5-1-2015

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Published in:
Health Psychology

DOI:
10.1037/hea0000134

Publication date:
2015

Health Psychology
2015, Vol. 34, No. 5, 539–546

0278-6133/15/$12.00 http://dx.doi.org/10.1037/hea0000134

Expression of Executive Control in Situational Context: Effects of Facilitating Versus Restraining Cues on Snack Food Consumption

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Objectives: To examine the effects of executive function (EF) on objectively measured high-calorie snack food consumption in 2 age groups and to explore the moderating influence of environmental cues. ***Methods:*** In Study 1, 43 older adults (M_{age} = 74.81) and in Study 2, 79 younger adults (M_{age} = 18.71) completed measures of EF and subsequently participated in a bogus taste-test paradigm wherein they were required to rate 3 highly appetitive (but high-calorie) snack foods on taste and texture. Grams of snack food consumed was measured covertly in the presence randomly assigned contextual cues (explicit semantic cues in Study 1; implicit visual cues in Study 2) that were facilitating or restraining in nature. ***Results:*** Findings indicated that in both age groups, stronger EF predicted lower consumption of snack foods across conditions, and the effects of EF were most pronounced in the presence of facilitating cues. ***Conclusions*****:** Older and younger adults with weaker EF tend to consume more high-calorie snack food compared with their stronger EF counterparts. These tendencies appear to be especially amplified in the presence of facilitating cues.

Keywords: executive function, dietary behavior, snacking, cognition, brain

Consumption of high-calorie foods leads to positive energy balance, which in turn is a risk factor for the development of obesity (Rosenheck, 2008; Bertéus Forslund, Torgerson, Sjöström, & Lindroos, 2005; Swinburn, Caterson, Seidell & James, 2004). Humans and other organisms have strong default preferences for foods that are calorie dense (Drewnowski & Greenwood, 1983; Drewnowski, 1997). This tendency may reflect longstanding evolutionary pressures to maximize caloric gain per forage under the conditions of relative food scarcity that characterized the vast majority of our evolutionary history (Ruse & Travis, 2011). It has been hypothesized that cognitive control resources are required for suspending such default dietary preferences, and recent attempts have been made to integrate cognitive control into contemporary theories of health behavior (e.g., Hall & Fong, 2013; Hall & Marteau, in press; Hofmann, Friese, & Wiers, 2008). To date, several studies have linked compromised neurocognitive performance and reduced prefrontal function with both obesity (Boeka & Lokken, 2008; Gunstad, Lhotsky, Wendell, Ferrucci, & Zonderman, 2010; Willeumier, Taylor, & Amen, 2011) and lack of success in weight loss (Pauli-Pott, Albayrak, Hebebrand, & Pott, 2010; Spitznagel et al., 2013).

Although obesity may have an adverse impact on cognitive function, there is accumulating evidence that weaker executive function (EF) is prospectively linked to more frequent consumption of high-calorie snack foods in observational studies (Allan, Johnston, & Campbell, 2010; Hall, 2012; Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010). More importantly, however, experimental paradigms have supported the causal status of EF in relation to dietary behavior by showing that modulation of brain centers that support EF cause corresponding modulation of craving for and consumption of appetitive snack foods (Uher et al., 2005; Fregni et al., 2008; Goldman et al., 2011; Lowe, Hall, & Staines, in press). In a recent example of this paradigm, we undertook direct modulation of the dorsolateral areas of the prefrontal cortex (DLPFC). This area is of significance in part because it is directly implicated in behavioral inhibition, the most "pure" facet of EF (Miyake & Friedman, 2012; Miller, 2000; Miller & Cohen, 2001). Participants in this study underwent a cortical stimulation paradigm wherein they were exposed to temporary down-regulation of the DLPFC or sham stimulation. As predicted, in the active stim-

This article was published Online First August 11, 2014.

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Author contributions: study design and conceptualization (PH, BT, CL, MM, TL, HP, YG), data collection and management (BT, CL, CV), data analysis (PH), writing (PH, BT, CL, YG). This research was supported by a seed grant to Peter Hall from the UW Chronic Disease Prevention Initiative.

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ulation condition (i.e., down-regulation of DLPFC) participants experienced stronger subjective cravings for appetitive snack foods, as well as higher consumption when quantified in grams consumed and total calories ingested. A few specific findings of this study were noteworthy, including the fact that the effects of DLPFC down-regulation were selective to high-calorie snack foods (i.e., consumption of control foods of lower appetitive value was not affected), and the effects were mediated by EF task performance.

Age Patterns in EF and Dietary Behavior

There is good reason to be interested in the predictive power of EF for calorie ingestion in all age groups. Among younger age groups (children, adolescents, and young adults), dietary behavior may still be malleable, and low EF may bias toward entrenchment of unhealthy patterns of consumption and accumulation of adiposity, both of which may be difficult to reverse later in life. Among older adults, EF is of concern because executive-level processes are particularly sensitive to the effects of aging (Rypma, Eldreth, & Rebbechi, 2007); for this reason, among older adults there is wide variability in degree and rate of decline of EFs (Wilson et al., 2002). Examining the effects of EF on high-calorie food consumption in older adults may be important for at least two reasons: (a) the continued relevance of dietary behavior for prevention of chronic illness later in the life span and (b) the importance of maintaining nutritional meal content, which may be threatened by ingestion of high-calorie snack foods with little nutritional value.

Social Constraints on Eating

Given the social constraints on excessive consumption of high-calorie foods in the modern world, it is unlikely that individual differences in EF manifest uniformly across all situational opportunities for caloric overconsumption. For example, it is unclear to what extent facilitating versus inhibiting environments moderate the effects of EFs on actual eating behavior. One prior study has documented the augmenting effects of facilitating cues on consumption of appetitive but unhealthy snack foods in younger adults (Hall, Lowe & Vincent, 2013). However, it is currently not clear whether such effects are similar in older adults, nor is it known whether the effects of different types of environmental cues have the same effects on caloric consumption. Given that there is more EF variability among older adults due to aging, it is possible that, in general, older adults' snack consumption may be more influenced by restraining and facilitating cues. Likewise, it is unclear to what extent the effects of cues generalize beyond simple semantic cues used in Hall et al. (2013). Although some snack-related cues in everyday life are indeed semantic in nature (e.g., media messaging), it is also true that visual cues are common, in the form of posters and media advertisements for snack foods. At present, it is unclear to what extent cues of a visual nature also disproportionately influence snacking behavior of those with relatively lower EF.

The purposes of the current investigation were to examine whether environmental cues moderate the expression of EF in relation to snack food consumption among older adults (Study 1) and to examine whether the effects involving environmental cues generalize to visual cues (Study 2). It was hypothesized that (a) snacking behavior would be influenced by facilitating and restraining cues in opposing directions, (b) relatively weaker EF would predict higher levels of snack food consumption across conditions, (c) EF effects on snack food consumption would be most amplified when cues are facilitating, and (d) these effects would be observed with both semantic (Study 1) and visual (Study 2) cues.

Study 1: Methods

Participants and Procedures

Participants were 43 older adults (M_{age} = 74.81 years) who were free of major medical comorbidities, color-blindness, severe vision impairment, and food allergies/sensitivities. Sample characteristics are presented in Table 1. Based on reported weight and height, 52.4% were in the normal weight range while 47.6% were overweight or obese. Participants all attended one laboratory session at one of two times of the day (10 a.m. or 3 p.m.) and were instructed to abstain from food and caffeine for 2 hr prior to this, with compliance checked upon arrival. Participants were seated at a computer and shown attractive images of the experimental foods on a monitor (5 s each) in order to stimulate appetite. Participants then completed three cognitive tests measuring executive control abilities (Stroop, go/no-go, and stop signal). Participants subsequently completed a taste test wherein they rated three appetitive but unhealthy foods on dimensions of taste, appearance, and texture. Participants were randomly assigned to one of three task instructions ("eat as much as you like in order to make your ratings" $n = 13$; "eat only the bare minimum needed to make your ratings" $n = 13$; or no specific instructions beyond orientation to the taste test itself $n = 16$). Instructions were delivered verbally and appeared on a sign in front of participants during the taste test. Participants were unaware that the purpose of the experiment was to quantify the amount of food consumed, thus minimizing demand characteristics. The change in food weight from before to after the taste test was covertly assessed as the primary dependent measure. Experimental foods included three high-calorie choices

Table 1
Participant Characteristics for Study 1

	Mean (*SD*)	% (*n*)
Age	74.75 (8.2)	
Body mass index	25.35 (4.3)	
Gender		
Female		72.5 (29)
Male		25.0 (10)
Ethnicity		
White		95 (38)
Other		5 (2)
Household income		
$0–$19,999		2.6 (1)
$20,000–$39,999		31.6 (12)
$40,000–$59,999		31.6 (12)
$60,000–$79,999		21.1 (8)
$80,000–$99,999		13.2 (5)
Accuracy % correct		
Go/no-go	94.9 (5.0)	
Stroop	92.1 (9.4)	
Stop signal	38.2 (30.9)	

(presented for 5 min each): regular full-fat potato chips, flavored full-fat potato chips, and Belgian milk chocolate. Participants were debriefed at the end of the study.

Measures

Stroop. The Stroop task (Stroop, 1992) is a valid, reliable, and widely used measure of EF (Kindlon et al., 1995; MacLeod, 1991; Wostmann et al., 2013). In this variant of the task, modeled after the version in Miyake et al. (2000), participants were instructed to indicate (by button press) the color (red, blue, green, yellow, orange, or purple) of a word or series of symbols, as quickly and accurately as possible. Participants were presented with a mixed block of trials: 36 trials with a string of asterisks, 12 congruent color word trials (e.g., the word "red" appearing in red-colored font), and 60 incongruent color word trials (e.g., the word "yellow" appearing in purple-colored font). Proportion of correct responses was the crucial dependent measure.

Go/no-go. The go/no-go (GNG) task is also a valid and reliable measure of EF (Kindlon et al., 1995; Keilp, Sackeim, & Mann, 2005; Wostmann et al., 2013), which assesses ability to inhibit a prepotent response (Casey et al., 1997). In this variant of the GNG, participants were required to press a button whenever a lowercase letter was presented on the computer screen and withhold their response when an uppercase letter was presented. A total of eight blocks of 60 test trials each were presented; in half of the test blocks, uppercase letters were predominant (5 upper, 1 lower), and in the other half, lowercase letters were predominant (1 upper, 5 lower). The variable of interest was reaction time (RT) on correct trials, with shorter RT being indicative of stronger EF.

Stop-signal. The stop-signal task (SST; Logan, Cowan, & Davis, 1984) is considered a valid and reliable measure of EF (Lijffijt, Kenemans, Verbaten, & van Engeland, 2005; Wostmann et al., 2013). In this version of the SST, modeled after Miyake et al. (2000), participants completed two blocks of trials. During the first block (48 trials), participants were asked to indicate (by button press) whether a word presented on the computer screen was animal or nonanimal; the second block (96 trials) utilized the same categorization task, but with the additional instruction to withhold response following a computer emitted tone. The variable of interest was percent accuracy during the second block.

Covariates. Age, sex, income, Body Mass Index (BMI; weight and height), and recent snack consumption were measured by self-report. Recent snack consumption was assessed with a pair of questions adapted from the Block Fat Screener: "How often in the past month have you consumed [potato chips, corn chips, popcorn/doughnuts, pastries, cake, pie, cookies]?"

Data Analytic Approach

The primary analyses utilized moderated hierarchical linear regression to test environmental cue effects (and cue by EF interactions) on snack food consumption. Effect coding was employed to compare the effects of each active condition (restraining cue/ facilitating cue) to the grand mean. All analyses used age as a covariate, given the substantial influence of age on EF scores; additional adjustments for demographics (sex, income), BMI, and recent snacking history (frequency) were added. Two data points were dropped from the Stroop analysis because of accuracies below .5 (.00 and .14, respectively), as these suggested lack of understanding of the task instruction. For descriptive analyses, high/low values of EF were defined by median split.

Results

The three experimental groups did not differ with respect to any demographic variables (age, sex, household income), BMI, or relationship status (all $ps > .050$). Stroop and GNG scores were significantly correlated ($r = -.283$, $p = .038$); SST performance did not correlate with Stroop ($r = -.114$, $p = .241$) or GNG performance ($r = .059$, $p = .358$). BMI was significantly correlated with age ($r = -.399$, $p = .004$), income ($r = .265$, $p = .049$), and total snack food consumed ($r = .338$, $p = .014$). Males and females did not differ in BMI, $F(1, 40) = 0.000$, $p = .993$, or total weight of snack food consumed during the taste test in grams, $F(1, 40) = 1.562$, $p = .219$.

Hierarchical moderated regression analyses revealed a manipulation (cue) effect on consumption in both active groups: those in the restraint condition ($M = 31.39$, $SD = 18.18$) ate significantly less ($\beta = -.427$ $t = -2.426$, $p = .021$), and those in the facilitation condition ($M = 73.00$, $SD = 46.05$) ate significantly more ($\beta = .435$. $t = 2.289$, $p = .018$) than the grand mean ($M = 53.52$, $SD = 36.57$).

In age-adjusted analyses, there was no significant main effect of Stroop performance on grams of snack food consumed ($\beta = -.185$, $t = -1.259$, $p = .216$), but there was a significant interaction between the manipulation effect and Stroop performance for the facilitation group ($\beta = -.386$ $t = -2.121$, $p = .042$). Specifically, the slope of the line predicting grams of snack food consumed from Stroop performance was significantly steeper for those in the facilitation condition ($\beta = -.543$ $t = -2.285$, $p = .045$) than the total sample ($\beta = -.185$ $t = -1.175$, $p = .248$). The slope of the line predicting food consumption from Stroop performance did not differ significantly from the total sample for the restraint condition ($\beta = .264$, $t = .887$, $p = .398$). Additional adjustment for demographics (age, income, sex), BMI, and past month consumption of snack foods revealed a significant main effect of Stroop ($\beta = -.312$, $t = -2.157$, $p = .041$), as well as the significant interaction between the facilitation effect and Stroop performance ($\beta = -.461$ $t = -2.290$, $p = .032$). Overall, those performing in the bottom half on the Stroop in the facilitation condition consumed 57.66% more snack food than those in the top half of Stroop performance in the same condition (see Figure 1).

There was a significant main effect of GNG performance on snack food consumed, such that those with stronger performance consumed fewer grams of snack foods during the taste test than their weaker counterparts ($\beta = .330$, $t = 2.078$, $p = .045$). However, the effect of GNG on snack food did not vary systematically with either the restraint ($\beta = .139$, $t = .903$, $p = .373$) or facilitation ($\beta = .156$, $t = .887$, $p = .382$) manipulation effect. Additional covariate adjustments did not affect the statistical significance of the main effect or interaction.

No significant main effects ($\beta = -.160$, $t = -1.072$, $p = .291$) or manipulation effect interactions ($\beta_{restraint} = -.094$, $t = -.485$, $p = .719$; $\beta_{facilitation} = .069$, $t = .363$, $p = .719$) were found for SST performance; additional covariates did not change these null effects. When examining the factor structure of the three measures of EF using an exploratory factor analysis, a two-factor solution

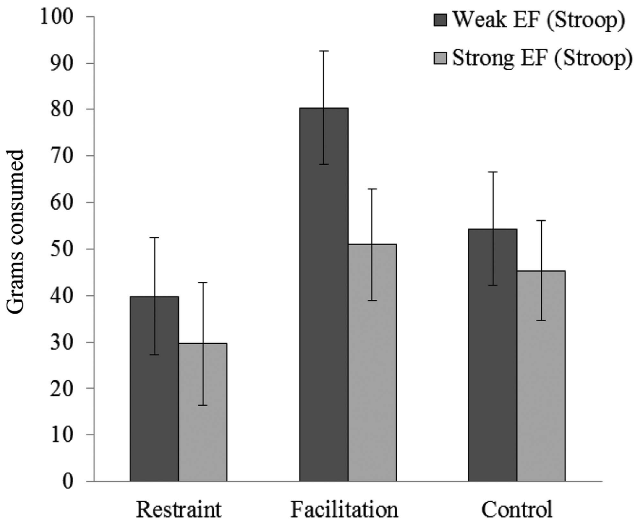

Figure 1. Snack food consumption (grams) of low- and high-executive-function (EF) participants under restraint, facilitating, or neutral semantic cues. $N = 43$ older adults; marginal means are estimated at the mean covariate value for the sample. The terms "weak" and "strong" in relation to EF represent relative differences rather than absolute values.

accounted for 92.63% of the variability; Stroop and GNG fell on a common "inhibitory" factor (factor loadings $> .900$) accounting for 58.23% of the variability while SST performance loaded on the second factor. As such, the null findings with respect to the SST may reflect lack of common covariance with the underlying inhibitory factor assessed by Stroop and GNG.

Study 2: Methods

The findings of Study 1 indicate that facilitative conditions enable expression of EF in eating behavior. However, the findings were not fully consistent across EF measures, possibly due to power limitations or to noncomparability of the EF measures themselves, which have very different response requirements and metrics for quantifying performance. With respect to the former, although we had sufficient power to detect the Stroop interactions due to the medium effect size ($f^2 = .200$), the small effect size for the GNG interactions ($f^2 = .109$) would have required a doubling of the sample size to achieve 80% power. With respect to the latter, all three of the EF measures used were in different metrics and not easily combinable into a single index, which would have improved analytic parsimony. In Study 2, we address these limitations by conducting an additional study with a larger sample size and use two indicators of EF that are easily combinable due to a common metric (i.e., an interference score).

Study 2 also expands on Study 1 to explore the effects of more implicit visual cues rather than explicit semantic cues, in order to examine the generality of the cue effect. Study 2 further utilizes a younger adult sample in order to examine the generalizability of the effects to younger (rather than older) adults.

Study 2 was identical in design to Study 1, with three exceptions: (a) visual cues were substituted for the semantic cues, (b) an interference score for both EF tasks (in this case flanker and Stroop) in order to allow for straightforward construction of an index score, and (c) a young adult sample to examine the generalizability of the effects to younger age groups.

Participants and Procedure

Participants for Study 2 consisted of 79 healthy young adults recruited from an introductory psychology participant pool ($M_{age} = 18.71$; Table 2). Eighty-one percent were normal weight, whereas 19% were overweight or obese. All participants were prescreened for liking of the experimental foods (quantified by a score of 7 or higher on the following two self-report items: (a) "How often do you experience cravings to eat potato chips/chocolate?" (response scale: 1 = *never*; 10 = *all the time*); and (b) "How strong are these cravings you experience to eat potato chips/chocolate?" (response scale: 1 = *extremely weak*; 10 = *extremely strong*). Individuals who scored 7 or above on the response scale (i.e., the top 30%) for both items and both experimental foods were eligible for selection.

The experimental protocol in Study 2 was identical to that of Study 1, except that visual cues were utilized. The stimulus in the facilitation condition was a 2' × 3' poster depicting a pepperoni pizza (Figure 2a), placed on the wall facing the participant during the taste test. The stimulus in the restraint condition was an identical poster with the pizza replaced by a round diagram of the same size depicting the food consumption recommendations from a food guide (Figure 2b). The control condition included a blank poster of identical size in relation to the other two conditions. The stimuli are presented in Figure 2.

Measures

The two measures of EF were the Stroop used in Study 1 as well as a flanker task. The flanker task was modeled on Eriksen and Eriksen (1974). The task was performed in two blocks consisting of 100 trials each, in which participants were asked to indicate if the central letter in a string of uppercase letters (e.g., HHHHH, SSSSS) was an "S" or an "H." The stimulus was either a congruent flanker trial (i.e., the central letter was the same as the flanker

Table 2
Participant Characteristics for Study 2

	Mean (*SD*)	% (*n*)
Age	18.71 (1.23)	
Body mass index	22.41 (3.34)	
Gender		
Female		65.8 (52)
Male		34.2 (27)
Ethnicity		
White		35.4 (28)
Other		64.6 (51)
Estimated household income		
$0–19,999		17.7 (14)
$20,000–$39,999		8.9 (7)
$40,000–$59,999		16.5 (13)
$60,000–$79,999		20.3 (16)
$80,000–$99,999		16.5 (13)
$100,000+		12.7 (10)
Interference, ms		
Stroop	35.13 (32.24)	
Flanker	44.42 (90.84)	

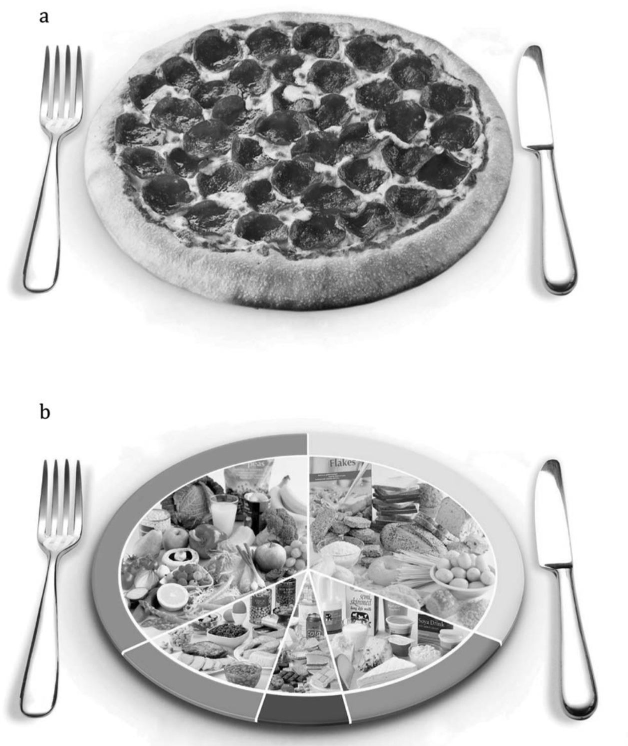

Figure 2. (a) Facilitation condition visual cue. (b) Restraint condition visual cue.

letters; HHHHH) or an incongruent flanker trial (i.e., the central letter was different from the flanker letters; SSHSS); the ratio of congruent to incongruent trials was 1:1. Each stimulus was presented for a maximum of 900 ms followed by an interstimulus interval of either 1,100 ms, 1,300 ms, or 1,500 ms, employed randomly. The Stroop was performed in a manner identical to that in Study 1. The crucial dependent variable in both cases was interference score, calculated as the RT on correct incongruent trials minus the RT on correct congruent trials; shorter RTs were taken to reflect stronger EFs. Both were converted to z scores and combined into a single composite measure for the sake of parsimony. This variable was then reverse scored so that higher scores on the measure indicate stronger EF.

Results

Again, the three experimental groups did not differ with respect to any demographic variables (age, sex, household income), BMI, or relationship status (all ps $> .050$). Stroop and flanker scores were significantly correlated ($p = .252$, $p = .025$). BMI was again correlated with amount of snack food consumed ($r = .202$, $p = .037$). BMI was not correlated with any other demographic variable, though males had significantly higher BMI than females, $F(1, 78) = 6.565$, $p = .010$. Males also consumed significantly more snack food than females, $F(1, 78) = 25.57$, $p < .001$.

Hierarchical regression analyses indicated a significant interaction between the manipulation effect and EF for the facilitation group in age-adjusted analyses ($\beta = -.277$, $t = -2.201$, $p = .031$). Specifically, the slope of the line predicting grams of snack food consumed from EF performance was significantly steeper for those in the facilitation condition ($\beta = -.469$, $t = -2.599$, $p = .016$) than the total sample ($\beta = -.113$, $t = -1.001$, $p = .320$); the corresponding slope for the restraint manipulation ($\beta = .020$, $t = .100$, $p = .921$) and the control condition ($\beta = .035$, $t = .176$, $p = .862$) were not significantly different from that of the total sample. Additional adjustment for demographics, BMI and past month consumption of snack foods revealed a main effect of EF on grams of snack food consumed ($\beta = -.213$, $t = -2.078$, $p = .042$), as well as a two-way interaction between the manipulation effect and EF for the facilitation group only ($\beta = -.304$, $t = -2.548$, $p = .013$; Cohen's $f^2 = .106$). Overall, those performing in the bottom half on the EF composite in the facilitation condition consumed 28.57% more snack food than those in the top half of EF performance in the same condition (see Fig. 3).

Discussion

The current investigation examined the extent to which restraining versus facilitating cues moderated the effects of EFs on observed consumption of appetitive but unhealthy snack foods in two age groups. Findings across both studies indicated that weaker EF performance predicts higher consumption across cue conditions, but that such effects are strongest in the presence of facilitative cues. Specifically, in Study 1, those with weaker EF consumed 58% more than their relatively stronger EF counterparts when semantic cues were facilitating; in Study 2, using visual cues, the corresponding number was 29%. The main and interactive effects involving EF were robust to adjustment to demographics, body composition, and past snack consumption. Together, the findings suggest that EFs may have larger effects on snack consumption in relatively permissive environments.

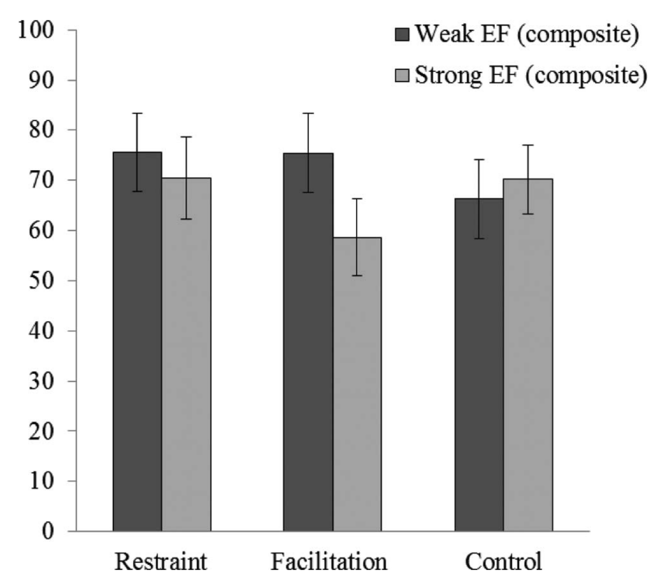

Figure 3. Snack food consumption (grams) of low- and high-executive-function (EF) participants under restraint, facilitating, or neutral visual cues. $N = 79$ young adults; marginal means are estimated at the mean covariate value for the sample. The terms “weak” and “strong” in relation to EF represent relative differences rather than absolute values.

These results replicate prior findings using the taste-test paradigm to examine semantic cues in young age groups (Hall et al., 2013) and extend them to include visual cues and older adult samples. As a result, it is possible to draw conclusions about cues in general and their possible influence on the expression of executive control of dietary behavior and to generalize to both young and older adult age groups. The findings also add to the growing body of research linking EFs to dietary behavior more broadly (Allan et al., 2010; Hall, 2012; Fregni et al., 2008; Lowe et al., in press). It is interesting to note that in the current investigation, the effects of EF on snacking behavior are smaller (about half the effect size) in Study 2 (visual cues) than those in Study 1 (semantic cues). The reasons for this are unclear, but it could be that younger adults have a more restricted range of EF or that the effect of visual cues is indeed smaller than more explicit semantic cues. Future research will be required in order to examine this question more directly.

Despite the similarity of effects across studies, there are some discrepancies within Study 1 that warrant mention. Specifically, with respect to the consistency of the SST effects, the SST does not appear to fall on the same inhibitory factor that the Stroop and GNG did; this could be for a number of reasons, including idiosyncrasies in response distribution characteristics, as well as the possibility that SST assesses perseveration more so than pure inhibition. In both studies, it not possible to rule out the possibility that presentation of the foods initially may have somehow influenced EF performance or that other unmeasured confounds might explain some of the interactions involving EF (e.g., literacy, subjective hunger level). Future studies might benefit from using normed measures of EF to make norm-referenced identification of high and low EF participants, and using larger sample size to ensure adequate power to detect interaction effects involving all EF measures. It may also be useful to explore the potential role of other cue types including social cues on the expression of EF in dietary behavior.

With respect to interpretation of findings, it is important to note that the moderating effect can be interpreted in more than one way. For theoretical reasons, we are interested in the role of cues on the expression of executive control, vis-à-vis their role in establishing prepotency for a given behavior. For this reason, we interpreted the interactions in both studies as implying that cue type moderates the relation between EF and snacking behavior. However, it is equally possible to interpret EF as a factor that modulates the effect of cue type on behavior. That is, for those with weak EF, situational cue type matters more. There is no statistical method for disentangling these alternative possibilities, and certainly both are equally interesting from a health promotion perspective.

Strengths and Limitations

Strengths of the current investigation include the use of objective measures of snack food consumption, experimental manipulation of environmental cues, careful employ of expectancy reduction procedures (i.e., the taste test cover story), and the use of standardized measures of EF. The findings also provide replication and extension of previously published findings in a different age group (Study 1) and different modality of cue presentation (Study 2), which increases confidence in the reliability of the findings and their generalizability. Limitations include the limited sample size in Study 1 and the fact that we did not manipulate EF in either study. The lack of direct manipulation of EF limits the causal inferences that can be made about EF in relation to snack food consumption. However, we have recently documented causal effects of EF using this same taste-test paradigm (Lowe, Hall & Staines, 2014).

Conclusions

In conclusion, the current findings suggest that older adults are generally responsive to environmental cues with respect to snack food consumption: They tend to eat significantly less when cues are restraining and significantly more when cues are facilitating. Likewise, individual differences in EF appear to predict how much consumption takes place in this age group; however, the effects of EF are amplified mostly in the presence of facilitating cues. In the case of younger adults, a similar picture emerges, such that those with stronger EF consume less snack foods than their weaker EF counterparts, with most of this difference emerging under conditions of facilitating cues. With respect to the latter, across studies, it appears that both semantic and visual cues influence the expression of EF in snacking behavior, though the former may be more potent than the latter. The findings of the current studies are in keeping with several contemporary theories of health behavior that incorporate neurocognitive factors, including temporal self-regulation theory (Hall & Fong, 2013). Temporal self-regulation theory posits that EF should be most influential when prepotency for snacking is high, as would be the case when unrestrained consumption is cued. Findings are also consistent with prior studies linking EF to snack food consumption and weight gain in experimental and observational study contexts (e.g., Allan et al., 2010; Hall, 2012; Lowe et al., 2014; Nederkoorn et al., 2010).

Implications

Given that the effects of facilitating cues may generalize to ecologically valid visual cues used in advertising, there may be significant public health implications for the current findings. For example, limiting exposure to facilitating cues may be important for those with relatively weaker EF integrity when they are attempting to regulate their snack food consumption. It appears that this is especially true among older adults who have more EF variability.

Likewise, in order to facilitate good dietary self-control, EF optimization may be an important objective for both younger and older adults. There are a number of routes to EF optimization, including physical exercise (e.g., Colcombe et al., 2004; Liu-Ambrose et al., 2010), brain-training paradigms (e.g., Anguera et al., 2013; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008), and social stimulation. Among these, physical exercise is perhaps the most well-established (Colcombe & Kramer, 2003; Smith et al., 2010) and is probably the most ideal choice, given that it has a host of other physiological and psychological benefits that the other options do not have. Broadly speaking, it may be that EF-enhancing activities (whatever the modality) may be important components of dietary behavior interventions that aim to limit consumption of highly appetitive (but highly unhealthy) snack foods, particularly in the context of environments that are facilitating in nature.

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Received December 27, 2013
Revision received June 2, 2014
Accepted June 5, 2014 ■