Power of Food ModeratesFood Craving, Perceived Control, and Brain Networks Following a Short-Term Post-Absorptive State in Older Adults

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Abstract

The Power of Food Scale (PFS) is a new measure that assesses the drive to consume highly palatable food in an obesogenic food environment. The data reported in this investigation evaluate whether the PFS moderates state cravings, control beliefs, and brain networks of older, obese adults following either a short-term post-absorptive state, in which participants were only allowed to consume water, or a short-term energy surfeit treatment condition, in which they consumed BOOST®. We found that the short-term post-absorptive condition,in which participants consumed water only, was associated withincreases in state cravings for desired food, a reduction in participants' confidence related to the control of eating behavior, and shifts in brain networks that parallel what is observed with other addictive behaviors. Furthermore, individuals who scored high on the PFSwere at an increased risk for experiencing these effects. Future research is needed to examine the eating behavior of persons who score high on the PFS and to develop interventions that directly target food cravings.

Keywords

aging; brain networks; food; cravings; self-efficacy

With the twofold increase in obesity over the past 20 years(Flegal, 2005) and the fact that older adults have not escaped this epidemic(Villareal, Apovian, Kushner, & Klein, 2005),there is an increased urgency to better understand the etiology of eating behavior in this population. This problem is particularly timely given the *Graying of America* will occur

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Declaration of Conflicting Interests The authors declare that they have no conflicts of interest with respect to their authorship or the publication of this article.

over the next 15–30 years(Manton & Vaupel, 1995). In response to this need, we examine how either a short-term post-absorptive state, in which participants were only allowed to consume water, or a short-term energy surfeit treatment condition, in which they consumed BOOST®, influence older adults'(a) craving for desired foods, (b) self-regulatory beliefstowards controlling eating behavior, and (c) brain networks. A question of particular interest iswhether these responses are moderated by scores on the Power of Food Scale (PFS)(Lowe et al., 2009).

Lowe and colleagues(Lowe et al., 2009) have shown that people differ in the drive to consume highly palatable food withinobesogenic food environments; a characteristic assessed using the PFS. These authors found that the PFS was significantly related to the disinhibition (r = .61) and hunger scales (r = .63) of the three factor eating questionnaire, as well as the emotional and external eating subscales of the Dutch Eating Behavior Questionnaire, r = .54 and r = .66, respectively. Within the appetite literature, Clark and colleagues (Clark, Abrams, Niaura, Eaton, & Rossi, 1991) have proposed that participants' confidence in their ability to resist eating due to internal states and external circumstances represents an important cognitive dimension of self-regulation.Despite favorable findings withthis construct (Linde, Rothman, Baldwin, & Jeffery, 2006; Rejeski, Mihalko, Ambrosius, Bearon, & McClelland, 2011; Richman, Loughnan, Droulers, Steinbeck, & Caterson, 2001), recent work by Nordgren and colleagues has argued that health cognitions are unstable and profoundly influenced by visceral states such as hunger and appetite (Nordgren, van der Pligt, & van, 2008; Nordgren, van, & van der Pligt, 2009). Because our interest was studying responses to two different short-term post-absorptive states, one with water and a surfeit treatment condition with BOOST®, we employed a brief state-based measure of confidence for controlling eating behavior ($CCEB_{state}$) that was developed in line with work by Bandura (1986) and a measure of state craving developed by Cepeda-Benito and colleagues(Cepeda-Benito, Gleaves, Williams, & Erath, 2000).

Finally, Alonso-Alonso and Pascual-Leone(Alonso-Alonso & Pascual-Leone, 2007) have proposed that dysfunction in the right prefrontal cortex (PFC) is a root cause of obesity. That is, rather than the appetitive drive per se being the cause of overconsumption, they argue that it is the inability of the right PFC to effectively self-regulate eating behavior. Central to the current investigation is the well documented effect that the craving to consume food increases with exposure to(Kelley, Schiltz, & Landry, 2005) and the active imaging of food cues(Pelchat, Johnson, Chan, Valdez, & Ragland, 2004), increases in cravingthat werefound to be related to activation in the hippocampus, insula, and caudate.

Therefore, in this study,we sought to determine whether scores on the PFS would be related to the $CCEB_{state}$ and state cravingsfollowing two different short-term post-absorptive states, one in which participants were allowed to consumewater only and a second surfeit treatment condition in which participants consumed BOOST®. Research has shown that liquid meal replacements are an effective strategy for curbing short term hunger (Mattes & Rothacker, 2001). The hypothesis was that individuals scoring high on the PFS would exhibit a substantial increase in food craving and a loss of control related to eating behavior as compared to those scoring low on the PFS, and that this effect would be magnified in the short-term post-absorptive treatment condition in which participants consumed water only.

Additionally, we examined brain networks after repeated exposure to food cues expecting that the short-term post-absorption state, in which participants consumed water only, would most likely yield changes in the brain regions associated with craving, particularly increased connectivity in the basal ganglia and insula (Pelchat, Johnson, Chan, Valdez, & Ragland, 2004), and that these effects would be accentuated for those scoring high on the PFS. We also predicted that alterations in basal ganglia connectivity would be associated with

changes in motor system connectivity as a reflection of food-seeking motivation. Parenthetically, we focused on the sensorimotor cortex because of the conceptual nature of the research question. That is, we manipulated sensory cues (i.e., palatable food) and reasoned that individual difference in the drive to consume palatable food (i.e., the PFS) would increase activity in sensorimotor networks.

Engaging external environmental cues, as promoted by the food cue manipulation employed in the current study, can result in alterations in the activity and connectivity of the default-mode brain network (DMN), since this network represents the resting state of the brain (Gusnard & Raichle, 2001; Raichle et al., 2001). The brain areas that make up the DMN include precuneus/posterior cingulate extending into the medial temporal lobe, anterior cingulate/medial prefrontal cortex, and bilateral occipito-parietal cortices. Furthermore, it has recently been demonstrated that the posterior cingulate/precuneus portion of this network is one of the most highly connected regions in the brain and serves as a brain network hub for the DMN(Hagmann et al., 2008; Sporns, Honey & Kotter, 2007). Therefore, the posterior cingulate/precuneus region was selected as the primary region of interest for this sub-network and we anticipated that there would be greater disruption of this region in the short-term post-absorptive state with water only, particularly for those scoring high on the PFSdue to a lingering preoccupation with the food cues(Kavanagh et al., 2005).

Methods

Participants

A sample ($n = 22$) ofobese (BMI ≥ 30 kg/m^2 but ≤ 40 kg/m^2), sedentaryolder adults (50–80 years of age) was recruited from Forsyth County, NC.All were Caucasians and were excluded if they were either actively dieting orinvolved in more than 60 min of structured exercise each week. Active dieting was defined as currently involved in a research study of weight loss, participating in a commercial weight loss program, or engaging in a self-directed program to lose weight. Structured exercise was any structured type of aerobic or resistance training performed in bouts lasting ≥ 10min. Both active dieting and structured exercise habits were assessed via interview. Other exclusion criteria included: (1) the presence of a systemic uncontrolled disease or psychiatric illness determined via self-report, (2) a binge eating disorder, (3) the inability to safely undergo magnetic resonance imaging, (4) currently undergoing active treatment for cancer, or (5) unable to read or speak English. Of the 22 that were randomized to treatment, 3 were unable to complete the study leaving a final n of 19. One individual was lost due to complications from preexisting back-pain, another became claustrophobic during the first day of scanning, and the third had a large artifact in the prefrontal region of the fMRI. Participantsreceived $225 to compensate for their time commitment.

Measures

Power of Food Scale (PFS)—The PFS assesses the drive to consume highly palatable food in an obesogenic food environment (Lowe et al., 2009); higher scores are associated with a higher drive. The total score has been shown to have good test-retest reliability (r = 0.77), is internal consistent (α = 0.91), and support exists for its construct validity(Lowe et al., 2009). Three subscale scores can be calculated: food available, food presence, and food tasted. Because the total score has such high internal consistency, we felt justified in restricting our attention to this single score of the PFS. Furthermore, examination of the separate subscales for the PFS fell beyond the scope of the current study.

Food Craving Questionnaire (*the*FCQ$_{state}$)—The FCQ$_{state}$assesses state craving for specific foods using a 5-point scale (1 = strongly disagree; 5 = strongly agree) with the mid-

point being anchored by the label *neutral*. The $FCQ_{state}$is based on a unifying construct and has a Cronbach alpha of 0.94. The $FCQ_{state}$is distinct from the concept of Food Restraint and has been found to exhibit a statistically significantly reductioncompleted prior to and then following breakfast(Cepeda-Benito et al., 2000).

Confidence for Controlling Eating Behavior ($CCEB_{state}$)—We developed a 4-item measure of self-efficacy for eating behavior for the consumption of favorite foods that is state-based (Bandura, 1986). Participants rate their confidence in being able to resist or control eating their favorite food right now, at this moment. The items are rated on a 10 point scale ranging from 0 "not at all confident" to 10 "very confident", with the anchor "moderately confident" spanning the values from 4–6 and centered at 5. The four items include the following: (1) if available, I could resist eating my favorite foods; (2) at the current time, I feel like I have good control over my appetite; (3) at the moment, I feel as if I could restrain myself from eating foods that I enjoy; and (4) currently I feel that I could avoid snacking between meals.In this sample, a principal component analysis yielded a single dimension that captured 78.4% of the item variance. All factor loadings were in excess of 0.80 with a Cronbach alpha reliability of 0.90.We have also examined the dimensionality of this measure in a larger sample of college students and found nearly identical results. Specifically, in a sample of 111 college undergraduates, 48 men and 63 women, we found that a single factor accounted for 72% of the variance in the 4 items that all items had loadings in excess of 0.70; the 4-item scale had a Cronbach alpha internal consistency reliability of 0.87.

The Interview for the Diagnosis of Eating Disorders (IDED-IV)—The semi-structured interview described by Kutlesic and colleagues(Kutlesic, Williamson, Gleaves, Barbin, & Murphy-Eberenz, 1998) was employed to exclude participants with a binge-eating disorder.

In-Person Screening & Assessments

An in-person screening visit was completed to obtain an informed consent, to gather biometric data, to assess whether participants were currently dieting, to assess volume of structured physical activity, and to screen for binge eating disorders. At this time participants were asked to both identify and rate the pleasantness of their two favorite foods. Eligible participants completed the PFS and were scheduled for two imaging visits (7–10 days apart).

Experimental Protocol for the Two Scanning Visits

Participants completed two, early morning 4-hour visits beginning around 8:00 am. During each visit, participants consumed a prepared breakfast: 350 calories for females; 450 calories for males. The breakfast meals were designed by a staff nutritionist to provide a heart healthy balance of macronutrients consisting of approximately 25% fat, 15% protein and 60% carbohydrate. Participants were allowed to choose macronutrients from a menu of options. Following breakfast, participants completed baseline assessments of the $FCQ_{state}$and the $CCEB_{state}$. They then were not allowed to consume any food for 2.5-hours. During this period of food restriction, participants were only allowed to consume water and remained in the research center to be monitored by nursing staff. Approximately 45-min before the imaging procedure, participants completed an MRI safety form,if necessary a lense fitting procedure to correct for poor vision, and were then instructed and given practice on the task to be performed during the fMRI.

Once the fMRI forms and protocol had been described, participants either consumed a can of BOOST® (the short-term energy surfeit condition—240 calories) or consumed an

equivalent volume of water (the short-term post-absorptive condition with water only)—NO BOOST®. They then completed a second round of the FCQ_{state} and $CCEB_{state}$. The food restriction manipulation was counterbalanced. Specifically, 10 participants were randomly assigned to receive the BOOST® meal on their first visit, whereas the other 10 received the NO BOOST® manipulation; for the second visit, participants received the opposite treatment from the one that they received on the first visit.

Food Cue Scanning Task

Participants wore goggles in the scanner that were directly interfaced with a computer screen. The task that they performed involved the visualization of words that were presented on a computer screen for 30-sec each. There were two word blocks and 6 words in each block representing either 2 different neutral stimuli or 2 different favorite foods identified during the in-person screening. Within each block, the words were presented in random order with the restriction that each of the four words was presented at least once in each block. Each block lasted 5 min and 20 sec with a 20 sec visual cross fixation period preceding and following each word.

The instructions for the visualization phase of the task were as follows: "During the task, you will see words on the screen in front of you. Some of these words describe your favorite foods and others are non-food related. Each time a word appears, I want you to think about that word and what it represents. So, for example, if the words `baked potato' appeared, imagine the ingredients that you like to put on the potato, see the steam coming out of it, think about how it smells, its texture, and how it would taste. I want you to try to use as many senses as possible to come up with the best image you can. Hold on to that image for the entire time that the word is on the screen. Now, I want you to do the same thing for the non-food words. So, if the word `desk' appears, where is it? How many drawers does it have? Is the wood dark or light? Is it rough or smooth? Once again, hold onto that image for the entire time it is on the screen. Between each word, you will see a cross on the screen. During this time do not think about anything in particular, just focus on the cross. In addition, at two different times during the task, you will be asked to provide ratings of (1) your hunger, (2) craving for your favorite food, and (3) how vivid the image was. You will see your response to these scales using computer images that appear in your goggles."

Immediately following each block, participants provided rating for their hunger, level of craving, and vividness of the images using visual analogue scales ranging from 0 ("not at all") to 100 ("extreme"/"very well"). After completing the two-blocks of words and follow-up questions, participants were asked to simply lie quietly in the scanner and to focus on the cross for a final period which lasted 5 min and 20 sec. This post-exposure resting scanning period was used to examine brain networks.

Scanning Protocol

All scans were performed on a 1.5 T GE scanner using an 8-channel neurovascular head coil (GE Medical Systems, Milwaukee, WI, USA) and included anatomic imaging, perfusion imaging, two runs of fMRI with a food visualization task, and a post-exposure resting fMRI to evaluate differences in brain networks between the two treatment conditions and as moderated by scores on the PFS.

Functional images for the network analyses measured changes in the T2*-relaxation rate that accompany changes in blood oxygenation.The T2* signal is sensitive to changes in blood oxygen content. As brain activity changes the oxygen content of the blood in the same area also changes. Thus, the T2* signal is an indirect measure of changes in neural activity (Ogawa et al., 1990). Functional imaging was performed using multi-slice gradient-EPI (TR

= 2000 ms; TE = 40 ms; field of view = 24 cm (frequency) × 15 cm (phase); matrix size = 96 × 86, 40 slices, 5 mm thickness, no skip; voxel resolution = 3.75 mm × 3.75 mm × 5 mm. The subjects performed no task but were asked to keep their eyes open looking at a fixation cross for the 5 min 20 s resting fMRI scan.

Statistical Analyses

The self-report data was analyzed using SAS Proc Mixed which allows testing of both fixed and random effects and inclusion of both subject level and individual measure level covariates and interaction terms. The random subject effect allows for covariances between the repeated measures within a given subject. The model we tested included (a) the baseline measure of the outcome variable for each subject assessed after breakfast prior to each experimental treatment(a covariate), (b) a fixed effect for treatment (BOOST® versus NOBOOST®), (c) the subject's score on the PFS, and (d) the interaction between treatment and the PFS that was entered as a vector. Order effects was tested in preliminary analyses and found to be non-significant.

Imaging Processing and Network Analyses—Prior to generating brain networks, all scanning images were realigned and normalized to standard space using FSL (Smith et al., 2004).The time courses were extracted for each voxel in gray matter based on the Automated Anatomical Labeling atlas(Tzourio-Mazoyer et al., 2002)and band-pass filtered to remove signals outside the range of 0.009–0.08 Hz (Biswal, Yetkin, Haughton, & Hyde, 1995; Fox et al., 2005). Mean white matter, CSF, and motion correction parameters were regressed from the filtered time series to account for physiological noise. A correlation matrix was then produced by computing Pearson correlations between all possible pairs of voxels (~21,000 voxels). This produced a 21,000 × 21,000 matrix with each cell (ij) representing the partial correlation coefficient between nodes i and j. A threshold was then applied to the correlation matrix and all cells that surpassed this threshold were assigned a value of 1. Remaining cells were set to zero. The threshold was defined such that the relationship between the number of nodes and average number of connections at each node was consistent across subjects to produce an adjacency matrix. Specifically, the relationship $S=\log(N)/\log-(K)$ was the same across subjects as described previously (Hayasaka & Laurienti, 2010). For this paper, the threshold $S = 2.5$ was used. All remaining analyses were performed using the binary 21,000 × 21,000 adjacency matrix.

To assess network organization, two separate types of analyses were performed. The first type of analysis evaluated the number of connections between a region of interest (ROI) and the remaining brain voxels. The analysis used the pre- and post-central gyri as defined in the AAL as the region of interested. The first order connections (i.e. areas directed connected to the ROI) were assessed by counting the number of connections between the ROI and each voxel. Second order connections (i.e. connections one link away from the ROI) were assessed by counting the number of connections each brain voxel had with the first order connections. Direct connections to the sensorimotor cortex were very similar across conditions and groups, whereas second order connections revealed interesting findings. Given that the sensorimotor cortices are primary processing regions, it is not surprising that only minor differences were noted in first order connections. However, as one moves away from the primary cortices, differences in network connectivity become apparent. Thus, the results presented here focus on the second order connections from the sensorimotor cortex. Direct connections to the sensorimotor cortex were virtually identical and are not discussed.

The second type of analysis evaluatednetwork community structure. A network community, or neighborhood, is a group of nodes that are more highly interconnected with each other than they are with other neighborhoods in the network. Neighborhoods were identified using

the modularity metric proposed by Newman(Newman & Girvan, 2004) using a spectral portioning algorithm(Ruan & Zhang, 2008).Group neighborhood consistency maps were generated using scaled inclusivity (SI) according to the method of Steen and colleagues (Steen, Hayasaka, Joyce, & Laurienti, 2011). The neighborhood consistency maps are derived such that the outcome is a spatial distribution showing the areas that belong to a particular neighborhood. This is a multivariate problem where membership in a community for any one voxel is dependent on the relationships between all voxels. Traditional statistical tests cannot be used due to the multivariate nature of the data. The most common method used to evaluate group community structure is to average the correlation matrices across subjects and generate a single neighborhood map. Unfortunately, such averaging does not maintain the network structure typical of the individual subjects (Simpson, Moussa, & Laurienti, in press). Thus, we prefer to use methods that demonstrate the consistency across subjects (Moussa et al., 2011; Burdette et al., 2010) and have recently demonstrated that SI effectively captures the community structure in known networks without observer bias (Steen, Hayasaka, Joyce, & Laurienti, 2011). While the SI maps are quantitative, the reader may want to view the images in a qualitative fashion to evaluate the spatial representation of the consistency of the particular community of interest. The values in each voxel (color-coded in the figures) represent how consistently across the group any one voxel belonged to the neighborhood in question. While not a traditional statistic, one can consider the value of each voxel as the confidence, relative to all other voxels, that it belongs to the neighborhood in question.

Results

Descriptive data for the sample can be found in Table 1. The success of the BOOST® manipulation is supported by the statistically significant treatmentdifference in the 3-item FCQstate hunger subscale score following 2.5h of food restriction; hunger was higher in the NO BOOST® [Mean (SE) = 8.30 (0.76)] than BOOST® condition [6.15 (0.61);Mean Difference = 2.12; $\underline{t}$ (19) = 2.33, $\underline{p}$ = .03). It is important to note, however, that ratings of hunger were not excessive in the NO BOOST®treatment condition given that the minimumscore for hunger subscale of the FCQ hunger is 3 and the maximum is 15. This is why it is best to conceptualize the NOBOOST ® condition as a short-term post-absorptive state, in which participants were only allowed to consume water, and the BOOST® condition as a short-term energy surfeit treatment condition, in which they consumed BOOST. Of interest is that fact that ratings of hunger and cravings on the 100 unit VAS scales during the presentation of food cues in the scanner werealso higher in the NOBOOST® condition than in the BOOST® condition: M (SE) for hunger = 64.87 (6.78) and 32.80 (6.61), respectively [t (19) = 4.47, p <.001]; for craving the M (SE) were 60.19 (7.39) and 42.75 (7.69), respectively [t (19) = 2.64, p = .016]. In addition, participants' reported a relatively high degree of vividness for the imagery of the food and non-food cues during the fMRI protocol, although the cues were reported to be somewhat more vivid in the NO BOOST® condition: M(SE) for NO BOOST® and BOOST® conditions were 87.21 (2.41) and 83.47 (1.98), respectively [t (19) = 2.19, p = .044].

The $M \pm SD$ for the PFS total score was 2.76 (1.05). It is also interesting to point out that BMI was not found to be related to scores on the PFS ($r = .29$, $p = .21$); however, the PFS had a strong relationshipwith scores on the IDED-IV, $r = .65$, $p = .002$.

Treatment Effects on Food Craving and Self-Efficacy

Separate mixed model ANCOVAs were employed to examine data for the FCQ$_{state}$ and the CCEB$_{state}$. For the food craving model, the baseline covariate was significant ($p < .001$) and there was a main effect for the PFS ($F(1, 17) = 5.31$, $p = .03$) and a marginal PFS by treatment interaction term ($F(1, 17) = 3.95$, $p = .06$). The main effect for the PFS indicated

that, averaged over the BOOST® and the NO BOOST® treatments, those with higher PFS scores had higher FCQ_{state} scores than those scoring low on the PFS. Table 2 provides estimates of treatment differences at 4 different values of the PFS—the average, 1.0, 2.0, 3.2, and 4.6. Note that participants with average values on the PFS or higher—3.2 and 4.6—had higher FCQ_{state} scores (i.e., higher cravings) on the day that they did not consume BOOST® as compared to the day they did consume BOOST®. No such difference was observed for low scores on the PFS. This pattern in the data is consistent with associations between the PFS and FCQ_{state} within each treatment condition: $= .36$ ($p = .11$) with BOOST® and $r = .57$ ($p = .009$) in the NO BOOST® condition. Moreover, when correlating PFS scores with ratings of hunger and craving during the fMRI protocol, the relationships were higher in magnitude and statistically significant in the NOBOOST® condition as compared to the BOOST® condition: $r = .46$ ($p = .05$) for hunger and $r = .58$ ($p = .008$) for craving in the NOBOOST® condition; $r = .22$ ($p = .35$) for hunger and $r = .36$ ($p = .12$) for craving in the BOOST® condition.

For the $CCEB_{state}$ measure, there was a significant effect for the baseline covariate ($p < .001$). More important, there was a significant PFS by treatment interaction term ($F(1, 17) = 7.97$, $p = .01$). As shown in Table 3, participants scoring at the average value of the PFS and those scoring above—3.20 and 4.60— had significantly lower $CCEB_{state}$ scores (i.e., lower perceived self-control) when in the NOBOOST® as compared to the BOOST® condition, a pattern that makes sense give that low score on the $CCEB_{state}$ describe contexts in which people lack control. Once again, this effect was consistent with the lack of a relationship between PFS scores and the $CCEB_{state}$ while on BOOST®, $r = -.19$ ($p = .43$), yet the moderate relationship observed between these two variables in the NO BOOST® condition, r = −.56 (p < .01).

Network Analyses

As shown in Figure 1, the neighborhood connectivity of the cerebellum included consistent interactions with the basal ganglia and thalamus in the NOBOOST® condition; this effect was particular prominent for participants that scored high on the PFS. In addition, this latter subgroup also exhibited a high connectivity between these regions and the visual cortex.

Figure 2 shows the network neighborhood for the sensorimotor cortex. This neighborhood was focused upon the pre- and post-central gyri that represent the primary sensory and motor cortices. The neighborhood also included the medial and lateral premotor areas anterior to the primary cortices. The neighborhood was highly interconnected in the NO BOOST® condition for both study populations. In the BOOST® condition the low PFS group showed a dramatic loss in consistency in this neighborhood, an effect not observed in the high PFS group. This change in neighborhood consistency suggests that the sensorimotor cortex was engaged in novel network connectivity in the BOOST® condition for the high PFS group.

Because the precuneus is the hub of the default mode network (DMN) (Hagmann et al. 2008), a 12 mm spherical region of interest was placed in this region to calculate the average number of connections in each subject and condition. The mean connectivity in the precuneus was then compared with an independent t-test to compare groups and a dependent t-test to compare conditions within groups. The analyses revealed that connectivity was significantly increased in the Low PFS group following BOOST® compared to NO BOOST® (p = 0.04). In addition, the Low PFS group on BOOST® had higher connectivity (p=0.05) than the High PFS group on BOOST®. Other comparisons were not significant. The connectivity maps shown in Figure 3 reflect those areas that were within one step of the sensorimotor cortex. The red circle in Figure 3 highlights the precuneus. Examination of the precuneus across the four panels reveals that only older adults' who consumed BOOST®

and scored low on the PFS had high connectivity between the sensorimotor cortex andthis region. This suggests that the liquid meal replacement was effective in allowing the brains of these older adults to return to the default-mode after exposure to food cues. Not so for those participants who scored high on the PFS. Despite being fed a liquid meal replacement, their precuneus was not within one connection of the sensorimotor region. This pattern was consistent with connectivity between the medial prefrontal and orbital frontal cortex (green arrows) and the insula (yellow arrows), suggesting that these older adults are predisposed to process internal cues related to food and that these cues dominate conscious thought, a hypothesis that is consistent with responses to the FCQ and the $CCEB_{state}$ completed just prior to entering the scanner.

Discussion

Following ashort-term post-absorptive state in which participants were only allowed to consume water (NO BOOST®),we observed that state cravings (FCQ_{state}) were higher and confidence for controlling eating behavior ($CCEB_{state}$) lower thanon the day that participants'consumeda BOOST® supplement—an energy surfeit state. Moreover, the effect was greater among those scoring high as opposed to low on the PFS. This finding extends the work of Lowe and colleagues(Lowe et al., 2009) in demonstrating that obese participants who score high on the PFS experience a reduction in their self-regulatory efficacy when exposed to favorite food cues 2.5h into a short-term post-absorptive state in which participants are allowed to consume water only.Indeed, it would appear that the PFS does assess the strength of the appetitive drive for palatable foods in the absence of an energy need. This reduction in self-efficacy was accompanied by increases in food craving and both effects were substantial in magnitude as supported by the shared varianceofthe PFS with both $CCEB_{state}(r^2 = 31\%)$ and $FCQ_{state}(r^2 = 32\%)$ in the NOBOOST®treatment condition.

A unique feature of this study is the data collected on brain networks. As a number of authors have suggested, food cues are capable of triggering changes in the brain that are common to addictive agents such as cocaine and nicotine(Pelchat et al., 2004; Lowe & Butryn, 2007). Within the current study, two general points deserve comment. First, in the NO BOOST® treatment condition, the neighborhood connectivity of the cerebellum included consistent interactions with the basal ganglia and thalamus, particularly for those scoring high on the PFS; moreover, these neighborhood areas were connected with the visual cortex.Research with cats has reported that stimulation of the cerebellum leads to eating behavior(Berntson, Potolicchio, Jr., & Miller, 1973),whereas the mesocorticolimbic dopamine pathway appears to be particularly important to wanting(Robinson & Berridge, 2003)and drug addiction (Grant et al., 1996). Furthermore, in their elaborated intrusion theory of desire,Kavanagh and colleagues(Kavanagh, Andrade, & May, 2005) argue that sensory images are especially important to craving because they are networked with and stimulate the sensory and emotional qualities of the target being craved. These findings suggest that individuals who score high on the PFS may be prone to binging episodes and to consuming disproportionate amounts of palatable food even though they may not have a binge eating disorder.The relationship of the PFS to the IDED-IV certainly suggests that this pattern of behavior warrants further empirical study.

Second, we found that in the BOOST® condition the brains of participants who had scored low on the PFS returned to their default-mode network. This was not true of those who scored high on the PFS and was consistent with the connectivity observed between the medial prefrontal and orbital frontal cortex and the insula, suggesting that participantsscoring high on the PFS are predisposed to process internal cues related to food and that these cues dominate conscious thought(Kavanagh et al., 2005), a hypothesis that is consistent with responses to the $FCQ_{state}$and the $CCEB_{state}$ completed just prior to entering

the scanner. The insula has been described as the primary gustatory cortex (Simon, de Araujo, Gutierrez, & Nicolelis, 2006), is active during the presentation of food cues (Wang et al., 2004), and has been found to be related to the anticipation of food consumption (Stice, Spoor, Ng, & Zald, 2009).

This study is not without limitations. The target sample was restricted to an older, obese population that was not currently dieting. To our knowledge, the PFS has not been validated with older adults and it is not known if responses to food cues are age-dependent. Also, it is possible that responses may have differed if participants wereinvolved in an active weight loss intervention. Second, the current methods enabled us to examine resting networks after exposure to food cues but <u>not</u> network activity during actual exposure to food and neutral cues. This is due to the fact that the food cues and neutral cues were presented in the same experimental run. Thus, at the current time, we do not know whether the observed effects in brain networks were due to the post-absorptive state itself or to actively imaging food cues. We are currently in the process of performing a follow-up study using a design that will allow the use of network analyses during both food cue exposure and neutral cue exposure. And third, because we did not have a normal weight control group, we cannot draw conclusions about whether the findings from this study are dependent on the obese status of our participants. Nonetheless, the brain network data are compelling, make use of cutting-edge technology, and offer strong support for the utility of the PFS in conjunction with state-based assessments in the study of eating behavior.

In summary, wedemonstrate that exposure to palatable foods even in the absence of an energy need is associated with increases in state cravings for desired food, a reduction in self-regulatory self-efficacy, and shifts in brain networks that parallel what is observed with other addictive behaviors. Clearly, individuals who score high on the PFSare at an increased risk for experiencing these effects; in fact, the consumption of food does not totally mitigate the "intrusion" that food cues have on the brain networks of this subgroup. Future research is needed to examine the eating behavior of persons who score high on the PFS and to develop interventions that directly target food cravings in this subgroup. Although one approach to treatment would be to encourage several small meals across the day to help contain their food cravings, we believe that mindfulness-based interventions warrant consideration since they have proven effective in treating obsessive-compulsive behavior(Schwartz, 1996) and analogies have been drawn between this disorder and the preoccupation and elaboration of food cues that occurs during extreme episodes of desire and craving(Kavanagh et al., 2005).

Acknowledgments

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Brief restriction from foodincreases cravings and lowersself-regulatory beliefs.

Brief restriction from food alters brain networks, suggesting food is addictive.

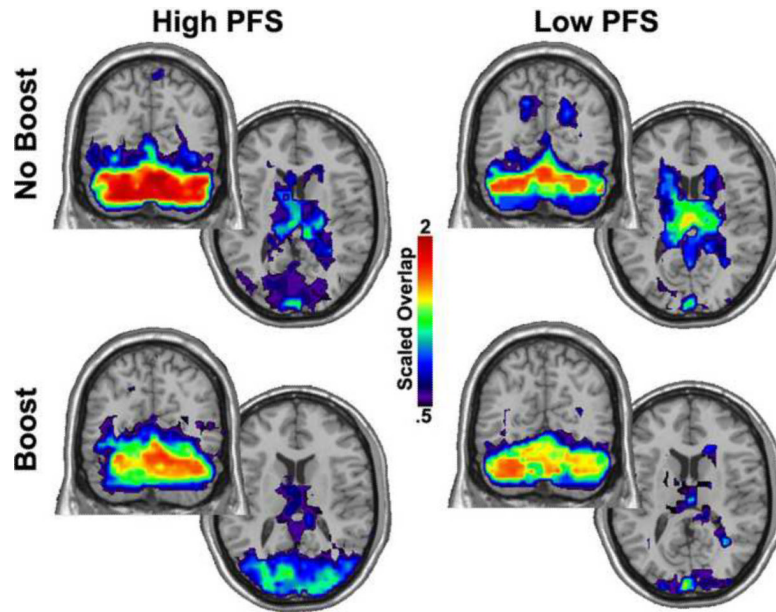Scores on the*Power of Food Scale* moderated the observed effects.

Figure 1. Neighborhood of the cerebellum by PFS category
The figure shows a single coronal slice through the cerebellum and an axial slice through the basal ganglia and thalamus. The color bar represents the SI value (described in methods) scaled by population size. This is a relative value that indicates the consistency of the community structure across subjects. Note that the basal ganglia and thalamus are consistently in the cerebellum neighborhood in the NO BOOST condition. A larger extent of visual cortex is in the cerebellum neighborhood in the High PFS group. Also note the reduction in consistency of the cerebellum itself in the High PFS group from the NO BOOST condition to the BOOST condition. Right side of the images represents the right side of the brain in this and all subsequent images.
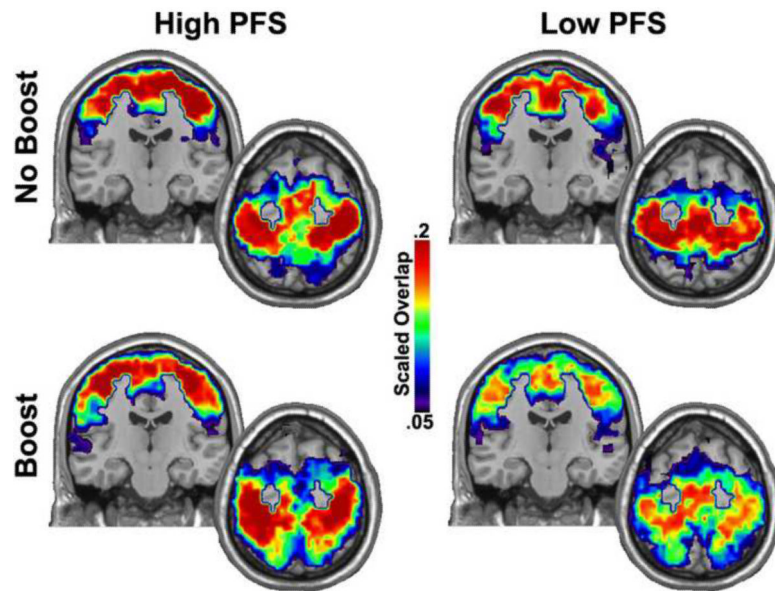
Figure 2. Neighborhood of the sensorimotor cortex by PFS Category
These Images show an axial and coronal slice through the sensorimotor area including medial regions. Also, note that the neighborhood extends anterior into premotor regions. Both groups exhibit consistent organization within this spatially focused neighborhood. There is a relative reduction in the consistency across subjects in the Low PFS group in the BOOST condition. The color bar represents the SI value (described in the methods) scaled by population size.
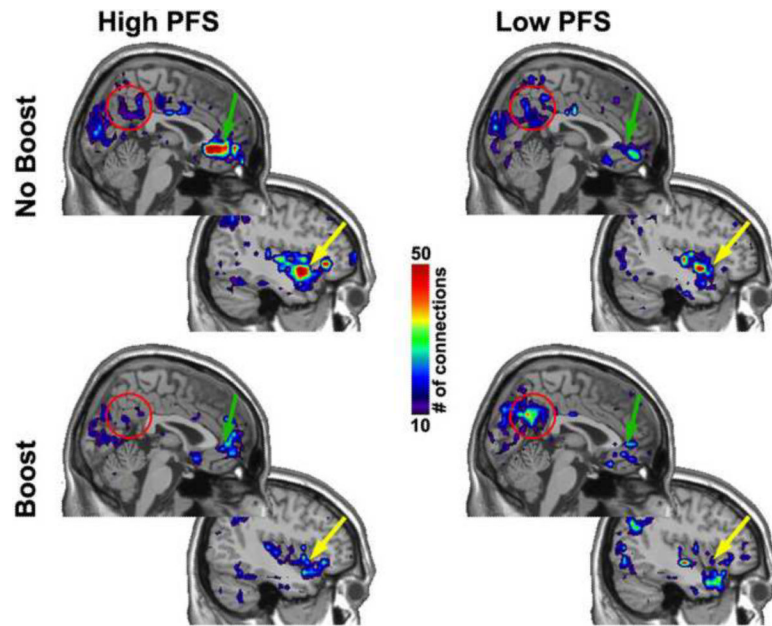
Figure 3. Maps showing the connectivity to sensorimotor cortex
These maps show two sagital slices. The upper left image is directly at midline and the other image is sliced through the insular cortex on the right side of the brain. Results on the left were virtually identical and therefore are not shown. Colored regions show the areas that are within one link of sensorimotor cortex based on functional networks. Calibration bar shows the average number of connections across subjects.

Table 1

Descriptive Characteristics of Participants

Characteristic		Mean (±SD) or N (%)
Age		64.65 (±6.84)
Sex		
	Men	8 (40%)
	Women	12(60%)
Education		
	High School	8 (40%)
	4-year College	6 (30%)
	Post-Graduate	6 (30%)
Income (annual)		
	<$35,000	6 (30%)
	$35,000–$49,999	4 (20%)
	$50,000–$74,999	5 (25%)
	>75,000+	5 (25%)
BMI (kg/m2)		33.97 (±2.67)
Weekly Exercise (min)		7.75 (±14.18)
Smoking History		
	Never Smoked	18 (90%)
	Past Smoker	2 (10%)
Comorbidities		
	Cardiovascular	5 (25%)
	Hypertension	12 (60%)
	Arthritis	8 (40%)
	Diabetes	4 (20%)
	Cancer	2 (10%)

Table 2

LS Mean Treatment Differences in State Craving by PFS Scores[*]

PF Score	Estimated Treatment Difference	Standard Error	t Value	p Value
2.76[**]	7.12	2.34	3.05	.007
1.00	−0.86	4.64	−0.19	.855
2.00	3.68	2.90	1.27.	.223
3.20	9.12	2.54	3.58	.002
4.60	15.47	3.21	13.21	.005

[*] The least square mean treatment differences, standard errors and associated tests are directly derived from the SAS Proc Mixed procedure which allows for both random (here subject) effect(s) and the aforementioned "fixed" effects of treatment, baseline covariate, PFS and the PFS*treatment interaction. Note that the estimated treatment difference varies with PFS because of the PFS*treatment interaction. As in regression, standard error of the treatment difference is smallest at the average value (2.76) of the regressor (i.e., the Power of Food Scale). The values chosen other than the mean were selected to represent the distribution of the scores.

[**] The mean score for the Power of Food Scale.

Table 3

LS Mean Treatment Differences in Self-Efficacy by PFS Scores

PF Score	Estimated Treatment Difference	Standard Error	*t* Value	*p* Value
2.76 *	−15.61	3.97	−3.93	.001
1.00	3.59	7.90	0.45	.655
2.00	−7.32	4.95	−1.48	.158
3.20	−20.41	4.31		.0002
4.60	−35.68	8.12	−4.39	.0004

*
represents the mean PFS Score; PFS = Power of Food Scale