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Choice architecture meets motivation science: How stimulus availability interacts with internal factors in shaping the desire for food

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ABSTRACT

Recent research on choice architecture has highlighted the role of external aspects such as stimulus proximity or availability on consumption. How such external factors interact with internal, intraindividual factors, however, is very poorly understood. Here we show how the wanting for palatable food emerges from the interplay of one key external factor, availability, and two key internal factors central to motivation science, need state and learning history. Across three experiments in the food domain, we find converging evidence for a main effect of stimulus availability which is qualified in theoretically predicted ways by a three-way interaction such that food desire peaks when the availability of tempting food stimuli is accompanied by high need states and a positive learning experience. A pooled analysis across the three studies supported this general conclusion. We conclude that nudging effects are strongest when external factors of choice architecture synergize with internal factors in critical ways.

Problematic choice environments have been identified as key drivers of the “obesity epidemic,” particularly in industrialized countries (French, Story, & Jeffery, 2001; Hill & Peters, 1998; Wadden, Brownell, & Foster, 2002). This increasing recognition of the role of physical choice environments in influencing consumption is reflected in a widespread interest in the concepts of “choice architecture” and “nudging” at the intersection of psychology and economics, often referred to as behavioral economics (Thaler & Sunstein, 2008). This body of work has revealed quite a number of different factors in which small-scale physical environments may exert their influence on choices and preferences (Hollands et al., 2013; Münscher, Vetter, & Scheuerle, 2016). For instance, the newly proposed TIPPME framework by Hollands and colleagues (Hollands et al., 2017) distinguishes between placement (i.e., availability, position) and property (i.e., functionality, presentation, size, information) classes of interventions in proximal physical microenvironments (for a related taxonomy, see Stroebe, 2008). Such typologies are highly useful in structuring this growing area of research. Taxonomies such as TIPPME, however, do not delineate the mechanisms of action that underlie each intervention type but rather set the stage for “primary and secondary research directed towards furthering understanding of such mechanisms.” (Hollands et al., 2017, p. 5).

Whereas a recent review suggests that measures that change the availability or proximity of products appear a highly promising behavioral intervention in practice (Hollands et al., 2019), not every choice architecture intervention is generally effective. A recent meta-analysis by Hummel and Maedche (2019) of more than 100 primary publications revealed that only 62% of nudging effects were statistically significant. We thus believe it is time to not only ask the general question, of *whether* a given intervention is effective or not (across the sample under study); rather, we also need to ask *when* a given intervention may be effective or not, and *why* that is.

The present work seeks to make such a contribution by examining the basic processes through which one important aspect of placement, the availability of tempting food stimuli, triggers the emergence of food desire as a key driver of consumption. In line with our theoretical focus on the interplay of external and internal factors in shaping desire, we therefore focused on desire (a.k.a. wanting or approach motivation) as the dependent outcome of interest. Ample research, however, attests that desire is a proximal and key predictor of actual consumption behavior (for an overview, see Hofmann & Nordgren, 2015). Specifically, we investigate how availability, an external factor related to the proximal physical choice environment, interacts with internal parameters of the individual entering such an environment. Drawing on past

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work from motivation science, we propose two internal key factors: need state and learning history. We aim to show that the effects of stimulus availability on desire can only be optimally predicted if these two internal parameters are considered, such that desire emerges most readily when an available stimulus matches a background of both (a) a high internal need state (i.e., hunger) and (b) a positive learning history.

Multiple frameworks in motivation science, including drive theory by Hull (1943), could serve as a theoretical background for advancing this integration of choice architecture and motivation science. For the present work, we focused on the more recently proposed and neuro-scientifically informed dynamical model of desire (Hofmann & van Dillen, 2012) which applies to appetitive desires across domains including primary desires such as for food and sex, or acquired desires such as for alcohol, synthetic drugs, or one's smartphone featuring social media rewards. In a nutshell, the model postulates desire for a particular stimulus to emerge from a dynamic interplay of external factors (such as stimulus availability), and relevant internal factors such as an individual's current or chronic need state (e.g. hunger, caloric restriction, withdrawal/abstinence, homeostatic deprivation) as well as an individual's learning history (positive and negative experiences with the stimulus of interest). The latter internal factor encapsulates the appetitive learning experiences an individual has gained due to repeated interaction with the stimuli in the environment.

The dynamical model of desire proposes that both of these internal predispositions (need state and learning history) modulate the intrinsic incentive value (Berridge & Robinson, 1998; Robinson & Berridge, 2008) of encountered objects, thus increasing an individual's preparedness to react to such cues (Hofmann & van Dillen, 2012). Attractive objects therefore gain more momentum when they fit an individual's motivations, due to matching with one's (current or chronic) needs (i.e. need states) and matching with one's prior positive appetitive experiences (i.e. learning history). This broad model proposes an interaction among stimulus features, need state, and learning history which forms the basis for our current prediction of a stimulus availability × need state × learning history interaction.

Prior research suggests the importance of each of these factors. First, research on cue reactivity to tempting food or drug cues generally suggests an increase in desire following stimulus exposure (e.g., Carter & Tiffany, 1999; Ferriday & Brunstrom, 2008), in particular of attractive compared to neutral cues (van Dillen & Andrade, 2016). Second, research on need deprivation has shown that need states (i.e. hunger or thirst) can trigger approach and attentional biases towards the desired object (Aarts, Dijksterhuis, & De Vries, 2001; Mogg, Bradley, Hyare, & Lee, 1998; Seibt, Häfner, & Deutsch, 2007; Tapper, Pothos, & Lawrence, 2010), and are generally predictive of food desires (Cepeda-Benito, Fernandez, & Moreno, 2003; Meule, Lutz, Vögele, & Kübler, 2012; Rogers & Hardman, 2015). Third, a variety of scholars postulated an important role of learning history in shaping the effects of availability on desire or proxies of desire (Coelho, Jansen, Roefs, & Nederkoorn, 2009; Ferguson & Shiffman, 2009; Hermans & Van Gucht, 2006; Hofmann & van Dillen, 2012; Jansen, 1998).

Prior research moreover points to the importance of considering these factors not only in isolation, but as dynamically affecting one another: need states such as hunger do not invariably bias all individuals towards food approach (van Dillen & Andrade, 2016), and learning history is often moderated by need states as well as other contextual factors. Even though the basic yet conditional effects of need state and learning history in shaping desire seem relatively well-understood in the field of motivation science, there is a dearth of research infusing work on choice architecture from behavioral economics with a mechanistic level of understanding (i.e., when and why do we see effects of stimulus availability?). In the present work, we therefore build a bridge between the two areas by linking the two internal, motivational factors of need state and learning history with stimulus availability as a key environmental factor of interest in much research on choice architecture.

1. The present research

Building on the dynamical model of desire, we investigated the interplay of the availability of food stimuli in the choice environment with two internal factors (i.e. need states and learning history) on the experienced desire towards food. As food stimuli we chose candy and fast-food, as these have clear intrinsic value due to their high caloric content and can thus be considered potent triggers of desire through availability. We hypothesized that both internal factors together modulate the incentive value of encountered desirable cues by providing a "fertile" internal background for the effects of stimulus availability to unfold. More specifically, we expected highest levels of experienced desire when candy availability is paired with a high current need state (i.e. hunger) and a high positive learning history towards the desirable cues. In other words, stimulus availability should unleash its full motivational potential only under these boundary conditions. We conducted three experiments ($N = 362$) to test this prediction of a stimulus availability × need state × learning history interaction. All materials, data, and code are available at https://osf.io/3kyuw/.

One major hurdle that had to be overcome before our assumptions could be tested, was to develop a valid measure of an individual's past learning experiences (see supplementary materials). To this end, we developed a nine-item self-report measure to assess individuals' learning history towards specific stimuli that consists of two different subscales, namely *valence* and *rewards* (see Supplementary Table 1). Valence sought to assess the positivity of previous experiences an individual has gained in reference towards candies and candy consumption (e.g. "I have mainly gained positive experiences with candies"). Meanwhile, rewards sought to assess an important source of such experiences, namely past rewarding behavior, either self-induced (e.g. "Whenever I perform well, I reward myself with candies") or promoted by parents (e.g. "My parents have often influenced my behavior using candies"). We did not entertain strong a priori predictions regarding the effects of these two subscales. Since the below analyses consistently supported predictions for the valence but not the reward subscale, we present the results separately for the two subscales. We will come back to the difference between the two scales in the discussion section.

2. Experiment 1

Experiment 1 served as a first test of the combined effect of availability (manipulated between participants), need states (measured as continuous variable), and learning history (measured as continuous variable) on the emergence of candy desires as dependent outcome. As outlined in the introductory section, we predicted desire for high-rewarding but high-caloric and unhealthy foods (candy, fast-food) to be strongest in the combination in which participants were exposed to candy cues, reported a high current need state (i.e. hunger) and a positive learning history towards candies.

3. Method

3.1. Participants

102 Participants (82 females, 20 males, $M_{age} = 22.13$ years, $SD_{age} = 5.69$) were recruited on campus at the University of Cologne for a laboratory experiment ostensibly on "object perception and evaluation", lasting approximately 20 min. The mean BMI of the participants was 22.25 ($SD = 5.03$). All participants were able to choose between €4 or course credit as an acknowledgment for participation. All participants gave informed consent at the beginning of the experiment. The means, standard deviations and correlations between core variables are depicted in Table 1.

Table 1
Means, standard deviations and zero-order correlations between core variables for Experiment 1.

Variable	M	SD	Correlations						
			1	2	3	4	5	6	7
1. Condition	—	—	—						
2. Learning history Composite	3.05	1.08	-.03	—					
3. Valence	3.85	1.38	.13	.73***	—				
4. Rewards	2.05	1.67	-.18†	.71***	.03	—			
5. Hunger	1.29	1.05	-.26**	.29**	.14	.27**	—		
6. Positive affect	19.25	3.78	.02	.09	-.07	.20*	.09	—	
7. Negative affect	21.06	4.26	.04	-.03	-.10	.06	.15	.68***	—
8. Desire for Candies	2.02	1.75	.34***	.31**	.29**	.16	.25*	-.02	.00

Note. Higher scores indicated higher learning history, higher valence, higher rewards, higher need state, more positive affect, more negative affect, higher desire for candies. Condition was dummy-coded with 0 = control condition and 1 = candy exposure condition.
†$p < .08$. *$p < .05$. **$p < .01$. ***$p < .001$.

Table 2
Regression results for core variables predicting desire for candies in Experiment 1.

Variable	B	SE B	95% CI	t	p
VALENCE subscale					
Availability	1.07	0.33	[0.41, 1.73]	3.22	.002
Valence	0.14	0.16	[-0.18, 0.45]	0.86	.391
Need State	0.70	0.22	[0.26, 1.14]	3.17	.002
Availability × Valence	0.56	0.25	[0.06, 1.06]	2.24	.028
Availability × Need State	−0.60	0.34	[-1.27, 0.07]	−1.78	.078
Valence × Need State	0.02	0.14	[-0.25, 0.30]	0.17	.865
Availability × Valence × Need State	0.54	0.24	[0.06, 1.01]	2.25	.027
Positive Affect	0.00	0.05	[-0.10, 0.11]	0.09	.931
Negative Affect	−0.02	0.05	[-0.11, 0.08]	−0.33	.746
REWARDS subscale					
Availability	1.55	0.32	[0.91, 2.2]	4.79	<.001
Rewards	0.04	0.13	[-0.23, 0.3]	0.28	.780
Need State	0.73	0.22	[0.29, 1.17]	3.30	.001
Availability × Rewards	0.36	0.20	[-0.04, 0.76]	1.77	.081
Availability × Need State	−0.37	0.33	[-1.03, 0.29]	−1.11	.272
Valence × Need State	−0.11	0.11	[-0.33, 0.11]	−0.99	.323
Availability × Rewards × Need State	0.18	0.17	[-0.17, 0.52]	1.02	.311
Positive Affect	−0.01	0.06	[-0.13, 0.1]	−0.23	.816
Negative Affect	−0.03	0.05	[-0.13, 0.08]	−0.51	.610

Note. $N = 102$. Condition was dummy-coded with 0 = control condition and 1 = candy exposure condition. Continuous variables were mean-centered. CI = confidence interval for *B*.

- As can be seen from the upper half of Table 2, utilizing the valence subscale of learning history, there was a main effect of the availability, replicating the simple *t*-test above, as well as need state. Most crucially, there was a significant three-way interaction between availability, need state, and learning history (valance subscale), $B = 0.54$, $p = .027$.

3.2. Procedure

The experiment was always conducted between 11 a.m. and 5 p.m. After providing informed consent, all participants were asked to indicate their current hunger state as a measure of their current need state (e.g. "At the current moment …, I am hungry", 4 items, α = 0.92). Next, all participants indicated their past learning experiences towards candies using the validated learning history measure (valence, α = 0.85; rewards, α = 0.87). In order to reduce awareness between the assessed predictor and criterion variables, participants subsequently worked on a 5-min filler task. We asked all participants to color Mandalas that were located on the table in front of each participant. The task was presented as a measure of artistic perception and production.

After the filler task, all participants underwent our experimental manipulation of availability. To this end, we randomly assigned participants to either a control condition (n = 51) or a candy exposure condition (n = 51). A closed box was placed next to the computer monitor of each participant, which either included five different candies (= candy exposure condition; e.g. chocolate bar, gummy bears, M&M's) or five different flowers (= control condition; e.g. tulips) in a numbered order. Participants were asked to take out and rate each object successively on nine (filler) items (= 45 statements overall). In order to increase the ecological validity and efficacy of the availability manipulation (Stritzke, Breiner, Curtin, & Lang, 2004), we asked all participants to perceive and rate these objects on multiple modalities (e.g. tactile feelings, olfactory perceptions). However, tasting any of the presented stimuli was prohibited. Next, the stimuli were removed and participants filled out a mood measure (PANAS) to assess and control for possible mood effects, before they went on indicating their current desires for candies, embedded in twelve filler items (e.g. "How colorful were the objectives").

3.3. Measures

PANAS Questionnaire. We employed the PANAS questionnaire as a common measure of mood (Krohne, Egloff, Kohlmann, & Tausch, 1996), encapsulating two affective states, positive affect (α = 0.60) and negative affect (α = 0.64).

Desires measure. Our dependent variable of desire, was assessed using a self-reported desire measure, consisting of five items we have developed. The items consisted of the following statements: "How much do you feel a desire to eat sweets?", "How much appetite do you have for sweets?", "How much do you feel an urge to eat sweets?", "How badly do you want to eat candy?" and "How much do you feel like snacking candies?". Cronbach's Alpha confirmed the internal consistency of our desire measure (α = 0.97).

4. Results

4.1. Randomization check

Despite the random assignment to conditions, there were significant differences between experimental conditions in age, $M_{CG} = 21.02$, $SD_{CG} = 3.76$, $M_{EG} = 23.24$, $SD_{EG} = 7.00$, $t(100) = 2.00$, $p = .049$, and in need state, $M_{CG} = 1.56$, $SD_{CG} = 1.02$, $M_{EG} = 1.02$, $SD_{EG} = 1.02$, $t(100) = 2.68$,

p = .009. However, note that participants in the control condition experienced significantly more hunger than participants in the candy exposure condition, which should result in a more conservative test for our basic predictions. None of the other control variables differed significantly between conditions, such as the Body Mass Index (BMI) (p = .475), gender ($\chi^2 = 1.00$, p = .318), educational background (χ^2 = 5.12, p = .163) or participants' learning histories (all p's > 0.076).

4.2. Effects on desire

A simple t-test on desire by experimental condition revealed a main effect of availability, such that desire was more pronounced in the presence of the candy, $M_{EG} = 2.62$, $SD_{EG} = 1.84$, as compared to its absence, $M_{CG} = 1.42$, $SD_{CG} = 1.43$; $t(100) = 3.67$, $p < .001$, $d = 0.73$. To illuminate this main effect brought about by the proximal micro-environment, we conducted moderated regression analysis using the PROCESS macro for SPSS (Hayes, 2013) including need state and learning history as key moderators and controlling for positive and negative affect as covariates (inclusion vs. exclusion of these controls did not affect statistical conclusions). The valence and rewards subscales of the learning history measure were uncorrelated, $r = 0.031$, $p = .755$, hence separate analyses for the two subscales were conducted.

As illustrated in Fig. 1, the interaction pattern is in line with our predictions: In the no-availability condition, the simple two-way interaction effect between need state and valence was not significant (B = 0.02, $t(92) = 0.17$, 95% CI [-0.25, 0.30], $p = .865$), and, descriptively, desire levels were rather low. However, when the candies were available, the simple two-way interaction between need state and valence was significant ($B = 0.56$, $t(92) = 2.85$, 95% CI [0.17, 0.95], $p = .005$). Decomposing this simple two-way interaction effect in the availability condition, showed that the association between valence and desire was not significant for participants scoring low (−1 SD) on need state (B = 0.11, $t(92) = 0.56$, 95% CI [-0.28, 0.49], $p = .577$), but was significant for participants scoring high (+1 SD) on need state ($B = 1.28$, $t(92)$ = 3.61, 95% CI [0.58, 1.99], $p < .001$). Descriptively, desire was highest when availability, high need state, and high valence came together (mean desire score of 4.2 out of 6). In contrast, across all other seven possible combinations, the mean desire score was significantly lower (mean = 1.44; range = 0.37 to 2.36). Regarding the rewards subscale of learning history, no reliable three-way interaction emerged, $B = 0.18$, p = .311 (see lower half of Table 2). Hence, the present interaction effect of learning history appears specific to the valence subscale.

5. Discussion

In line with the predictions, Experiment 1 demonstrated that the effect of a common factor in choice architecture, availability, was most strongly pronounced under conditions of high internal need state and positive learning history. Even though there was a main effect of availability when results were analyzed across all subjects, it is clear that it crucially hinges on corresponding internal factors. This finding is conceptually important in that it suggests an important and easily overlooked link between external choice architecture and internal states and predispositions.

6. Experiment 2

Experiment 2 applied our theoretical framework to the domain of fast food desires, while introducing slight changes to probe the generalizability of the findings. In contrast to Experiment 1, we conducted an online experiment using a different manipulation of availability (i.e. graphical depictions) this time targeting fast food, and we measured the dependent variable, desire, in a different manner (Meule et al., 2012). While participants were confronted with real (i.e. *in vivo*) cues in Experiment 1, we used graphical illustrations of either control (i.e. flowers) or fast food stimuli in Experiment 2. Research has shown that such a technique can have similar effects sizes compared to real food exposure and can even result in stronger availability effects compared to utilizing olfactory cues (Boswell & Kober, 2016), while representing a modality that is close to real life experiences in people's everyday food environments (Stritzke et al., 2004).

7. Method

7.1. Participants

A total of 138 participants (106 females, 32 males, $M_{age} = 22.30$ years, $SD_{age} = 3.63$) took part in an online experiment on "perception and evaluation of pictures." The mean BMI of the participants was 22.70 ($SD = 5.44$). Participants were recruited online (subject pool and social media). The experiment lasted approximately 15 min and all participants were able to take part in a lottery to win Amazon gift cards, each worth of €10. All participants gave informed consent before the actual experiment started. The means, standard deviations and correlations between the core variables are depicted in Table 3.

7.2. Procedure

The procedure follows the same logic as the previous experiment. First, we measured need state (e.g. "How hungry are you at the present moment", 0 = *not at all* to 4 = *very much*, 3 items, $\alpha = 0.93$), before assessing individuals' learning history towards fast food (valence, α = 0.89; rewards, $\alpha = 0.74$). Similar to Experiment 1, participants next engaged in a filler task. This task required participants to list all federal states of Germany that came up to their minds. Next, participants were either randomly assigned to a control condition ($n = 67$; flower pictures), or a fast food exposure condition ($n = 71$; fast food items, e.g. Burgers, Hot Dogs).[1] Participants viewed ten flower or fast food stimuli in total and rated each picture on ten filler items, resulting in an amount of 100 statements (e.g. "How colorful is the depicted object") to be answered.

Subsequently, the stimuli were removed and participants reported on their mood by means of the PANAS questionnaire (positive mood α = 0.70, negative mood $\alpha = 0.70$; Krohne et al., 1996), and filled out the Food Cravings Questionnaire-State (FCQ-S, 6 items, e.g. "I have an intense desire to eat fast food", Meule et al., 2012, $\alpha = 0.88$) on five-point scales (0 = *totally disagree* to 4 = *totally agree*) as the dependent measure of desire towards fast food.

8. Results

8.1. Randomization check

The randomization was successful. There were no significant differences between conditions for any demographic (age, gender, BMI, education), predictor (need state, learning history), or control (positive and negative affect) variables (all $ps > .307$).

8.2. Effects on desire

A simple t-test on desire by experimental condition revealed a main effect of availability, such that desire was more pronounced in the presence, $M_{EG} = 0.83$, $SD_{EG} = 0.76$, as compared to absence, $M_{CG} = 0.51$, $SD_{CG} = 0.61$, of the food stimuli, $t(136) = 2.69$, $p = .008$, $d = 0.46$. Hence, the main effect for stimulus availability from Experiment 1 was

[1] The employed pictures were pilot tested on Amazon's Mechanical Turk (MTurk). The pilot test revealed, as expected, that the fast food pictures were significantly more tempting but significantly less positive than the flower stimuli, while there was no difference in arousal between the two types of stimuli.

Table 3
Means, standard deviations and zero-order correlations between core variables in Experiment 2.

Variable	M	SD	Correlations						
			1	2	3	4	5	6	7
1. Condition	—	—	—						
2. Learning history composite	1.48	0.98	.01	—					
3. Valence	2.25	1.38	.00	.96***	—				
4. Rewards	0.53	0.76	.03	.73***	.50***	—			
5. Need State	0.92	1.03	.05	.04	.04	.04	—		
6. Positive affect	17.47	4.49	-.02	.12	.07	.20*	.20*	—	
7. Negative affect	19.30	4.75	-.09	.11	.05	.21*	.08	.73***	—
8. State fast food craving	0.68	0.71	.23**	.37***	.33***	.32***	.22*	.15†	.02

Note. Higher scores indicated higher learning history, higher valence, higher rewards, higher need state, more positive affect, more negative affect, higher desire for candies. Condition was dummy-coded with 0 = control condition and 1 = fast food exposure condition.
† $p < .08$. * $p < .05$. ** $p < .01$. *** $p < .001$.

replicated. To illuminate this main effect brought about by the proximal micro-environment, we conducted moderated regression analysis using the PROCESS macro for SPSS (Hayes, 2013) including need state and learning history as key moderators and controlling for positive and negative affect as covariates (again, inclusion vs. exclusion of these controls did not affect statistical conclusions). Other than in Experiment 1, the valence and rewards subscales were significantly correlated, $r = 0.50$, $p < .001$. To scrutinize the effects of the two subscales, and for reasons of consistency in reporting, separate analyses for the two subscales were nevertheless conducted. As can be seen from the upper half of Table 4, utilizing the valence subscale of learning history, there was a main effect of availability as well as of learning history. Over and above these main effects, the regression analysis ($R^2 = 0.27$, $p < .001$) revealed a significant three-way interaction effect between availability, need state, and learning history ($B = 0.18$, $t(128) = 2.09$, 95% CI [0.01, 0.35], $p = .001$), replicating results from Experiment 1. The interaction is depicted in Fig. 2. No other interaction effects emerged for this analysis (all $ps > .10$). Furthermore, and consistent with Experiment 1, no reliable three-way interaction emerged for the rewards subscale of learning history (see lower half of Table 4).

Table 4
Regression results for core variables predicting state fast food craving in Experiment 2.

Variable	B	SE B	95% CI	t	p
VALENCE subscale					
Availability	0.25	0.11	[0.04, 0.47]	2.34	.021
Valence	0.14	0.05	[0.03, 0.25]	2.62	.010
Need State	0.08	0.08	[-0.08, 0.23]	0.99	.323
Availability × Valence	0.05	0.08	[-0.11, 0.20]	0.61	.540
Availability × Need State	0.01	0.11	[-0.20, 0.22]	0.12	.902
Valence × Need State	0.01	0.06	[-0.11, 0.13]	0.17	.868
Availability × Valence × Need State	0.18	0.08	[0.01, 0.35]	2.09	.039
Positive affect	0.03	0.02	[-0.01, 0.06]	1.42	.159
Negative affect	−0.02	0.02	[-0.05, 0.02]	−1.02	.309
REWARDS subscale					
Availability	0.25	0.11	[0.03, 0.46]	2.25	.026
Rewards	0.42	0.13	[0.17, 0.68]	3.30	.001
Need State	0.11	0.08	[-0.05, 0.27]	1.35	.180
Availability × Rewards	−0.23	0.15	[-0.54, 0.07]	−1.50	.135
Availability × Need State	0.09	0.11	[-0.13, 0.3]	0.82	.416
Valence × Need State	0.20	0.14	[-0.07, 0.48]	1.47	.145
Availability × Rewards × Need State	0.03	0.19	[-0.34, 0.4]	0.15	.881
Positive Affect	0.02	0.02	[-0.02, 0.05]	0.96	.340
Negative Affect	−0.02	0.02	[-0.05, 0.02]	−0.99	.325

Note. $N = 138$. Condition was dummy-coded with 0 = control condition and 1 = fast food exposure condition. Continuous variables were mean-centered. CI = confidence interval for *B*.

Follow-up analyses showed that the simple two-way interaction effect between valence and hunger was not significant for participants in the control condition ($B = .01$, $t(128) = 0.17$, 95% CI [-0.11, 0.13], $p = .868$). In contrast, this simple two-way interaction effect between valence and hunger was significant when participants were confronted with desirable fast food cues ($B = 0.19$, $t(128) = 3.19$, 95% CI [0.07, 0.30], $p = .002$), showing that both internal factors modulated the motivational relevance of food but not control cues. Decomposing this simple two-way interaction effect in the availability condition, showed that the association between valence and desire was not significant for participants scoring low (−1 *SD*) on need state ($B = 0.02$, $t(128) = 0.20$, 95% CI [-0.14, 0.17], $p = .844$), but was significant for participants scoring high (+1 *SD*) on need state ($B = 0.38$, $t(128) = 4.48$, 95% CI [0.21, 0.55], $p < .001$). Hence, as predicted, participants experienced significantly stronger state fast food cravings in the combination in contrast to a situation in which the positive learning history, in terms of valence, was absent (−1 *SD*). In further accordance with the predictions, participants experienced significantly stronger fast food cravings in the combination in contrast to a situation in which they reported a low (−1 *SD*) need state ($B = 0.35$, $t(128) = 3.58$, 95% CI [0.16, 0.54], $p = .001$) or a situation in which the food stimuli were absent (= control condition) ($B = 0.59$, $t(128) = 2.61$, 95% CI [0.14, 1.03], $p = .010$).

9. Discussion

Experiment 2 presents a conceptual replication of the key hypothesis in the domain of fast food. Although Experiment 2 utilized a different manipulation of availability, employed a different measure of desire, as well as recruited an online sample, the findings of Experiment 2 closely replicate those of Experiment 1. As in Experiment 1, and as widely documented, choice architecture (availability) exerted a main effect on desire. More important, and as predicted, desire was strongest when all three key factors, availability, need state, and positive learning history, came together (mean desire score of 1.40 out of 4) and significantly reduced [mean = 0.54, range = 0.26 to 0.81] for all other combinations.

10. Experiment 3

Experiment 3 had several aims. As Experiment 1 suffered from a failed randomization, we sought to conceptually replicate findings from Experiment 1 with some slight modifications. First, in contrast to the

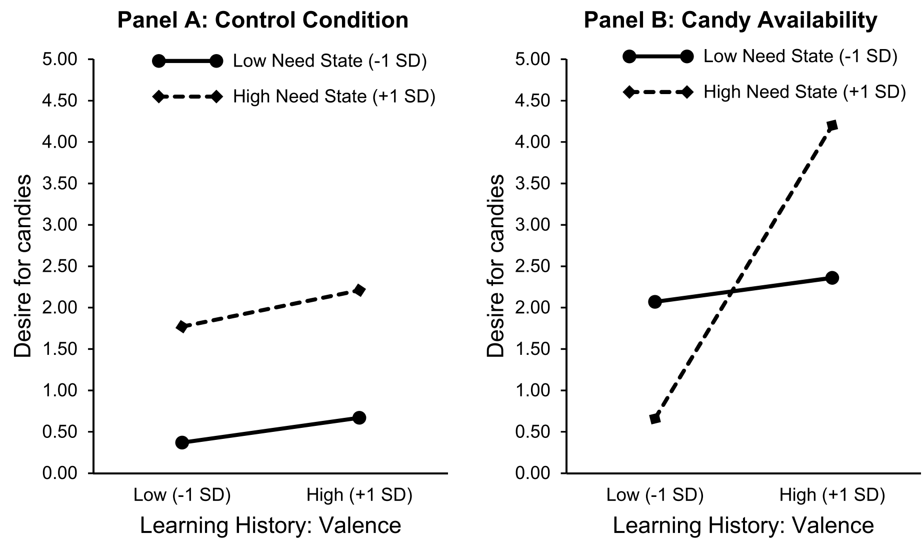

Fig. 1. Experiment 1: Three-way interaction effect between experimental condition (control condition vs. candy availability condition), need state, and learning history (valence) on desire for candies. Estimated slopes are based on values one standard deviation below and above the mean of need state and learning history.

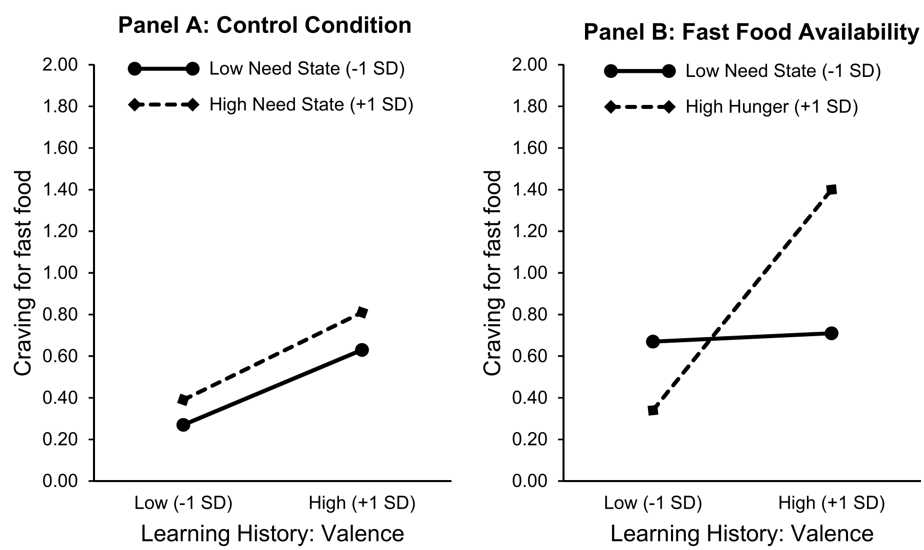

Fig. 2. Experiment 2: Three-way interaction effect between experimental condition (control condition vs. candy exposure condition), valence and need state on fast food craving. Estimated slopes are based on values one standard deviation below and above the mean of valence and need state.

prior experiments, we measured objective need state (i.e. time since last eating) instead of relying on individuals' self-reported hunger to increase generalizability. Second, we additionally assessed individuals' explicit liking of candies to gauge the independent contribution of learning history and such a more general attitude measure. It is widely acknowledged that explicit liking relies on prior learning experiences (e.g., de Leeuw, Engels, Vermulst, & Scholte, 2008; Hermans & Van Gucht, 2006).

11. Method

11.1. Participants

122 participants (83 females, 39 males, $M_{age} = 23.76$ years, $SD_{age} = 6.30$) were recruited on the campus of the University of Cologne for a laboratory experiment ostensibly on "product perception" for an exchange of either course credit or €4. The mean BMI of the participants was 22.77 ($SD = 3.77$). All participants gave informed consent in line with local regulations before the experiment started. The means, standard deviations and correlations of all core variables are displayed in Table 5.

11.2. Procedure and analysis strategy

The procedure of Experiment 3 closely resembled Experiment 1. Participants' current need state was assessed with a single-item measure by asking participants when they last ate before taking part in the experiment on a four-point scale. As a visual inspection of the need state measure as well as a Kolmogorov-Smirnov test showed that the variable was not normally distributed, $p < .001$, we therefore reverted to a median-split approach for analysis (0 = low need state: less than one or 2 h since last eating, $n = 65$; 1 = high need state: more than 2 h, $n = 57$). We next assessed participants' learning history towards candies ($\alpha = 0.87$ for valence, $\alpha = 0.80$ for rewards) as well as explicit liking of candies (e.g. "How much do you like candies"; 4 items; $\alpha = 0.87$). Next, participants engaged in the same filler task as in Experiment 1. As in Experiment 2, the valence and rewards subscales were significantly correlated, $r = 0.51$, $p < .001$. For reasons of consistency, we report

Table 5

Means, standard deviations and zero-order correlations between core variables in Experiment 3.

Variable	*M*	*SD*	Correlations *1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1. Condition	—	—	—							
2. Learning history composite	2.91	1.08	.05	—						
3. Valence	3.98	1.26	-.03	.90***	—					
4. Rewards	1.58	1.20	.14	.83***	.51***	—				
5. Explicit liking	2.95	0.79	.02	.58***	.63***	.35***	—			
6. Time since last eating	2.25	1.01	.11	-.08	-.03	-.13	-.09	—		
7. Positive affect	20.47	3.96	.02	.14	.02	.25**	.04	-.10	—	
8. Negative affect	22.33	4.32	.03	.20*	.10	.28**	.07	-.04	.69***	—
9. Desire for candies	1.35	1.28	.25**	.28**	.18*	.32***	.37***	.11	.30**	.23*

Note. Higher scores indicated higher learning history, higher valence, higher rewards, higher need state, more positive affect, more negative affect, higher desire for candies. Condition was dummy-coded with 0 = control condition and 1 = candy exposure condition.
*p < .05. **p < .01. ***p < .001.

separate analyses for the two subscales.

As our critical manipulation of availability, we randomly assigned participants to either a control condition (household articles, e.g. sponge, eraser, tea bag) or a candy availability condition (e.g. chocolate bar, jelly bears, cookies). Each stimulus was presented and rated in a fixed order. Participants had to answer nine different statements for each object (e.g. smell, moldability, visual appeal). Next, the stimuli were removed and participants indicated their positive and negative mood via the PANAS questionnaire (Krohne et al., 1996; α = 0.52 for positive affect, α = 0.55 for negative affect). Self-reported desire for candies was assessed using five developed items on a five-point VAS scale (e.g. "How much do you experience a desire to eat candies", 0 = *not at all* to 4 = *very much*, (Wewers & Lowe, 1990); α = 0.98), embedded in twelve filler items.

12. Results

12.1. Randomization check

The randomization was successful. There were no significant differences between conditions for any demographic (age, gender, BMI, education), predictor (need state, learning history), or control (positive and negative affect) variables (all *p's* > 0.14).

12.2. Effects on desire with the valence measure

A simple *t*-test on desire by experimental condition revealed a main effect of availability, such that desire was more pronounced in the presence, $M_{EG} = 1.69$, $SD_{EG} = 1.41$, as compared to absence, $M_{CG} = 1.04$, $SD_{CG} = 1.06$, of the food stimuli, $t(120) = 2.88$, $p = .005$, $d = 0.53$. To illuminate this main effect brought about by the proximal micro-environment, we conducted moderated regression analysis using the PROCESS macro for SPSS (Hayes, 2013) including need state (dummy-coded) and learning history as moderators and controlling for positive and negative affect as covariates (again, inclusion vs. exclusion of these controls did not affect statistical conclusions).

Over and above the main effect of availability, the regression model ($R^2 = 0.47$, $p < .001$) showed a non-significant three-way interaction effect among condition, need state, and the valence measure of learning history in the expected direction ($B = 0.66$; $p = .054$; see upper half in Table 6). This interaction is depicted in Fig. 3. Follow-up analyses showed that the simple two-way interaction effect between valence and need state was not significant for participants in the control condition ($B = .02$, $t(112) = 0.07$, 95% CI [-0.49, 0.52], $p = .943$). In contrast, the simple two-way interaction effect between valence and need state was significant when participants were confronted with fast food cues ($B = 0.68$, $t(112) = 3.00$, 95% CI [0.23, 1.12], $p = .003$). Decomposing this simple two-way interaction effect, showed that the association between valence and desire was not significant for low need state ($B = -0.04$, *t*

Table 6

Regression results for core variables predicting desire for candies in Experiment 3.

Variable	*B*	*SE B*	95% CI	*t*	*p*
VALENCE subscale					
Availability	0.46	0.28	[-0.11, 1.02]	1.61	.111
Valence	0.17	0.17	[-0.17, 0.5]	0.99	.327
Need State	0.29	0.29	[-0.28, 0.86]	1.00	.317
Availability × Valence	−0.20	0.22	[-0.63, 0.23]	−0.93	.354
Availability × Need State	0.31	0.42	[-0.52, 1.13]	0.74	.462
Valence × Need State	0.02	0.25	[-0.49, 0.52]	0.07	.943
Availability × Valence × Need State	0.66	0.34	[-0.01, 1.34]	1.95	.054
Positive Affect	0.12	0.04	[0.05, 0.19]	3.28	.001
Negative Affect	−0.01	0.03	[-0.08, 0.05]	−0.42	.675
REWARDS subscale					
Availability	0.46	0.29	[-0.11, 1.03]	1.61	.111
Rewards	0.02	0.18	[-0.33, 0.37]	0.12	.906
Need State	0.43	0.34	[-0.23, 1.1]	1.29	.201
Availability × Rewards	0.15	0.24	[-0.33, 0.63]	0.61	.543
Availability × Need State	−0.02	0.45	[-0.92, 0.88]	−0.04	.967
Valence × Need State	0.24	0.34	[-0.43, 0.91]	0.72	.475
Availability × Rewards × Need State	0.11	0.41	[-0.7, 0.91]	0.26	.794
Positive Affect	0.10	0.04	[0.02, 0.17]	2.61	.010
Negative Affect	−0.02	0.03	[-0.08, 0.05]	−0.44	.659

Note. $N = 122$. Condition was dummy-coded with 0 = control condition and 1 = candy exposure condition. Need state was dummy-coded with 0 = low need state and 1 = high need state. CI = confidence interval for *B*.

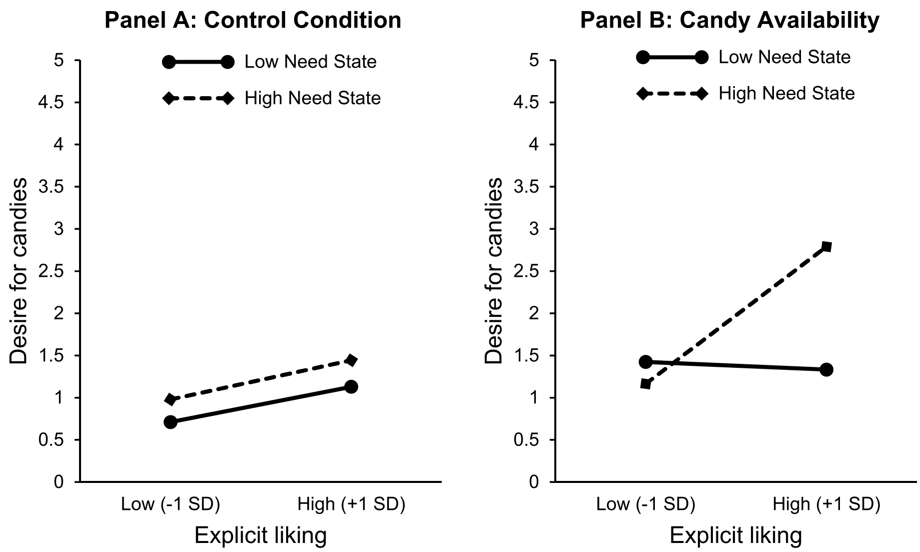

Fig. 3. Experiment 3: Three-way interaction effect between experimental condition (control vs. candy availability), need state, and the valence subscale (Panel A) as well as explicit liking (Panel B) on desire for candies. Estimated slopes are based on values one standard deviation below and above the mean of need state and valence/explicit liking.

(112) = 0.27, 95% CI [-0.30, 0.23], p = .789), but was significant for high need state (B = 0.64, t(112) = 3.51, 95% CI [0.28, 1.01], p < .001). Desire was thus again strongest in the combination of availability, high need state, and high liking (mean desire score = 2.79) and was reduced to a mean score of 1.44 or lower (mean = 1.17) whenever a given underlying factor or a combination was absent. The inclusion or exclusion of the explicit liking measure, moreover, did not change the statistical conclusions (crucial three-way interaction: B = 0.56; p = .081).[2] Furthermore, again, there was no interaction effect regarding the rewards subscale of learning history (see lower half in Table 6).

13. Discussion

As in the previous two experiments, there was a reliable main effect of stimulus availability in shaping desire for attractive food. However, even though results were in the expected direction, Experiment 3 did not support the three-way interaction finding from these prior studies for threshold of statistical significance with regard to the valence subscale of the learning history measure. The precision of the three-way interaction in Experiment 3 may have been limited by our decision to use only a one-item proxy of hunger, time since last eating, instead of subjective hunger ratings, which was moreover not normally distributed, preventing us from including it as continuous predictor.

14. Pooled analysis across studies 1 to 3

To put the present conclusions on a stronger empirical basis, we pooled the data from Experiments 1 through 3, despite some procedural differences, and performed a pooled or "mega"-analysis (Sternberg, Baradaran, Abbott, Lamb, & Guterman, 2006). For this analysis, we z-standardized the predictor and dependent variables within each of the three studies before pooling the variables for joint regression analyses using the valence subscale, the rewards subscale, as well as the overall learning history composite score. As can be seen from Supplementary Table 2, combining the data of all three experiments (N = 362) suggested a highly reliable three-way interaction effect across studies for the valence subscale, β = 0.30, t(9,352) = 3.15, 95% CI [0.115, 0.495], p = .002, but not for the rewards subscale, β = 0.08, t(9,352) = 0.84, 95% CI [-0.113, 0.282], p = .399. Finally, combining both subscales into a composite also resulted in a reliable three-way interaction across studies, β = 0.23, t(9,352) = 2.30, 95% CI [0.037, 0.415], p = .019.

15. General discussion

How do food desires emerge? In this work, we addressed this issue by scrutinizing the interplay of stimulus availability, a key external factor in the proximal choice environment, and two internal factors from motivation science, need state, and learning history. In line with the dynamical model of desire (Hofmann & van Dillen, 2012), we expected food desire to be strongest in the confluence of stimulus availability with high rather than low current need states (i.e. hunger) and a positive rather than negative learning history towards the attractive stimuli of interest. Experiments 1 and 2 strongly, and Experiment 3 only descriptively, corroborated these predictions when utilizing the valence subscale of the learning history measure. Results from a combined analysis of all three experiments suggests that this conclusion is generalizable across settings and measures.

One additional consistent pattern of findings was that the predicted three-way interaction only obtained for the valence subscale of our newly created measure of learning history, but not the rewards subscale. This could have to do with the greater breadth of the valence subscale, limited self-insights into current and past reward structures reducing the validity of the rewards scale, or additional aspects that future research should clarify. The pooled analysis suggests that the absence of an interaction effect using the rewards subscale may be due to a power issue. Exploratory analyses of the non-significant three-way interaction effect using the rewards subscale showed a pattern that closely resembles the one for the valence subscale. Further supporting this assumption, we were also able to obtain the predicted three-way interaction effect using the learning history composite in the pooled analysis. An additional supplementary analysis, finally, revealed similar effects

[2] Because the explicit liking measure was strongly correlated with the valence subscale of the learning history measure, r = 0.63, p < .001, and moderately correlated with the rewards subscale, r = 0.35, p < .001 (see Table 5), we conducted an additional exploratory analysis, utilizing the explicit liking measure. This exploratory regression model revealed a significant three-way interaction effect (plotted in Supplementary Fig. 2) between availability, need state and explicit liking (B = 0.99, t(112) = 2.00, 95% CI [0.01, 1.97], p = .048), mimicking the earlier observed pattern of findings for the valence subscale. This additional finding suggests that explicit liking may function as a good proxy for the valence subscale of learning history.

for the conceptually related explicit attitude measure as a proxy for learning history. In light of these findings, we therefore recommend prioritizing the valence subscale at present as a suitable practical candidate for pinpointing who might and who might not be affected by availability, and to keep exploring the utility of the reward subscale.

In terms of theoretical implications, the present findings lend strong support for more complex models spelling out how aspects of choice architecture interact with internal motivational factors. Even though we obtained a main (i.e., overall) effect of the availability manipulation in affecting individuals' desire scores, a better, *systematic* understanding of the interplay of external and internal factors which goes beyond such main effects may mark one important next step in choice architecture research. At present, and reminiscent of the behaviorism debate in psychology, there is a danger that ignoring such internal factors may result in an overly simplified or even distorted understanding of the role of the external environment in shaping an individual's motivation, and ultimately behavior. Indeed, intrinsically rewarding cues such as high-calorie foods have a strong, generic appeal. But our findings consistently demonstrate that the occurrence of desires is strongest when stimulus availability is coupled with a resonating need state and a positive learning experience towards the available stimulus. In contrast, when the available tempting stimulus is presented against the background of a low need state and/or a less positive learning experience, the choice architecture manipulation will not unleash its full potential. This insight not only has clear-cut implications for future research investigating the effects of nudging interventions but also suggests new intriguing ways to reduce the full-blown occurrence of (unwanted) desires which posit a clear risk for successful self-regulation (Hofmann & Kotabe, 2012).

15.1. Practical implications

The present findings point to the utility of diverse theory-based interventions to boost self-regulatory success, especially those that eliminate or reduce the full-blown occurrence of (unwanted) desires, making strenuous self-control efforts redundant (Hofmann & Kotabe, 2012; Hofmann & van Dillen, 2012; Kotabe & Hofmann, 2015). First and foremost, the strategy that is most closely aligned with the choice architecture literature, is to reduce the availability of tempting stimuli so as to prevent the experience of (unwanted) desires in the first place. This strategy therefore accords well with the popular saying: "out of sight, out of mind". Indeed, recent findings suggest that people high in self-control are better in navigating through the environment in a way that precludes the emergence of problematic desires and hence reduces the necessity of exerting (active) inhibitory attempts (Galla & Duckworth, 2015; Hofmann, Kotabe, & Luhmann, 2013; Hofmann, Luhmann, Fisher, Vohs, & Baumeister, 2014). However, given the omnipresence of alluring stimuli, these strategies are constrained by limits on how easily choice environments can be altered.

A second, different way to successfully reduce the full-blown occurrence of (unwanted) desires, as suggested by our model and findings, is by changing an individual's learning history, and thus the incentive value triggered upon stimulus encounter (Berridge & Robinson, 1998, 2003; Robinson & Berridge, 2008). Indeed, research shows that techniques such as evaluative conditioning (Hofmann, De Houwer, Perugini, Baeyens, & Crombez, 2010) or the retraining of automatic action tendencies may reduce desire experiences (Wiers, Eberl, Rinck, Becker, & Lindenmeyer, 2011). Viewer from a larger perspective, this factor points to the role of food rewards in socialization processes (e.g., sweets as reinforcers of behavior).

A third possible strategy, suggested by our model and findings, to boost self-regulatory success may be found in preventing the experience of high need states at the moment of stimulus encounter—an approach that has not received much attention yet in the context of choice architecture research. This aspect accords well with the conventional wisdom to never go grocery shopping on an empty stomach. In the eating domain, for instance, consuming small portions of food more frequently to increase experienced satiation (Redden, 2015), might offer an intriguing strategy to reduce the full-blown experience of (unwanted) desires. Support for the possible role of satiation comes from a study that has shown that people who are good in self-control tend to satiate faster to unhealthy but not healthy products compared to their less self-controlled counterparts (Redden & Haws, 2013).

15.2. Limitations and future research

One limitation of the present line of work is that, despite the fact that self-report measures are a viable, reliable and valid method to assess desire (Rodríguez-Martín & Meule, 2015; Sayette & Wilson, 2015), we did not investigate the generalizability of our findings employing nonverbal measures of desire (see Sayette & Wilson, 2015 for a discussion). However, previous research has shown that reactions to measures are not necessarily translated into consciously experienced desires (Tiffany, 1990) and that availability effects on nonverbal measures are significantly smaller than effects on self-reports (see Carter & Tiffany, 1999, for a meta-analysis on cue reactivity effects). However, there is an unresolved ongoing debate whether nonverbal measures (e.g. physiological responses, attentional biases) represent the core essence of desire, are antecedents or consequences of experiencing desires (Sayette & Wilson, 2015). Hence, self-report measures of experienced desires may best capture the psychological feelings and core essence of 'desire' (see also Tiggemann & Kemps, 2005, for a related argument). In addition to measurement, demographic and cultural factors, as well as varying operationaliziations of availability may each present useful avenues for future research into the generalizability of the present findings.

Another point for discussion is that on a broader conceptual level an interactive model implies a desire of zero when a given factor is missing, which is at odds with the present findings. However, within our studies, the underlying factors (i.e. availability, need states, learning history) were not completely absent among participants but rather certain participants reported having a low current need state (i.e. low hunger state) or having acquired only a low positive learning history towards a certain object. Even, for participants in the control condition, a complete absence of tempting food cues was not possible. Participants still had to indicate their learning history towards a certain category (i.e. candies or fast food) and had still to indicate their current level of desire towards a certain food category. Therefore, even for participants in the control condition tempting stimuli likely were at least somewhat available, potentially eliciting some level of desire.

Third, it should be noted that our studies were limited to the food domain since high-caloric foods are omnipresent, easily accessible and often very affordable and hence entice human beings to indulge in these. Nevertheless, we believe that our findings are not restricted to the eating domain but may very well generalize to other domains (e.g. cigarette craving, alcohol craving). Indeed, prior research has also gained evidence for an interactive nature of desire in other domains, including cigarette craving (e.g., Payne, Smith, Sturges, & Holleran, 1996; Sayette, Martin, Hull, Wertz, & Perrott, 2003) and alcohol cravings (George et al., 2001; Myrick et al., 2004).

Moreover, an additional avenue for future research is also to investigate how subjective availability, such as sensory imagery of desires, interacts with internal factors in triggering desire. As proposed by the Elaborated Intrusion theory (EI) of desire (Andrade, May, van Dillen, & Kavanagh, 2015; Kavanagh, Andrade, & May, 2005), it is these intrusive thoughts and sensory mental images of the experiences of achieving or enacting one's desires that waxes the experience of desires and motivates an individual to indulge in one's desires (Andrade et al., 2015; Connor et al., 2014; Hofmann & van Dillen, 2012; Kavanagh et al., 2005; May et al., 2014; May, Andrade, Kavanagh, & Hetherington, 2012). Indeed, sensory imagery and intrusiveness has been shown to be a strong predictor of desire strength (May et al., 2014).

Future research could also apply our findings to the domain of hedonic deprivation. In our study, we addressed need states only from a homeostatic viewpoint in terms of homeostatic hunger that follows a period of food deprivation, rather than conceptualizing need states due to chronic deprivation of a particular food category. This *hedonic deprivation* has also been shown to increase desires for the deprived category, specifically (Blechert, Naumann, Schmitz, Herbert, & Tuschen-Caffier, 2014; Moreno-Dominguez, Rodriguez-Ruiz, Martin, & Warren, 2012), and can interact with available stimuli in eliciting desire (e.g., Blechert et al., 2014; Sayette et al., 2003). Our findings therefore offer intriguing insights into the boundary conditions under which hedonic deprivation triggers strong desire states.

16. Conclusion

Taken together, the present set of findings seems to largely support our core prediction: that the effects of choice architecture may be best understood by connecting choice environments with internal processes that effectively shape how external aspects are translated into traceable changes in motivation to approach or consume the stimuli of interest. To be clear, throughout our experiments, we found that availability exerted a robust main effect on food desire, collapsing across participants' variation in need states or past learning history. However, our findings clearly indicated that this main effect of availability was primarily driven by a specific combination of high need state and positive learning history. In other words, by conceptualizing and scrutinizing the interactive nature of desire, we were able to better identify the boundary conditions under which availability works best or worst. In the spirit of Lewin's famous dictum that nothing is as practical as a good theory, we believe that a better basic understanding of the mechanisms underlying choice architecture may also provide highly useful from a practical, public policy, perspective to the extent that such relevant internal factors are known, can be measured, or can themselves be addressed or manipulated through interventions.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.appet.2020.104815.

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