural processes associated with goal-directed decision making. Though scarcity as a conceptual phenomenon has generated much recent interest in how it might moderate decision-making behavior in important ways, to date there has been no experimental efforts to systematically induce a scarcity "mindset" and examine how this might affect both behavior and brain. Here, we employed a task in an

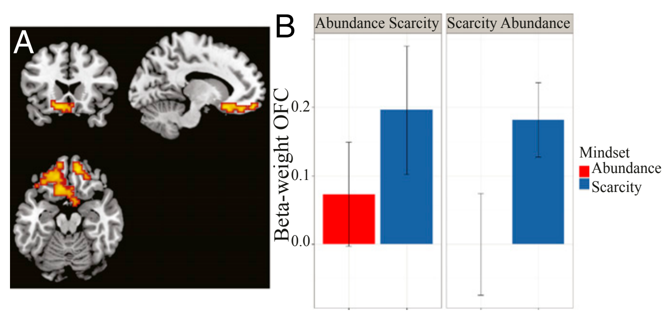

Fig. 3. (*A*) Increased BOLD activity for scarcity > abundance in the OFC during the evaluation phase of the bidding task, whole brain $P < 0.001$ unc., p (FEW) = 0.001, k = 152, peak MNI = [–13,21,–18]. (*B*) Beta weights of activity of the OFC during evaluation of the products. Plotted per mindset (scarcity/abundance) and per order (scarcity first, abundance second/abundance first, scarcity second). Mindset significantly increased activity in the OFC.

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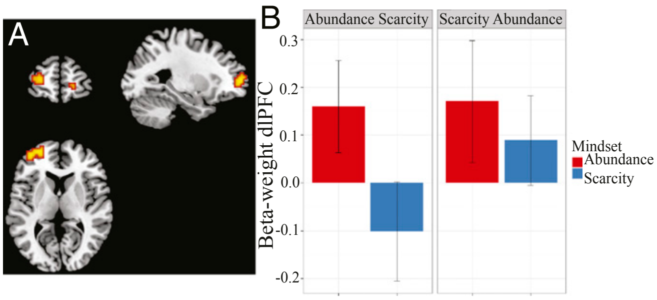

Fig. 4. (*A*) Increased BOLD activity for abundance > scarcity in the left dlPFC during the bidding phase of the bidding task, whole brain $P < 0.001$ unc., p FWE = 0.064, k = 51, peak MNI = [−27,60,7]. (*B*) Beta weights of activity of the left dlPFC during bidding for the products. Plotted per mindset (scarcity/abundance) and per order (scarcity first, abundance second/abundance first, scarcity second). The scarcity mindset was significantly related to decreased activity in the left dlPFC. This effect was significantly larger when participants started with abundance and switched to scarcity than the group of participants that started with scarcity and switched to abundance.

attempt to induce mindsets of both scarcity and abundance within participants, and further to examine how such a mindset could have spillover effects onto unrelated decisions, in this case decisions about how much to bid in a consumer choice task. Use of a controlled manipulation such as this offers advantages over other approaches, for instance hypothetical scenarios ("imagine you have limited resources") or field studies, and in particular it allowed us to use functional brain imaging to assess the impact of these two disparate mindsets on neural activity.

In this study, we employed a task in an attempt to induce mindsets of both scarcity and abundance, respectively, within participants, to examine how these mindsets might have spillover effects onto an unrelated consumer choice task. First, participants reported being less confident and more stressed in the scarcity manipulation compared with that of abundance, indicating that we successfully induced differences in mindset across conditions. We did not observe a main effect of mindset on bidding behavior, nor was there evidence that participants' behavior was differently impacted by whether a product was either hedonic or utilitarian in nature in the scarcity or abundance mindset. However, and importantly, we did find that participants' bidding behavior interacted with mindset and retail price, namely, that the relationship between amount bid and retail price was significantly stronger in the scarcity mindset. Compared with abundance, in a scarcity mindset, participants made lower bids for food items that were lower in retail price and higher bids for more expensive items. One interpretation of this finding is that in scarcity, participants are more attenuated to actual value of products, that is, the retail price. Retail price was a strong predictor of bidding behavior in the current setting; stronger reliance on this predictor might indicate stronger reliance on internal standards (e.g., "bid what it is worth in the shop"), in line with ref. 17. This finding is especially interesting in light of the low retail prices of the food items offered on sale here. Therefore, future efforts should investigate consumer choice behavior in a scarcity mindset for costlier purchases.

Another important aspect of this study is that it allows investigation of the neural underpinnings of consumer choice in a scarcity mindset. In accordance with our hypothesis, mindset effects were present in the OFC during product valuation and in left dlPFC, during product bidding. More specifically, the OFC showed enhanced neural activity when evaluating the consumer products in a scarcity mindset compared with in an abundance mindset. In contrast, the left dlPFC showed reduced neural responsivity when participants made their bids for products in scarcity compared with abundance. Additionally, we found task-related activations independent of the mindsets, indicating participants were actively engaged in the task. Right dlPFC, dACC, and left anterior insula were more active in relation to higher bids, consistent with previous studies demonstrating an association between right dlPFC activation and higher auction bids (24, 32). When participants received positive compared with negative feedback, that is, when they "outbid" the computer, areas related to reward processing such as the NAcc and vmPFC exhibited greater activity (for reviews see refs. 33 and 34).

The effect of scarcity on OFC activity is notable in light of ample research demonstrating contextual effects on valuation and choice (35). For example, past research has shown that the OFC responsivity to food diminishes when participants are satiated (36, 37) and also that subjective pleasantness affects OFC activity, as demonstrated by giving participants information about the price of products (38). The current results further emphasize contextual influences on OFC activity (28), demonstrated here by heightened activity of the OFC in the scarcity versus abundance mindset. During the scarcity mindset, there was significantly reduced activity in the left dlPFC and posterior parietal cortex (PPC) when participants made their bids, again in accordance with our hypothesis that scarcity influences the neural regions associated with goal-directed attentional allocation. The dlPFC and PPC are part of the frontoparietal network, associated with working memory (39), task switching (40), and fluid reasoning and attention (41). Therefore, we report evidence here that a mindset invoked by scarcity can impact activation in brain areas associated with attention in goal-directed decision making.

Interestingly, experiencing scarcity after an episode of abundance strongly decreased dlPFC activation, compared with when participants experienced the scarcity mindset first. When participants experienced scarcity first and then switched to abundance, dlPFC activity did not significantly differ. This suggests that the effects of scarcity may be somewhat dependent on the baseline state to which the current, scarce state is compared. Hence, the effects of scarcity appear here most prominently when they can be compared directly to previously experienced states of abundance. Of course, the transition from scarcity to abundance might have been especially salient in the current task paradigm and is likely to be less dramatic and more gradual in real life. Therefore, the distinction between the two mindsets here could have increased the use of comparative processes and might be less relevant outside of this experimental setting. On the other hand, previous work has shown similar comparative effects in interpersonal decision making. Across many behavioral economic paradigms, people are shown to be sensitive to social comparisons, evaluating themselves by making upward comparisons, that is, comparing yourself to one better off than you (42, 43). This suggests that the feeling of scarcity, may be affected by both individually experienced fluctuations in scarcity levels as well as comparison with others who have more resources.

It is possible that the scarcity manipulation employed here may have induced negative affect or stress in participants, and indeed we believe that the scarcity mindset is a complex amalgam of many affective states, likely including the aforementioned two. However, one advantage of our cognitive neuroscience approach is that we observe here a neural "readout" of the experience of scarcity in our participants, and crucially, that this pattern of brain activation is dissociable from those that have been previously shown to be associated with manipulations such as stress and negative affect. Notably, when comparing the scarcity and abundance mindsets here, we find increased OFC activation under conditions of scarcity, whereas the literature has previously demonstrated less sensitivity to rewards under acute stress (44). For example, several well-regarded studies have shown that reward-related activity is blunted during stress, finding reduced sensitivity to reward in the OFC and striatum (45–47). Those findings are in contrast to the increase in OFC responsivity in the anticipation phase and increase in vmPFC reactivity (although marginally significant) in the feedback phase of the consumer decision in scarcity that we observed. This suggests that scarcity and stress do not have the same effect on neural processes that underlie valuation. Future research could usefully invest in disentangling the commonalities and differences between a scarcity mindset and other sources of stress and negative affect.

Independent of mindset, we found that higher bids were related to increased activity in the right dlPFC and dACC, consistent with previous studies showing an association between right dlPFC activation and higher auction bids (24, 32). This activity was not significantly moderated by the mindset manipulation, in line with the small behavioral effect of mindset on willingness to pay. We suggest that participants might have had a behavioral strategy performing the bidding task. This idea can be supported by visual inspection of the trial-by-trial data per individual (*SI Appendix*, Fig. S2), with the data indicating that some participants have a strong preference for ranges of the bidding scale (e.g., not higher than €1.50), or certain amounts of the scale (e.g., €0). Given the familiarity of these everyday supermarket goods to participants, it seems plausible that participants' bidding behavior might well have been more impacted by product characteristics such as retail price rather than second-order attributes such as their hedonic or utilitarian nature, which could explain the lack of behavioral effects when examining these two product categories. Clearer distinctions between these categories could be usefully examined in future studies, for example using products that are more readily identified as either hedonic (e.g., perfume) or utilitarian (e.g., toilet brush). Future studies exploring food choices could ensure that participants withhold food intake for 3–4 h before the experiment, which would likely increase salience of the food products. However, given that hunger is shown to also affect consumer choice for nonfood objects (11), in the current study we chose to avoid possible interaction effects between our scarcity manipulation and scarcity of food.

In summary, this study demonstrated that neural processes underlying consumer decisions are affected by a scarcity mindset. These findings support the notion that the feeling of scarcity can directly impact goal-directed value-based decision processes. Moreover, transitions from abundance to scarcity may be especially salient for these goal-oriented processes, by leading the decision maker to a comparison of a previously positive state of the world (abundance) to the current inferior one (scarcity). Understanding how the different computations that underlie value-based decision making are affected by scarcity can contribute greatly to our understanding of the important real-life consequences of scarcity on (mal)adaptive decision making.

Methods

Participants. Forty-seven participants (27 females) took part in this experiment (mean age 23.5) and provided written informed consent. This study was approved by the local medical ethics committee (Commissie Mensgebonden Onderzoek regio Arnhem-Nijmegen 2014/288 "Imaging Human Cognition"). Participants received a fee of €27 for completing the task, plus payout of one randomly selected bidding task trial (product + bid excess) as well as a bonus for completion of each of the two stage games (2x€4). Exclusion criteria are discussed in *SI Appendix*.

Procedure. Upon arrival in the laboratory, participants received instructions for the stage games task and the bidding task. Participants were instructed that the stage games consisted of three perceptual tasks, and that the stage games would occasionally be interrupted to play the bidding task, at unpredictable moments. In the bidding task, participants placed bids on 144 different supermarket food items. We used a BDM auction mechanism to determine whether the product is selected for pay out or not (16). Fig. 2 outlines the time structure of the bidding task. For full details of the bidding task see *SI Appendix, Experimental Procedures*. After the practice trials, participants were tested on their knowledge of the BDM auction mechanism and their understanding that the current amount of tokens in the stage games was not connected to the amount they could spend in the bidding task. After completing the scanning session, participants rated how they felt during the task as a function of the amount of tokens they initially received.

One to two weeks after the fMRI session, participants returned to the laboratory and provided subjective ratings for each product and received their selected product. The delay was intended to minimize the influence of the decisions during the fMRI session on these subjective ratings. Participants rated how they found the products hedonic and utilitarian, how much they liked the product, how often they bought the product, and how much they were willing to pay for the product (for details see *SI Appendix*). Retail prices were never revealed to participants. All tasks were presented with Psychophysics Toolbox version 3 under Matlab 2014a (Mathworks).

Behavioral Analyses. We investigated whether participants reported different feelings (of confidence, stress, motivation, and excitement) dependent on the mindset they were in. We performed a MANOVA analysis with self-rated levels of confidence, stress, motivation, and excitement as dependent variables, with the independent variable of mindset (scarcity/abundance). Results were obtained using the MANOVA, summary, and summary.aov functions from the base package in RStudio (48).

To investigate participants' consumer decisions in the bidding task, we created models using linear mixed models with the mixed functions from lme4 (49) and lmerTest (50) in RStudio (48). Models were fitted using restricted maximum likelihood and Satterthwaite approximation for degrees of freedom to obtain P values for all models.

To understand the bidding behavior of participants, we examined how the individual preferences for each product affected bids. Our first model included centered individual ratings per participant per product on a scale of hedonic, utilitarian, liking, frequency of buying, and centered retail price per product. To account for the nested nature of the data, we added random intercepts and slopes for the main effects of hedonic, utilitarian, liking, frequency of buying ratings, and centered retail price per participant and we added a random intercept per product.

Next, we tested a model in which we investigated the effect of a scarcity mindset (scarcity/abundance) and product type (hedonic/utilitarian) and order of the mindsets (SA/AS) on bidding behavior of the participants. In this model, we included mindset and product type, order of the mindsets, and their interactions to predict participants' bids. To account for the nested structure of the data, we included random slopes and intercepts per mindset (scarcity/abundance), product type (hedonic/utilitarian), and their interaction per participant. As a dependent variable, we used participants' bids on every trial.

To examine our main question of whether bidding behavior is more in line with subjective preferences in the scarcity manipulation, we tested if individual willingness to pay for the products 1–2 wk after the scanning session affected bids in the scarcity and abundance mindset differently. We chose this measure as we thought it would most closely reflect a baseline preference for the products irrespective of the mindsets. We created a model to investigate bidding behavior as a function of mindset (scarcity/abundance), order of the mindsets (SA/AS), and centered individual ratings of willingness to pay. This model also included regressors for the interaction between mindset and willingness to pay. Per participant, we added random intercepts and slopes for all repeated measure variables and their interactions.

We examined two exploratory models investigating how bidding in the scarcity and abundance mindsets could be differentially impacted by the actual retail prices of the products. The first model included bid amount as the dependent variable and mindset (scarcity/abundance), retail price (in euros), and mindset order as independent variables. To account for the nested structure of the data, random intercepts and slopes were added for mindset, retail price, and their interaction per participant. In a second model, we controlled for individual differences for the products, by additionally including covariates collected in the behavioral followup several weeks after the scanning session, namely, participants' ratings of hedonic, utilitarian, liking, and frequency of buying.

fMRI Acquisition and Preprocessing. Functional imaging was conducted with a 3T Siemens Magnetom Skyra MRI scanner. First, high-resolution T1-weighted structural images (MPRAGE, 192 slices, TR 2300 ms, TE 3.03 ms, voxel size $1 \times 1 \times 1$ mm) were acquired. This was followed by collection of functional images using a multi echo T2*-weighted sequence. Thirty-five functional images per volume were collected in an ascending, interleaved manner, with a flip angle 90, TR 2250 ms, TE 9.4 ms, 8.9 ms, 8.4 ms, and 7.9 ms, field of view 224 mm, voxel size $3 \times 3 \times 3$ mm, and 0.5 mm slice gap. Participants were lightly restrained by placing a tape over their forehead and cushioning. The task consisted of two runs of ∼35 min each, the first 30 volumes were discarded for each run. Images were processed and analyzed with SPM 12 (The Wellcome Trust Center for Neuroimaging, London, UK, https://www.fil.ion.ucl.ac.uk/spm/). First, the four TE readouts were combined and realigned using the multiecho sequence via standard procedures (51). Functional images were slice-time corrected with the middle as reference and realigned to the first volume, and then they were spatially normalized into a standard space (MNI template), resliced to 3-mm isotropic voxels, and smoothed with an 8-mm FWHM Gaussian kernel.

fMRI Analyses. The general linear model for the bidding task included eight regressors per run, time locked to each of the three different decision-making phases: two regressors per run for the evaluation phase, one for hedonic, and one for utilitarian products. Two regressors per run for the bidding phase one for hedonic and one for utilitarian products. We added bid amount as a parametric modulator for these two regressors to investigate neural response to bid as function of the different product types. The feedback phase of the decision was represented by four regressors per run, to distinguish between the positive and negative feedback, and to distinguish between hedonic and utilitarian products. We also added six motion regressors (three translation and three rotation parameters) per run, resulting in a total of 32 regressors.

Next, contrast images comparing run one and run two were created for each subject on the first level and entered into a second level, random-effects analysis. Here, we grouped participants together according to the between subjects counterbalancing of order (scarcity first vs. abundance first). This allowed us to model the fMRI signal according to the counterbalanced order of the conditions. The following contrasts as well as their inverse comparisons were defined: (*i*) valuation phase, scarcity > abundance; (*ii*) bidding phase, scarcity > abundance with bid as parametric modulator; and (*iii*) feedback phase, outbid the computer yes > no.

To investigate whether the effects of mindset were modulated by order (scarcity first or abundance first) and product type (hedonic versus utilitarian), beta weights were extracted for the functional clusters in each phase. The beta weights were then submitted to repeated measure ANOVAs with mindset (scarcity/abundance) and product type (hedonic/utilitarian) as within subject's factors and order (SA/AS) as between subject's factor. To investigate neural differences in the feedback phase of the decision, the within subject's variable feedback (positive versus negative) was also included in the model.

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