Passing clouds move over static coloration patterns (Figure 1A). The basic components of these patterns include local light and dark features, such as lines, squares and spots, as well as more global mottles and stipples [3]. The European cuttlefish has about 35 such components, while *Metasepia pfefferi* has about 17 [5]. The expression of chromatic components is co-ordinated to produce about a dozen body patterns, which are used for camouflage and communication [3,6–8]. Much as human faces can combine our basic expressions of emotion, for example happiness and surprise, or fear and disgust, body patterns can be combined with great potential for versatility, allowing subtlety in camouflage design and visual signalling.

Within this repertoire of patterns, the passing clouds are fascinating and enigmatic. They appear in all the main cephalopod groups: squid, cuttlefish and octopus, often with wavelength comparable to the body length and a frequency of about 1 Hz, moving either forwards or backwards. Their function is not clear: they are sometimes used when hunting, and it has been suggested that they may 'hypnotise prey' [4]. European cuttlefish use passing clouds when swimming, and although they are conspicuous they may prevent predators from judging the animal's velocity, like an enhanced version of military 'dazzle' patterns [9]. *Metasepia tullbergi* has an exceptionally complex display, the dark bands pass over four contiguous regions on each side of the body, each with a separate point of origin. When they are expressed in more than one region the waves are synchronised. The waves can move at a ten-fold range of speeds but keep a constant wavelength, which means that one band is normally visible in each region at any time. The waves can also 'blink', transiently disappearing from a patch of skin. These observations suggested that the 'passing clouds' are generated by central pacemakers, rather than (or perhaps in addition to) the myogenic waves that generate 'wandering clouds' [1,5] (Figure 1B).

Interestingly, Laan *et al.* [1] argue that the waves may be related to more conventional oscillatory movements, such as those used for swimming. This ties nicely with the finding that localised electrical stimulation of the optic lobes of the cephalopod brain (Figure 1B) can cause the animals to express familiar body patterns or to produce locomotor behaviour [5]. By comparison, the chromatophore lobes, which lie downstream of the optic lobes and contain the chromatophore motor neurons, seem a less likely centre for wave generation, because they seem to lack a somatotopic organization — neighbouring motor neurons do not project to neighbouring points on the body — which would allow them to propagate travelling waves across the skin [5].

A special appeal of cephalopods is that they are perhaps the nearest we will get to intelligent life from another planet. They have independently evolved vertebrate-like complexity, doing some things much like fish — or ourselves — and others very differently. What little is known offers much promise in the understanding of chance and necessity in brain evolution.

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Obesity: Cognitive Impairment and the Failure to 'Eat Right'

A recent study has found that obese women (but not men) have difficulty inhibiting food-rewarded, but not money-rewarded, appetitive behaviour, suggesting that obesity is associated with cognitive deficits that could selectively promote food intake, perhaps in a sex-dependent manner.

Terry L. Davidson[1] and Ashley A. Martin[2]

> *"If we could give every individual the right amount of nourishment and exercise, not too little and not too much, we would have found the safest way to health"*
>
> (From Hippocrates (460-377 BC) *Hippocratic Writings*. Chicago: Encyclopedia Britannica, 1955).

The prescription for health offered by Hippocrates more than 2000 years ago continues to be sound advice. Most of us are aware that failing to follow it can result in excess weight gain and increased risk of heart disease, type II diabetes, hypertension, stroke, and cancer. Indeed, it may be difficult to find anyone who doesn't know that they should "Eat right and exercise". Yet we are now in the midst of a global obesity pandemic. An obvious question is why millions of overweight and obese people are unable to eat right (i.e. less)? The findings reported in this issue of *Current Biology* by Zhang *et al.* [1] offer an answer to the question of why eating 'right' has become so difficult.

Zhang *et al.* [1] trained obese and normal weight men and women on two simple discrimination problems with different colored visual cues serving as discriminative stimuli for reward and nonreward. Half of the participants were trained with food rewards and

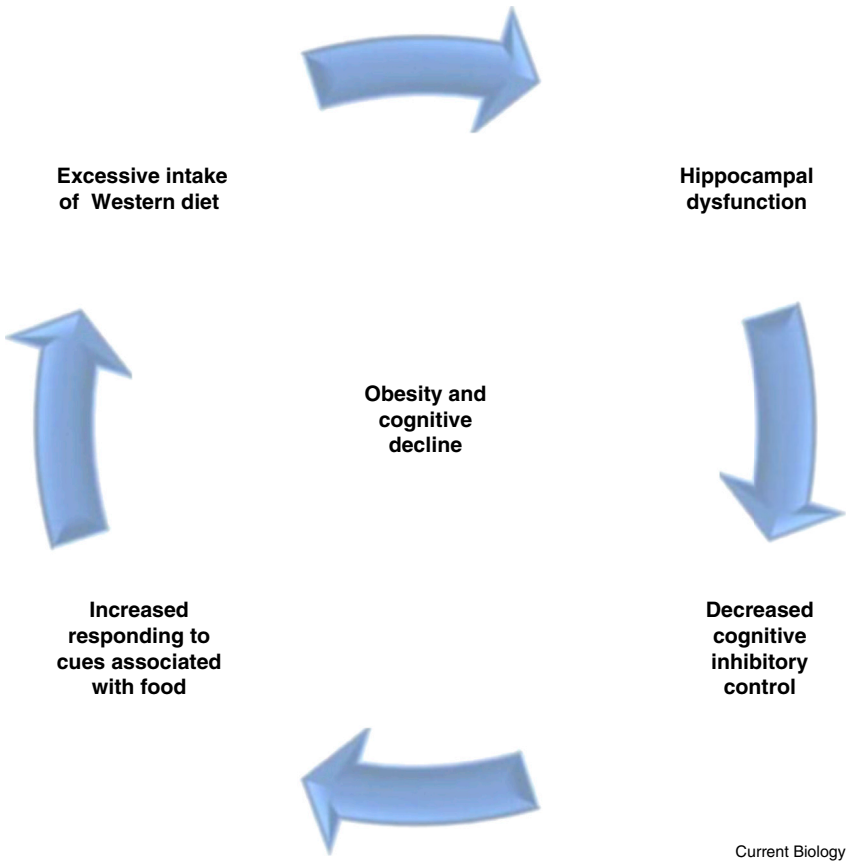

Figure 1. The 'vicious cycle' model of obesity and cognitive decline.

This vicious cycle model suggests that eating a Western diet — i.e. one high in saturated fats and sugar — produces pathologies in the hippocampus that interfere with the inhibitory control of eating behavior, thus reducing the ability to resist the power of environmental cues associated with food. This may ultimately result in overeating, excess weight gain, and more severe forms of cognitive impairment. (Adapted from [10,17].)

the rest were trained with monetary rewards. At the end of training, the discriminative contingencies were reversed for both the food-rewarded and money-rewarded conditions. With these procedures, the authors compared the ability of the participants to form simple cue–reward associations, as well as their ability to update their learning (that is, inhibiting previously learned cue–reward associations and learning new ones). The results showed that obese women were impaired in solving both phases of the discrimination when they were trained with food rewards, though *not* when they were trained with monetary rewards. In contrast, men were not impaired at solving either phase of the discrimination with either type of reward, regardless of their weight status. A regression analysis indicated that for females, higher body mass index (BMI), a common index of overweight and obesity, was significantly associated with poorer performance on the food-rewarded problem. Demographic variables (age, education level, income) were not significantly related to discrimination performance. The impairment shown by obese women was largely characterized by an inability to refrain from responding to the non-rewarded cue in the food-rewarded problem.

Impaired Learning and Impaired Weight Control

Previous research has identified a number of cognitive impairments that could weaken the ability to inhibit eating and regulate body weight (for a review see [2]). For instance, a reduced ability to recall what we've eaten in the recent past can make it difficult to keep track of our daily calorie intake, increasing our likelihood of overeating [3,4]. Likewise, deficits in cognitive-inhibitory control can make it difficult to refrain from thinking about food and from paying attention to the many cues related to food in the environment. These deficits could make it more difficult to resist the temptation to eat.

The results of Zhang *et al.* [1] provide new evidence that obesity is associated with cognitive deficits in humans that could potentially perpetuate, if not cause, overeating. Specifically, their findings suggest that obese females may have difficulty learning to inhibit their food-rewarded appetitive responses even in the presence of signals for nonreward. It seems likely that this deficit could also contribute to excess intake and weight gain. Indeed, it may be that a weakened ability to inhibit one's responses is one factor that prevents people from 'eating right' (i.e. controlling their intake) when confronted with highly palatable, energy-dense foods and the abundant cues that are associated with the pleasures of consumption.

Sex-dependent Effects of Obesity on Food-rewarded Behaviour

Zhang *et al.* [1] observed that obese women, but not obese men, were impaired in learning to solve their relatively simple discrimination problem. These findings underscore the importance of considering sex differences when investigating the links between cognition and body weight regulation. Of course, overeating and obesity are problems that affect men as well as women, and previous research indicates that being overweight or obese is associated with cognitive deficits in males [5,6].

To interpret Zhang *et al.*'s [1] findings, it should be kept in mind that there are many types of behaviours, stimuli, and learning and memory processes, in addition to simple discriminations, that are potentially involved with the regulation of eating and body weight [2], including several distinct mechanisms that could underlie the inhibition of appetite. The extent to which obesity is associated with sex-dependent deficits in these other types of cognitive processes is a topic that requires further study.

The finding that the same effects of obesity were not obtained with monetary rewards is intriguing and also merits further investigation. Other studies have reported inhibitory impairments in non-food paradigms [7,8] including tasks that have used monetary rewards [9]. It may be that rather than reward type *per se,* the food and monetary rewards used by Zhang *et al.* [1] differed in perceived magnitude or on other psychological dimensions. This could be the basis for the behavioral differences that were reported. It is also possible that the relationship between obesity and type of reward depends on task parameters or on the particular type of cognitive process that is measured.

Obesity and Changes in Brain Substrates for Cognition: A Vicious Cycle

Obesity and the consumption of obesogenic diets high in saturated fats and sugar (Western-style diets) are linked, not only to deficits in learning and memory processes, but also to signs of pathology in brain regions that underlie those processes [10]. In rats, consuming these diets is accompanied by inflammation, increased intrusion of microglia, and reduced levels of brain-derived neurotrophic factor in the hippocampus, a brain structure known to be a substrate for several learning and memory functions [11]. Intake of these diets also produces increased permeability of the blood-brain barrier and elevations in concentrations of potentially harmful substances in the hippocampus. These signs accompany impaired hippocampus-dependent learning and memory functions, including the ability to use certain types of cues to inhibit appetitive responding.

There is also ample evidence of diet- or obesity-induced impairments in human cognitive function [12]. For example, intake of diets high in saturated fat was found to be negatively correlated with performance on a hippocampal-dependent relational memory problem in children as young as 7–9 years old [13]. At the other end of the age continuum, mid-life obesity and intake of Western-style diets have been linked with increased incidence of cognitive dementias [14,15]. The hippocampal formation is also a foci for pathologies that are associated with these disorders [16].

The results of Zhang *et al.* [1] are consistent with findings from non-human animal models which show that consuming high-energy, obesity-promoting diets is associated with both brain pathologies and impaired learning and memory functions — impairments that could make it more difficult to inhibit appetitive and consummatory responses. We and others have proposed that impaired inhibition of these responses may be part of a 'vicious cycle' of obesity and cognitive decline, characterized by increased caloric intake, progressive deterioration of brain function, and impaired inhibition of appetitive behaviours which leads to further increases in intake and ultimately excess body weight gain (Figure 1). While research in our laboratory and elsewhere [10,17] has investigated the implications of this model with respect to hippocampal-dependent learning and memory processes, it may also have application to other brain structures and functions that play a role in both cognition and the regulation of intake [18]. The findings of Zhang *et al.* [1] emphasize the need to know more about the neural structures and circuits that underlie the cognitive control of eating.

Conclusion

The paper by Zhang *et al.* [1], along with other recent research on the relationship between obesity and cognitive function, provides an answer to the question of why so many people have been unable to follow the advice to 'eat right' as a means of achieving and maintaining a healthy body weight. It may be that many people are unable to follow this advice because the cognitive controls that normally help to put the brakes on intake are failing. This view suggests that one approach to the complex and pervasive problem of obesity is to make the brain structures that underlie these cognitive functions the targets of new therapeutic interventions.

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