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The competitive interaction between food cravings and unhealthy snacking: an application of the predator-prey model in psychology

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Abstract
The predator-prey model is widely used in various disciplines but not yet in psychology, where the competitive interactions featured in this model are actually not uncommon in behavioral data. This study attempts to introduce this model into psychology, using the relationship between food cravings and unhealthy snacking as an example. Self-efficacy, a determinant of health behavior, was used as a moderator of this relationship. Sixty female undergraduates completed a self-efficacy scale and a seven-day ecological momentary assessment in which they reported craving intensity and snack consumption five times per day. The results showed that food cravings stimulated subsequent snacking behaviors, and the lower the self-efficacy, the more likely people were to be driven by cravings. The act of snacking, in turn, eliminated the subsequent food craving, as if the act of snacking "preyed" on the food craving. The predator-prey model reflects a simultaneous facilitation-inhibition-bidirectional relationship or negative feedback mechanism, which should have broader applications in behavioral science.

Keywords Food cravings · Unhealthy snacking · Predator-prey model · Competitive interaction · Dynamic bidirectional relationship · Ecological momentary assessment

Introduction

The prevalence of overweight and obesity has long been a global public health concern. More than 1.9 billion adults aged 18 years and older were overweight, representing 39% of the world's adult population, over 650 millions of whom were obese (World Health Organization, 2021). Unhealthy snacking is often considered a contributor to extra energy intake and weight gain (Bes-Rastrollo et al., 2010; de Graaf, 2006). The ubiquity of energy-dense foods in daily life, especially tasty but unhealthy snacks, induces cravings for them. Do food cravings lead to actual snacking behavior, and does snacking eliminate or further stimulate cravings? We sought to examine the dynamic relationship between food cravings and unhealthy snacking to help understand the mechanisms underlying unhealthy snacking behaviors and inform obesity interventions.

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Food Cravings and unhealthy snacking

Food craving is an intense desire to consume a certain food or food type (Weingarten & Elston, 1990; Rodríguez-Martín & Meule, 2015) noted that it is a multidimensional and complex experience that includes cognitive (e.g., thoughts about food), affective (e.g., changes in moods), behavioral (e.g., seeking food), and physiological (e.g., salivation) aspects. The mechanisms of food cravings have been explored in previous studies; however, no general consensus has been reached. For example, theories from a physiological perspective suggest that people may crave food because of a lack of food or a lack of adequate nutrition and energy (Wardle, 1987). As another example, learning theories emphasize that individuals' food cravings may be a conditioned response to food-related cues in the environment (Rozin et al., 1991).

A large body of research has explored the relationship between food cravings and unhealthy snacking behaviors. Some laboratory studies found that the intensity of desire for energy-dense snacks positively predicted snack intake (Haynes et al., 2016; Martin et al., 2008; Sinha et al., 2019), while others found that food cravings only predicted the

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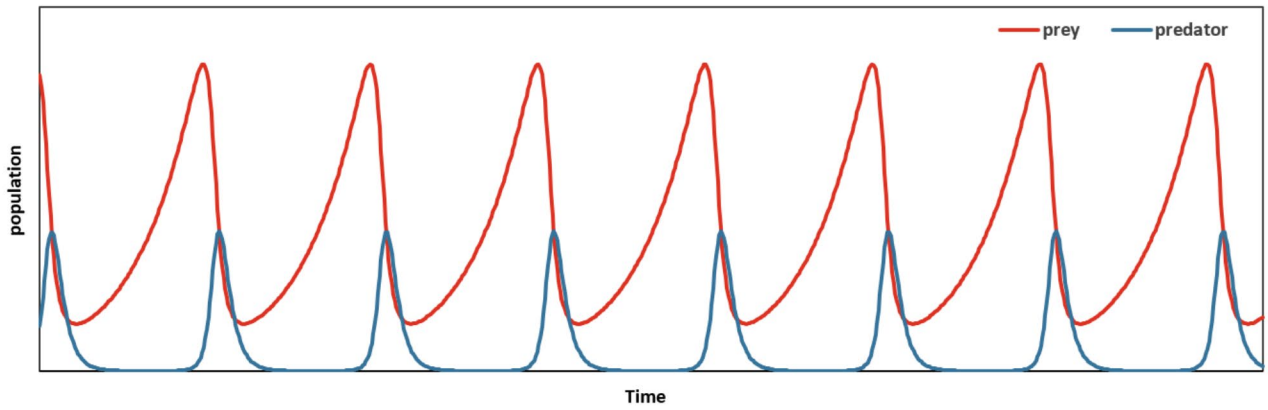

Fig. 1 Illustration of the interaction between predator and prey populations

intake of highly palatable foods but not the intake of bland foods (Massicotte et al., 2019). However, some researchers noted that laboratory studies had limited ecological validity and ignored temporal dynamics (Richard et al., 2017; Zorjan & Schienle, 2022). To better capture dynamic fluctuations in everyday life, some researchers have used ecological momentary assessment (EMA) and found that individuals' craving intensity positively predicts their unhealthy snack consumption (Grenard et al., 2013; Richard et al., 2017, 2019; Zorjan & Schienle, 2022).

EMA studies confirmed the predictive effect of food cravings on unhealthy snacking behavior; however, few of them have paid attention to the influence of unhealthy snack consumption on subsequent food cravings. A laboratory study revealed that even a small portion of snacks would reduce people's cravings for foods, not only immediately after consumption but also after 15 min (Van Kleef et al., 2013). However, contrary evidence also exists, such as studies suggesting that feeling full does not necessarily curb hunger but may instead trigger food cravings (Schepers & Bouton, 2017). Therefore, whether people's desire to eat diminishes or becomes more intense after snacking is still unclear, and how unhealthy snacking affects food cravings in daily life remains to be studied.

Additionally, the dynamic feedback mechanism underlying the bidirectional relationship between food cravings and unhealthy snacking remains unexplained. If food cravings promote unhealthy snacking, which consequently inhibits cravings, then these two consecutive effects in opposite directions would compete with each other, creating a negative feedback equilibrium mechanism. This type of mechanism has not been extensively studied in psychology; we usually deal with positive feedback, such as positive attitudes stimulating corresponding behaviors, which in turn further reinforce positive attitudes. In the case of negative feedback, we do not yet have a well-established model to study it; thus, perhaps we can borrow from ecology the predator-prey model, which describes a similar negative feedback mechanism.

Predator-prey model

The predator-prey model, also known as the Lotka-Volterra model, was independently developed by Lotka (1920) and Volterra (1926). It is a differential equation model that originally explains the dynamic system of two biological species, with one (predator) feeding on the other (prey), formulated as Eq. 1,

$$\begin{cases} dx/dt = ax - bxy \\ dy/dt = -cy + dxy \end{cases} \quad \text{(Eq. 1)}$$

where x and y are the populations of prey and predator, respectively, and dx/dt and dy/dt are their growth rates. The parameters a, b, c and d are all positive numbers. Parameter a is the natural reproduction rate of species x (prey) when there is no species y (predator), while parameter c is the natural death rate of species y in the absence of species x. Parameter b is the decreasing rate of prey population due to predation by predators, and parameter d is the increasing rate of predator population due to nourishment of prey. Parameters b and d reflect the impacts of their competitive interaction on their populations.

Figure 1 illustrates the dynamics of predator and prey populations that follow Eq. 1. As the number of prey increases, the number of predators will begin to increase. After the prey population peaks and begins to decline, the number of predators will grow to a maximum. Notably, there appears to be a "delay" between the increase in the predator population and the increase in the prey population,

with the peak of the predator population always occurring after the peak of the prey population.

By reinterpreting variables and parameters, the predator-prey model has been applied to a variety of fields, such as epidemiology (Fenton & Perkins, 2010), economics (Crookes & Blignaut, 2016), policing (Kim & Kim, 1997) and criminality (Abbas et al., 2017; Tripathi et al., 2021). In this study, we assumed that individuals' food cravings are the "prey" and that their unhealthy snacking behaviors are the "predators". Then, parameter *a* represents the rate of increase in food cravings when no snacks are consumed, while parameter *c* represents the rate of decrease in unhealthy snacking behaviors in the absence of food cravings. Parameter *b* reflects how snack consumption reduces, or in other words, satisfies people's cravings for food, while parameter *d* reflects how people's food cravings increase, or in other words, trigger their snacking behaviors. Therefore, the predator-prey model can help us quantify and test the hypothesized temporal dynamics of food cravings and unhealthy snacking as well as their competitive interaction.

In addition, the value of parameters in the predator-prey model may vary from person to person. We can also examine individual differences in the relationship between food cravings and unhealthy snacking. Self-efficacy, defined as individuals' beliefs in their capacity to perform certain behaviors to obtain desired outcomes (Bandura, 1977), is an effective predictor of dietary behaviors (Cruwys et al., 2020; Dehghan et al., 2021; Fernández et al., 2015). Researchers have found that people with high self-efficacy consume fewer high-calorie snacks (Churchill et al., 2014; Glasofer et al., 2013; Pearson et al., 2011), indicating a higher ability to resist the temptation to consume unhealthy snacks. Thus, despite craving unhealthy snacks, individuals with high self-efficacy are less likely to be driven by their desire for craved snacks. In other words, self-efficacy may moderate the relationship between food cravings and unhealthy snacking.

The Present Study

Reviewing the previous findings on the relationship between food cravings and unhealthy snacking, we found some studies that revealed that individuals' food cravings motivated their subsequent snacking behaviors (Richard et al., 2019; Zorjan & Schienle, 2022), which meant food cravings had a facilitative effect on subsequent unhealthy snacking. In contrast, there were also studies showing that individuals' unhealthy snack consumption inhibited their cravings for unhealthy snacks (Van Kleef et al., 2013), which meant unhealthy snacking had an inhibitory effect on subsequent food cravings. In this way, food cravings and unhealthy snacking interact in opposite directions: as one side becomes stronger, the other becomes weaker. Such a competitive relationship reminds us of a common example in ecology: the competitive relationship between predators and prey. Predators increase as the number of prey increases, and then the prey decrease as the number of predators increases, eventually reaching a dynamic equilibrium. Such a dynamic equilibrium may also be assumed in human behavior. For example, we do not crave food endlessly, nor can we eat unhealthy snacks endlessly. Individuals' desires for food and snacking behaviors are likely to form a dynamic equilibrium as well. Since the relationship between predator and prey is very similar to the relationship between unhealthy snacking and food cravings, it is worthwhile to apply the predator-prey model to study the relationship between food cravings and unhealthy snacking.

The main purpose of this study is to investigate the competitive interaction between food cravings and unhealthy snacking based on the predator-prey model. First, we introduced the predator-prey model into the field of health behavior by reinterpreting the meaning of parameters in the model. Then, we collected intensive longitudinal data on food cravings and unhealthy snacking through EMA and used multilevel regression models to estimate parameters. Moreover, we took self-efficacy as an example to explore possible individual differences in their bidirectional relationship. In addition, since a large number of studies found that individuals' BMI was significantly associated with their food cravings and unhealthy snacking behaviors (Abdella et al., 2019; Chao et al., 2014; Sinha et al., 2019), the effect of individuals' BMI was controlled for in our model. Two hypotheses were proposed:

H1: The relationship between food cravings and unhealthy snacking fits the predator-prey model. We expected that food cravings drive future unhealthy snacking, i.e., the interaction between food cravings and unhealthy snacking positively predicts the rate of change of unhealthy snacking ($+d$ in Eq. 1). We also expected that unhealthy snacking reduces future food cravings, i.e., their interaction negatively predicts the change rate of food cravings ($-b$ in Eq. 1).

H2: Self-efficacy moderates the relationship between food cravings and unhealthy snacking. We expected that people with higher self-efficacy have a smaller *d* parameter, i.e., their food cravings are less likely to trigger actual snacking behavior. However, with no clue from previous research, we did not predict the impact of self-efficacy on parameter *b*.

Method

Participants

A total of ninety female college students completed an eligibility test to check whether they met the following requirements: (a) people who claimed they usually intended to avoid unhealthy snacks but also admitted to occasionally unhealthy snacking (Inauen et al., 2016); (b) two to three regular meals per day; (c) daily access to a cell phone; and (d) getting up before 11 a.m. and going to bed after 11 p.m. every day (as participants were asked to complete a short questionnaire at 11 a.m. and 11 p.m. over seven days). This study focused on the female college student population for the following reasons: gender may be an influential factor in the relationship between food cravings and unhealthy snacking; females are relatively more likely to suffer from weight, body image, and other related problems; and based on our previous subject recruitment experience, more female subjects tend to participate in diet studies. Finally, sixty female undergraduates were eligible to participate in this study, doubling the minimum sample size required for multilevel analyses (30 participants; Hox & McNeish, 2020).

All participants were females and of Chinese Han ethnicity. They were aged 18 to 26 years (M = 20.67, SD = 1.90) and had a body mass index (BMI) between 14.88 and 25.44 (M = 20.00, SD = 2.20). A total of 53.4% of the participants spent between ¥1,000 ($ 148.09) and ¥2,000 ($ 296.16) per month, 37.9% spent between ¥2,000 and ¥3,000 ($ 444.28) per month, only 3.4% spent less than ¥1,000 per month, and 5.1% spent more than ¥3,000 per month.

Measures

Food Cravings

Based on previous studies (Nijs et al., 2007; Richard et al., 2017), three items were developed to measure individuals' cravings for foods. Specifically, participants were asked to report the extent to which they desired to eat something, desired to eat something high in calories, salts or saturated fats, and felt hungry at the moment. They responded on a scale from 1 ("at this moment, don't desire/not hungry at all") to 9 ("at this moment, extremely desire/hungry"). Individuals' food craving was measured by the average score of these items. To test the appropriateness of calculating the mean score of these items, within-person correlations between the three items were computed, which revealed strong associations between them (all $rs > 0.837$).

Unhealthy snacking

Unhealthy snacking may frequently occur at different times of the day. To capture the temporal fluctuation of an individual's snacking behavior in everyday life and to reduce the impact of retrospective bias, unhealthy snacking was measured frequently at 3-hour intervals during the day and at 12-hour intervals during the night. In line with previous studies on unhealthy snack consumption, a snack was conceptualized as "any food and sweetened beverages consumed between main meals" (Inauen et al., 2016). Based on the coding of the food products adapted to the Asia-Pacific food supply (Kelly et al., 2016), we summarized six categories of unhealthy snacks, such as sugar-sweetened drinks and dried fruit, with detailed information and examples. At the very beginning of every questionnaire, descriptions of all categories of unhealthy snacks were presented. Participants were first asked to report whether they had eaten any snacks since they completed the last questionnaire. If they had snacked at least one time, they would be asked to recall the times (from one time to nine times) of each category of unhealthy snack they had eaten since they completed the last questionnaire. In addition, for snacks for which participants were unsure of the category, they were asked to report the exact names of the snacks, which would later be classified into the most appropriate category based on discussion among the authors. Finally, unhealthy snacking was measured by the total snack consumption in the six food categories.

Self-efficacy

Self-efficacy was measured by the 10-item general self-efficacy scale (Schwarzer & Jerusalem, 1995). Participants were asked to rate the extent to which the description in each item accorded with their actual situation, from 1 ("not true at all") to 5 ("exactly true"). The internal consistency of this scale was 0.885 in this study.

Procedure

Participants were recruited from social networks. They first completed an online eligibility questionnaire, and eligible female undergraduates were invited to participate in the study. They completed a one-time long questionnaire and 35 short questionnaires five times a day for the next seven days. A reminder text message with a link to the short questionnaire was sent to them at 11 a.m., 2 p.m., 5 p.m., 8 p.m. and 11 p.m. each day. Finally, participants were rewarded based on their completion rate of the 35 short questionnaires. One participant was excluded from the data analysis because she

Table 1 *Descriptive Statistics and Correlations*

	M	*SD*	ICC	1	2	3
1 Craving	1.968	0.583	0.12	–	0.346***	–
2 Snacking	0.259	0.191	0.16	0.048	–	–
3 Self-efficacy	3.248	0.609	–	0.067	– 0.155	–
4 BMI	19.996	2.201	–	– 0.062	– 0.049	– 0.034

Notes: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$. Craving denotes food cravings; Snacking denotes unhealthy snacking; ICC denotes intraclass correlation. Between-person correlations are represented below the diagonal, and within-person correlations are presented above the diagonal.

completed the short questionnaires for only one day. The other participants completed 94.14% (ranging from 74.29 to 100%, *SD* = 6.48%) of the short questionnaires, reflecting relatively good compliance. Informed consent was obtained from each participant. This study was approved by the university's IRB board.

Analysis

We took two steps to prepare our raw data for further analysis. In the first step, we transferred our data to an equidistance time scale. In our questionnaire, food cravings measured participants' desire for food at that moment (e.g., 11 a.m.), whereas unhealthy snacking measured the total amount of unhealthy snacks participants consumed since the last questionnaire (e.g., 8 ~ 11 a.m.). Considering the differences in the time reference of food cravings ("at this moment") and unhealthy snacking ("since the last questionnaire"), we computed the average amount of unhealthy snacks that a participant consumed during the last period of time (e.g., 8 ~ 11 a.m.) and assumed it happened in the middle of this time period (e.g., 9:30 a.m.). In the second step, based on the established equidistance time scale, we filled in unavailable data in the following ways. First, since individuals were very unlikely to crave food and eat snacks when they were sleeping (i.e., 0 ~ 8 a.m.), the values of food cravings and unhealthy snacking within this time period were set to 0. Additionally, with the assumption that individuals' food craving tendencies and unhealthy snacking behavior were changing continuously, any systematic missing values during the day were estimated by averaging their previous and subsequent measurements.

After data preparation, descriptive statistics and Pearson correlation analysis among key variables were conducted. Intraclass correlations (ICCs) for food craving and unhealthy snacking were also computed. Then, based on the predator-prey model, two multilevel models were established to explore the competitive interaction between food craving and unhealthy snacking, with repeated observations (Level 1) nested within individuals (Level 2). Equation 2 shows the Level 1 model of food cravings, and Eq. 3 shows the Level 1 model of unhealthy snacking. The variables $d(Craving_{it})/dt$ and $d(Snacking_{it})/dt$ are the first derivatives of food cravings and unhealthy snacking. They were estimated using general local linear approximation (GLLA; Boker et al., 2010), where the rate of change at each time point was estimated based on adjacent time points. If the proposed relationship fits the prey-predator model, then in Eq. 2, β_{1i} should be positive and β_{2i} should be negative, and in Eq. 3, β_{1i} should be negative and β_{2i} should be positive. Finally, to investigate the individual differences in the relationship between food cravings and unhealthy snacking, the moderating effect of self-efficacy was tested by adding self-efficacy as a predictor to β_{0i}, β_{1i} and β_{2i} in Level 2 (Eq. 4).

Level 1:

$$d(Craving_{it})/dt = \beta_{0i} + \beta_{1i}(Craving_{it}) + \beta_{2i}(Craving_{it} * Snacking_{it}) + e_{it} \quad \text{(Eq. 2)}$$

$$d(Snacking_{it})/dt = \beta_{0i} + \beta_{1i}(Snacking_{it}) + \beta_{2i}(Craving_{it} * Snacking_{it}) + e_{it} \quad \text{(Eq. 3)}$$

Level 2:

$$\begin{aligned} \beta_{0i} &= \gamma_{00} + \gamma_{01}(Self-efficacy_i) + \gamma_{02}(BMI_i) + u_{0i} \\ \beta_{1i} &= \gamma_{10} + \gamma_{11}(Self-efficacy_i) + u_{1i} \\ \beta_{2i} &= \gamma_{20} + \gamma_{21}(Self-efficacy_i) + u_{2i} \end{aligned} \quad \text{(Eq. 4)}$$

Results

Descriptive statistics and correlations

The descriptive statistics and Pearson correlations among food cravings, unhealthy snacking, self-efficacy and BMI are presented in Table 1. The intraclass correlations (ICCs) for food cravings and unhealthy snacking were 0.12 and 0.16, respectively, indicating that most of their variances were within-person. At the between-person level, an

Table 2 *Parameter Estimation for the Models of Food Cravings and Unhealthy Snacking*

DV	IV	*B*	*SE*	*t*	*95%CI*
d(Craving)/dt	BMI	-0.002	0.005	-0.335	[-0.011, 0.008]
	Craving	0.026	0.007	3.794***	[0.013, 0.040]
	Craving×Snacking	-0.056	0.007	-7.843***	[-0.070, -0.042]
d(Snacking)/dt	BMI	-0.001	0.002	-0.481	[-0.004, 0.002]
	Snacking	-0.233	0.014	-16.465***	[-0.260, -0.205]
	Craving×Snacking	0.076	0.004	18.040***	[0.068, 0.085]

Notes: $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$.

Table 3 *The Moderating Effect of Self-efficacy on the Relationship Between Food Craving and Unhealthy Snacking*

DV	IV	*B*	*SE*	*t*	*95%CI*
d(Craving)/dt	BMI	-0.002	0.005	-0.486	[-0.011, 0.007]
	Craving	0.019	0.039	0.495	[-0.057, 0.096]
	Craving×Snacking	-0.014	0.027	-0.496	[-0.067, 0.040]
	Self-efficacy	0.003	0.025	0.136	[-0.046, 0.052]
	Craving×S-E	0.002	0.012	0.213	[-0.020, 0.025]
	Craving×Snack×S-E	-0.014	0.009	-1.647	[-0.032, 0.003]
d(Snacking)/dt	BMI	-0.001	0.002	-0.815	[-0.004, 0.002]
	Snacking	-0.309	0.044	-6.978***	[-0.396, -0.222]
	Craving×Snacking	0.133	0.016	8.303***	[0.102, 0.165]
	Self-efficacy	0.005	0.006	0.745	[-0.007, 0.016]
	Snacking×S-E	0.025	0.015	1.683	[-0.004, 0.054]
	Craving×Snack×S-E	-0.019	0.005	-3.567***	[-0.029, -0.008]

Notes: S–E = self-efficacy. $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$.

individual's BMI, self-efficacy, average food cravings and average unhealthy snacking were not significantly associated, whereas at the within-person level, an individual's fluctuation of food cravings was positively associated with their unhealthy snacking behaviors ($r = .346$, $p < .001$).

The dynamic relationship between Food Cravings and unhealthy snacking

Based on the predator-prey model, the competitive interaction between food cravings and unhealthy snacking was examined. Table 2 shows the results of the multilevel models. All four parameters in the model were significant, and their directions were exactly as expected from the predator-prey model, indicating that individuals' food cravings and unhealthy snacking did behave like prey and predators. For the dynamic process of food cravings, people's food cravings increased naturally over time ($B = 0.026$, $p < .001$), and snacking reduced cravings ($B = -0.056$, $p < .001$). The dynamic process of unhealthy snacking would "die out" without the presence of food cravings ($B = -0.233$, $p < .001$), and the desire for food would stimulate snacking behaviors ($B = 0.076$, $p < .001$). In summary, with individuals' cravings for food getting stronger, they would subsequently eat more unhealthy snacks. Once the unhealthy snacks that an individual consumed increased to a certain amount, their desire for food gradually declined.

Moderating effect of self-efficacy

To investigate possible individual differences in the dynamic models of food cravings and unhealthy snacking, we tested the moderating effect of self-efficacy. As shown in Table 3, the interaction between self-efficacy and the coupling term in the dynamic model of unhealthy snacking was significant ($B = -0.019$, $p < .001$), whereas the interactions between self-efficacy and other terms were nonsignificant. This result suggested that self-efficacy weakened the positive coupling between food cravings and unhealthy snacking. Individuals with higher levels of self-efficacy were less likely to consume unhealthy snacks even under the positive influence of the interaction between their cravings for foods and current unhealthy snack consumption.

Discussion

In this study, we introduced a predator-prey model to explain the competitive interaction between food cravings and unhealthy snacking using intensive longitudinal data. In line with previous studies (Richard et al., 2017; Zorjan

& Schienle, 2022), the predictive effect of food cravings on unhealthy snacking behaviors in everyday life was confirmed. Furthermore, we verified the impact of unhealthy snack consumption on food cravings (Van Kleef et al., 2013). Specifically, at the beginning of each day, people's desire for food gradually became stronger, followed by their unhealthy snacking behavior. As their snack intake increased to a certain amount, they would feel satisfied and be less tempted by food. As a result, their cravings for snacks began to diminish, as if their snacking behavior "preyed" on their food desire. These findings contribute to the literature by revealing the dynamic bidirectional relationship between food cravings and unhealthy snacking.

In addition, from a practical perspective, our findings may provide insights into intervention programs for the problems of being overweight and obese. On the one hand, food craving is confirmed to be a facilitative factor of subsequent snacking behavior, which suggests that relevant intervention programs can generate real-time responses when individuals report strong food cravings and guide individuals to take certain precautions, for example, staying away from tempting foods in the environment. On the other hand, individuals' unhealthy snack consumption is found to be an inhibitory factor in their cravings for unhealthy snacks. Just as predators in an ecosystem cannot be exterminated, moderate snack intake may not be entirely negative, and people may find a balance between satisfying cravings and staying healthy. Furthermore, self-efficacy has been found to moderate individual responses to food cravings, suggesting that people with different levels of self-efficacy may not differ in their food cravings but rather in their reactions to the cravings. This may shed light on the content and form of self-efficacy-based intervention programs.

Notably, the bidirectional relationship revealed in this study differs from most bidirectional relationships common in previous studies, where the two effects tend to be in the same direction. For example, Schultchen et al. (2019) found that higher levels of stress reduced people's physical activity, and people with lower levels of physical activity subsequently felt more stressed. In contrast, we found that people's food cravings drove them to snack, and their snacking behavior subsequently reduced their desire for food. This indicated that food cravings and unhealthy snacking mutually influenced one other in opposite directions, suggesting a negative feedback mechanism. In fact, negative feedback mechanisms are prevalent because they contribute to maintaining the dynamic balance of human, society and biological systems. The predator-prey model introduced in this study could be particularly helpful to study negative feedback mechanisms in dynamic systems.

However, the predator-prey model is rarely used in psychology. We only found Strogatz (2018) had used this model to discuss the dynamics of romantic relationships in a short book chapter. This model should have great potential in psychology and other social behavioral sciences. For example, in health psychology, we can test whether the relationship between sleepiness and sleep or the relationship between willingness to exercise and exercise would also fit the predator-prey model. This model may also apply to substance use, as Rogers (2017) noted that the appetites for food and drug have many similarities, with both food and drug cravings reflecting a strong desire to consume a specific food/drug (Weingarten & Elston, 1990). Future research could examine the circumstances under which drug cravings are more likely to stimulate actual drug use and the circumstances under which drug use fails to satisfy drug cravings, which may inform further understanding of drug addiction and corresponding interventions. Furthermore, a meta-analysis indicated that behavioral intention was not always the proximal antecedent of relevant behavior (Rhodes & Dickau, 2012). Some researchers have emphasized the importance of recognizing the waxing and waning of intentions and the possible "delay" between intentions and intended behaviors (Kroese & de Ridder, 2016). Since the predator-prey model allows a "delay" between variables (see Fig. 1), it may be of great value to investigate the intention-behavior gap using this model.

The predator-prey model can be extended in many ways. For example, this study explored the moderating effect of self-efficacy. In a "toxic environment" full of tasty but harmful snacks (Glasofer et al., 2013), people are easily driven by their food cravings to consume these unhealthy snacks, especially those with lower self-efficacy. Previous studies suggested that people low in self-efficacy may have less confidence in performing healthy behaviors and have less self-control over unhealthy snacking (Hankonen et al., 2014). Therefore, it made sense that they would be more susceptible to the toxic environment. In addition, some researchers suggested that food craving and snack consumption may be more tightly coupled in childhood than in adulthood (Silvers et al., 2014). Thus, the role of age and other developmental variables in the predator-prey model could also be examined. Finally, if researchers cannot determine the temporal order of their variables, they can also use this model to examine which variable is the prey (initiation) and which is the predator (following). If the signs of the obtained parameters do not match the predator-prey model, it may indicate other mechanisms, such as positive feedback.

This study has several limitations. First, the EMA was still based on self-reported data, and more objective measures, such as the caloric intake of snacks, should be considered in the future. In addition, the limited sample size of this study and the fact that it consisted mainly of female college

students with low body weight, 3 of whom had a BMI below 17, may have weakened the generalizability of our findings. Therefore, whether our results still hold in a sample with other characteristics (e.g., male participants, adolescent participants, and participants with a larger weight range) needs to be further explored. Moreover, the present study used a general measure of self-efficacy (Schwarzer & Jerusalem, 1995). Considering the principle of compatibility (i.e., associations between variables are stronger if they match in specificity or generality; Beus et al., 2015), a task-specific measure of self-efficacy may be more valid and appropriate and may detect stronger moderating effects in both directions. These possibilities remain to be tested in the future. Furthermore, the predator-prey model applied in this study is relatively simple. In fact, it has many variations according to specific situations and problems. Therefore, future studies interested in applying predator-prey models could consider more sophisticated versions and make them more appropriate for their research questions.

Conclusion

An unhealthy diet can lead to a variety of health issues, but many people cannot resist the desire to eat and engage in unhealthy eating, such as the frequent intake of unhealthy snacks. This study explored the dynamic bidirectional relationship between food cravings and unhealthy snacking and identified a negative feedback mechanism. Food cravings stimulated subsequent snacking behaviors, and the lower the self-efficacy, the more likely people were to be driven by cravings. The act of snacking, in turn, eliminated the subsequent food craving, as if the snacking behavior "preyed" on the food craving. This study is among the first to apply and extend the predator-prey model to behavioral data, and such interactions in opposite directions, with facilitation and inhibition occurring simultaneously, may have broader application in studying everyday behaviors that tend to maintain a state of equilibrium.

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Authors' contribution Hu and Luo conceived the research idea and designed the study. Luo conducted the experiment. Hu provided the key R code and Luo analyzed the data. Luo drafted the manuscript and Hu made critical revision.

Data Availability The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Compliance with ethical standards This study was approved by the Institutional Review Board of Beijing Normal University University (IRB #: 202204120046, masked for peer review). Informed consent was obtained from every participant in this study.

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