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**Liking vs. wanting food: Importance for human appetite control and weight regulation.**

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## Introduction

According to the French National Nutrition-Health Program (2001-2005) it is essential that an individual's food choice remains a 'free act' and that eating is recognised as a moment of pure pleasure. In order to fully appreciate these premeditated episodes of sensuality, it is not sufficient to focus only on the hedonic sensations arising from events in the mouth. The joy of eating can be as much to do with the preparation and effort that one invests in their chosen food and of course the expectancy and anticipation that intensify then peak in the final moments before ingestion. In summary, the pleasure of food can be seen as an interaction of liking and wanting, and experiencing one without the other – although pleasurable in isolation – stops short of full reward.

Advances in neurobiology are helping to characterise the substrate mediating hedonic processes of consumption, and they are precipitating the emergence of a new conceptual approach to reward where affect and motivation (a.k.a. liking and wanting) can be seen as the major force in guiding human eating behaviour. This concept is especially important for the study of ingestive behaviour in the modern world, where food is plentiful, cheap, energy-dense, and enticing, and physical activity is being reduced to a luxury afforded by environment and lifestyle. We have reached an age where weight control has been turned upside down from an instinctual, highly regulated system, to a process requiring considerable cognitive effort (Peters et al. 2002). Furthermore, where overweight and obesity have taken hold, losing weight and defending that loss (especially in an environment where our hedonic drives are encouraged and exploited) can change from a daily struggle, to a losing battle (e.g. Ikeda et al. 2005).

Parsing reward from a unitary process into distinguishable liking and wanting components in neurobiological studies (Berridge & Robinson, 2003) has struck a chord that is resonating across many disciplines and in different areas of research. In the field of ingestive behaviour alone it has implications for characterizing eating disorders and obesity, identifying pharmacological targets, the psychology of appetite control, phenotypic profiling of resistance and susceptibility to weight gain, and industrial product development. Despite the possibilities of a dual process modulation of food reward, several issues remain to be addressed: How can these concepts be operationalised for use in human appetite research? Can they be translated into observable entities that reflect the neural mechanisms by which they may be

influenced? Do liking and wanting operate independently to produce functionally significant changes in behaviour? Can liking and wanting be truly separated or will an expression of one inevitably contain elements of the other? In this review, current progress in applying processes of liking and wanting to the study of human appetite and ingestive behaviour are examined and the importance of these concepts for human appetite research are discussed.

#### Neurobiological study of liking and wanting

Our capacities in neuroscience can reveal – to some extent – the circuits responsible for the reward we derive from food. The picture emerging is that food reward, rather than being a unitary neurological entity, is represented functionally and structurally by distinct components. One such distinction, between processes associated with affective vs. motivational consequences of ingesting food, has received much recent attention (Berridge, 1996). With principle focus on opioid neurotransmission in the nucleus accumbens shell and the mesolimbic dopamine system, research has shown that core processes of ‘liking’ and ‘wanting’ can be separately manipulated in rodent models to produce patterns of behaviour that are either exclusively affective or motivational in conjunction with a food stimulus (see <http://www.lsa.umich.edu/psych/research&labs/berridge/Publications.htm> for a comprehensive list of publications).

#### How is liking measured?

In its simplest description, ‘liking’ is most commonly operationalised as the change in affect observed using a technique to analyse taste reactivity patterns in rats (Grill & Norgren, 1978). This involves a careful assessment of hedonic and aversive behavioural reactions thought to be universal affective expressions, some of which can also be observed – allowing for speed and body size – in primates and human infants (Berridge, 2000). Taste reactivity patterns are thought to provide a relatively pure indication of affect because they can be isolated from the sensory properties of a taste (see Berridge, 2000), they can be dissociated from the desire to eat (e.g. Berridge & Valenstein, 1991; Berridge et al. 1989) and they often correspond to human subjective ratings of palatability.

#### How is wanting measured?

If liking is operationalised as the pattern of reactive behaviours associated with affective aspects of food reward, then wanting is commonly measured by changes in the propensity to eat that are independent of shifts in liking. Therefore, any measure that requires the subject to actively engage with its environment in pursuit of a known food stimulus can be said to contain at least an element of wanting. It is worth emphasising at this juncture however that wanting (specifically termed by some as incentive salience attribution) is not adequately captured by appetitive drive or the non-specific desire for food in general. Wanting is hypothesised to be the consequence of an active process of assigning value to perceptual or representational events wherein sensory and cognitive inputs are transformed into desirable, attractive entities (Berridge, 1996). Hence wanting is likely to be modulated by sensory and/or cognitive influences which set it apart from other appetitive processes (e.g. needing). Wanting implies a direction, not just a force. Therefore, obtaining a measure of wanting that can be dissociated from a non-specific drive to eat (e.g. see Beagley & Holley, 1977 as cited in Berridge, 1996) can become awkward when a further separation from liking is required. In passing, the investigation of specific food cravings may provide a useful platform from which to further clarify these processes (e.g. Robinson & Berridge, 1993; Robinson & Berridge, 2000 Pelchat, 2002). Nevertheless, the more satisfactory measures of wanting concern the anticipatory or instrumental phase of reward seeking behaviour.

#### Implicit and explicit components

Through the separate examination of specific neural substrates in the brain, behavioural measures of liking and wanting are thought to reflect 'core' processes that can operate without conscious awareness. However, these implicit components clearly have their explicit counterparts which express themselves subjectively in the form of hedonic feelings from the ingestion of a specific food (conscious liking) and the intent or desire to consume a specific food (conscious wanting) (Berridge & Robinson, 2003). Therefore it is important that we know how core liking and wanting (operating at implicit and explicit levels of conscious awareness) might relate to influence behaviour.

Berridge (2004) used the term 'niceness gloss' (the pleasantness added by the brain to the sensory qualities of sweetness) in reference to the explicit component of liking, with implicit liking and its associated brain structures forming an unconscious core.

In this review, implicit liking was presented as capable of producing objective reactions without subjective awareness of their underlying cause. For instance, the subliminal presentation of picture stimuli (positive, neutral or negative facial expressions) caused no change in self reported mood ratings, but the emotional valence of the stimuli was positively associated with pleasantness rating, consumption and rated value of a beverage (Winkielman et al. 2005).

As explained above, the implicit component of wanting is linked to the attribution of 'incentive salience' to external stimuli. Explicit wanting (truer to the colloquial understanding of the word), has been described as the conscious desire for a cognitively represented outcome (Berridge, 2004). Interestingly, implicit wanting has also been shown capable of producing objective reactions independent of any subjective awareness (Berridge, 2004). For instance, it has been demonstrated that animals can show 'irrational wanting' for food rewards. In one study, activation of the dopamine system caused a reward cue (conditioned stimulus) for sucrose to become a hyper incentive, temporarily outstripping the reward value of the sucrose presented alone or with an irrelevant cue (Wyvell & Berridge, 2000). Such findings support the hypothesis that implicit wanting can be a more compelling influence on behaviour than explicit (conscious) wanting (Berridge, 2003).

In summary, liking and wanting are viewed as core processes with implicit and explicit features. Explicit liking (acutely perceived hedonic reaction) can be associated with explicit wanting (subjective desire for a perceived goal) and implicit wanting (incentive salience attribution). Implicit liking (unconscious affect) can also influence implicit wanting to influence ingestive behaviour without the subjective awareness of either process. Lastly, wanting can be irrational when implicit wanting for a reward is greater than explicit wanting, and not proportional to the experience or expectation of liking (e.g. Wyvell & Berridge, 2000).

#### From core processes to constructs in human appetite

If core processes of liking and wanting can independently modulate food reward both implicitly and explicitly, it is important to understand how they can be approached and rendered suitable for the study of ingestive behaviour in humans. Even to date, the role of food reward in human appetite is mostly treated as a single entity embodied by a 'palatability' or 'pleasantness' factor and its effects on appetite control (Yeomans, 1998). The logical view is that liking and wanting co-vary in a natural

two-way sequence. Therefore in behavioural terms we assume that a change in liking – e.g. through manipulating palatability – will lead to proportional adjustments in wanting – e.g. amount of the commodity consumed (Bobroff & Kissileff, 1986; Yeomans et al. 1997), and likewise changes in wanting – e.g. indirectly, through manipulating hunger and satiety – will effect changes in liking – e.g. hedonic response (Cabanac, 1979; Carr & Wolinsky, 1993). A dissociation of liking and wanting in the brain suggests that this self-evident liking↔wanting sequence may not always hold true, and this could throw new light on the way human ingestive behaviour is understood.

Translating liking and wanting into constructs amenable to the study of human ingestive behaviour has a number of obstacles, and most concern the accuracy and accessibility of our subjective consciousness. Firstly, our feelings may not do justice to the complexity of their underlying processes. For example, is the hedonic strength of a response a consequence of one underlying dimension (e.g. pleasantness) or a convergence of two (e.g. pleasantness and unpleasantness) or three (e.g. pleasantness, unpleasantness, and salience) or numerous other dimensions? Affective taste reactivity in rats and infants can simultaneously assess hedonic (i.e. positive) and aversive (i.e. negative) aspects of affect (Berridge, 2000), but asking humans to introspectively provide the same information may be too contradictory and confusing. In human appetite research, it has been suggested that distinct sets of underlying processes can be interpreted as a single more general variable which is only then partitioned cognitively into the required domains (Booth, 1987). The distorting potential of cognitions on affect is cautioned by Berridge (Berridge, 1996) where the accuracy of actively reconstructing emotional events is vulnerable to excessive cognitive processing. Hence – paradoxically – the more someone is encouraged to consider their feelings, the less reliable their responses may become. However, introspectionist constructions of underlying processes can refer to unconscious experiences as well as those in conscious awareness (e.g. hunger, craving, fullness, thirst), but it must be remembered that this method can only reveal a causal relationship between the construct and the behaviour for the elements of the experience that are explicit and subjective (Booth 1987a; Booth 1987b; Booth & Blair 1988). An adequate resolution of this problem requires more than the examination of these constructs and their behavioural correlates. In the case of liking and wanting, the utility of introspective constructions can only be judged in the context of their

interaction with objective mental/behavioural outputs and the ability to distinguish these from other environmental contingencies (e.g. Booth 1990). Alternatively, measures that are able to better reflect the unconscious components of these constructs or are less reliant on the cognitions of the subject, or are specifically designed to test for the dissociability of distinct underlying processes, could greatly facilitate a dual-process approach to the study of reward in human appetite research.

#### Reward and appetite control: homeostatic and hedonic interplay

A key issue in the study of appetite control is the relationship between reward and homeostatic drives arising from biological needs (Yeomans et al. 2004). Historically, hedonic processes have been viewed as a function of nutritional need-state. In a state of depletion, the hedonic response (experienced palatability) to energy providing foods is enhanced and when replete, the hedonic effect of these foods is reduced (Cabanac, 1989). This view is compatible with the link between energy density and palatability (Drewnowski, 1998) and also that the consumption of fats and sugars – rich sources of energy – may be under neuro-regulatory control (Levine et al. 2003). However, the idea of reward as a consequence of the fulfilment of nutritional need is not broad enough to explain non-homeostatic ingestive behaviour (non-compensated patterns of over or under consumption) and it is perhaps more useful to try and distinguish the neural substrates of homeostatic and hedonic systems and to assign them separate identities (Blundell & Finlayson 2004).

#### Homeostasis and hedonics: Separate identities...

The homeostatic substrate comprises a network of neuropeptides and biogenic aminergic neurotransmitters which link peripheral and central components. This system has been well characterised (e.g. Schwartz et al. 2000) and involves insulin, leptin, NPY, AgRP, MSH, CART, GLP-1, orexins, ghrelin, PYY, and other peptides along with serotonin pathways and other aminergic systems. A biological substrate mediating the reward processes of consumption is also being characterised and ostensibly involves glutamate, benzodiazepines, endocannabinoids, opioids and dopamine pathways (e.g. Saper et al. 2002; Flier, 2004). The implication of distinct neural substrates for homeostatic and hedonic systems is that processes of reward can operate free from biological need, and the extent to which this occurs can be

investigated. For example, pharmacological evidence suggests that these circuits are somewhat separate. In obese subjects, administration of the serotonin drug D-fenfluramine suppressed the sensation of hunger but had no effect on the appreciation of the pleasantness of food (Blundell & Hill, 1987). Conversely, an opioid antagonist reduced the rated pleasantness of palatable foods but had no effect on hunger (Yeomans & Gray 2002). This double-dissociation concept indicates that hedonic aspects of reward are associated with a specific biological substrate that can be pharmacologically dissected from the substrate-mediating hunger (Rogers & Blundell, 1991). This is supported by evidence from animal studies. In one study (Giraud et al. 1999), saline (control), NPY or an opioid agonist (DAMGO) was injected into the paraventricular nucleus of rats. The rats could freely consume from standard chow and 10% sucrose solution. After injection of NPY, food intake was increased relative to saline, and the rats were found to consume approximately half their calories from the chow and half from the sucrose solution. Injection of DAMGO also stimulated intake, but in this condition 85% of calories came from the sucrose. Therefore, NPY and opiates may represent a demarcation between energy-driven versus reward-driven feeding. However, it is still possible for a functional interaction to occur when the manipulation is made through the natural commodity (food) rather than through more selective pharmaceutical manipulations.

...or inseparable entities?

Advances in our understanding of the molecular and neural mechanisms behind appetite regulation are revealing how the reward system can interact with homeostatic mechanisms. As mentioned above, cannabinoid receptors and their endogenous ligands (e.g. anandamide) are implicated in the reward system. Peripheral and central administration of anandamide increased appetite in rodents, and this seemed to be related to alterations in incentive value (desire) for palatable foods (Kirkham & Williams, 2001). However, the cannabinoid system has been shown to interact with homeostatic processes in a number of ways (Stanley et al. 2005): Leptin signalling becomes defective when hypothalamic endocannabinoid levels are high (Di Marzo et al. 2001); activation of CB1 receptors prevent the melanocortin system from altering food intake (Verty et al. 2004); furthermore, CB1 receptors can be found on adipocytes where they may directly increase lipogenesis (Cota et al. 2003). Opioid neurotransmission also forms part of the biological substrate mediating reward

processes of consumption. For example, endogenous opioids are associated with the reinforcing effect of food (especially when palatable) (Welch et al. 1996; Yamamoto et al. 2000). However, there is evidence to show that in a fasted state, the reinforcing effect of food can be reinstated in enkephalin and  $\beta$ -endorphin knock-out mice (Hayward et al. 2002). Therefore, homeostatic processes may interact with hedonic signalling to override selective reward deficit. Erlanson-Albertsson (2005) summarised how ingestion of palatable food can offset normal (homeostatic) appetite regulation. In the brain, research shows that energy deficit is registered in the hypothalamus leading to the release of hunger signals and the activation of their receptors. Consumption of 'standard' food generates information on its energy content and taste in the brain stem. This information is transmitted to the hypothalamus leading to the release or upregulation of various satiety peptides, causing consumption to cease. However, a different scenario is apparent when the reward system is activated by highly palatable food. With ingestion of palatable food, taste sensing is different than with standard food; information is transmitted to the reward circuit, leading to the release or upregulation of reward mediators like dopamine, endocannabinoids, and opiates. The reward circuit has connections with appetite-controlling neurones in the hypothalamus that can increase the expression of hunger peptides such as NPY and orexins, while blunting the signalling of satiety peptides like insulin, leptin and cholecystokinin. Therefore when food is highly palatable, the drive to eat is maintained, with continued eating now mediated by reward rather than biological need (see figure 1). Hence although homeostatic and hedonic systems can be given separate identities (Blundell & Finlayson 2004), they are also – to an extent – inseparable, with neural cross-talk permitting functional interactions which may influence the organisation of ingestive behaviour. From this standpoint, the interaction of homeostatic and non-homeostatic pathways in the neuro-regulatory control of feeding may be given more importance than the two systems studied in isolation. From behavioural and anatomical observations, Berthoud (2006) suggested that projections from the hypothalamus to the nucleus accumbens may modulate the motivation to feed via metabolic signals. Furthermore, direct and indirect projections from the accumbens to the hypothalamus may explain the ability for mesolimbic processes – activated by relevant environmental cues and incentives – to essentially hijack the homeostatic regulatory circuits and drive up energy intake.

Further research is necessary to identify the pathways that mediate such interactions; however some progress has been made (see Berthoud 2004).

#### Liking, wanting and ingestive behaviour: A re-examination of selected studies

Considering that most studies have repeatedly shown that palatability – a factor influencing the reward value of food – has an effect on intake, this would support the notion that reward plays a role in the process of satiation (de Graaf, 1999). However, it is uncertain how processes of liking and wanting might independently modulate the effect of reward on appetite to influence ingestive behaviour. With a dual process perspective on reward, it becomes possible to re-examine some of the previous research investigating its impact on human appetite.

#### Intake and meal size

Manipulating the palatability of test foods is a common way to investigate how reward processes can influence ingestive behaviour. Most research using such an approach has found increased palatability to have a stimulatory effect on intake and meal size, leading some authors to propose a quantitative relationship between subjective shifts in palatability and corresponding adjustment of food intake in grams (e.g. Bobroff & Kissileff, 1986). However, differences in the palatability of foods do not provide a comprehensive indication of their reward value. In most cases a palatability manipulation (brought about by a change in the physical or sensory properties of a food) can only account for differences in liking for the food. Less can be assumed about the effects of the same manipulation on the desire or motivation to consume the food. It is interesting therefore, that a small number of studies do not find an association between palatability and food intake. For example, supplements of monosodium L-glutamate enhanced the palatability of a soup preload, but had no effect on the consumption of a test meal delivered 2 or 30 minutes later (Rogers & Blundell, 1990). Similarly, manipulation of the palatability of fat or carbohydrate based meals did not significantly decrease intake despite reduced hunger and enhanced satiety (Warwick et al. 1993). In one study, manipulated palatability of the test foods correlated to overall intake in only half the subjects (Lucas & Bellisle, 1987). Some free-living studies also indicate that the role of liking in determining meal size may not be as crucial as many laboratory studies have suggested. For instance, in obese and lean subjects, no correlation was found between liking for

preferred taste (sweet foods) and total intake of foods in that taste category, and there was very little variability between mean hedonic ratings for each taste category (sweet, savoury/salty, bitter, sour) in self-selected foods (Cox et al. 1999). Other research on free-living subjects in France and North America found a strong association between palatability and meal size, but demonstrated that over 70% of all recorded meals were rated at above neutral palatability (deCastro et al. 2000a; de Castro et al. 2000b). These studies suggest that the subjective pleasantness of meals is likely to play a role in food choice, but may be less important in accounting for the variability in amount consumed. Indeed, it is intuitive that in real life, where people have freedom of choice, palatability will be a relatively consistent factor in all meals. Therefore, in isolation liking for foods may not tell the whole story about reward driven food intake.

For example, in one quasi-experimental study, three different types of test meal (conventional four course, sandwich, and semi-liquid) at two levels of palatability (high or low) were compared after covert video recording (Guy-Grand et al. 1994). The palatability manipulation was only found to stimulate intake in the conventional meal, yet it produced comparable differences in subjective liking for all the meals. However, in the sandwich meal, bite rate was significantly greater in the lower palatability condition, and in the semi-liquid meal, pause duration was less. These behaviours seem at odds with the lower ratings of pleasantness for this level of palatability. Indeed, if bite rate and pause duration are taken as indicators of the subjects' overall motivation toward their food, then it appears that wanting was to some extent higher, despite the meals being less liked. Interestingly, studies that have employed some measure of eating rate in their methodologies have commonly found the palatability-dependent effects of rate on intake were confined to the initial stages of the eating bout (Bellisle et al. 1984; Bobroff & Kissileff, 1986; Spiegel et al. 1989; Yeomans, 1996) – presumably when motivation to eat is at a peak. Such measures may help to discern and separately track processes of liking and wanting within a meal.

#### Hunger and satiety

Previously in the literature, it has been disputed whether explicit liking may have an influence on hunger and satiety (see de Graaf, 1999). One early study (Hill et al. 1984) found an enhancing effect of an equi-caloric but preferred meal on rated

hunger. Even the sight of the preferred food increased hunger suggesting that the expectancy or anticipation of food (wanting) was stimulating appetite before liking for the food could be confirmed. Other research has found a hunger-dependent effect of palatability on intake (Spiegel et al. 1989). When lean subjects were deprived of breakfast, there was no difference in intake when offered either low or high palatability foods at lunch. When breakfast was reinstated, intake of the high palatability food was greater. One proposal is that liking is an important factor in food intake within an acceptable threshold of hunger; once this threshold is crossed, the palatability of available foods is then secondary to perceived energy requirements. Therefore, the mediating effect of liking on food intake may be overridden by potent homeostatic signals. Conversely, in a study where disguised high or low energy preloads were administered before tasty or bland test meals (Yeomans et al. 2001), subjects failed to compensate for the preloads when subsequent food was more palatable. It was argued that tasty foods prevented short-term responses to satiety cues. Thus, homeostatic signals may also be overridden by liking. However the system does appear to operate asymmetrically; although enhanced liking for foods can augment hunger (and therefore food intake), the presence of strong satiety developing over the course of a meal does not always downregulate a food's palatability (e.g. see Yeomans & Symes, 1999; Looy et al. 1992).

#### Ratings of subjective liking

Nearly all human studies interested in reward processes in appetite include some subjective measure of liking. Nevertheless, several studies have revealed that such introspective ratings may be of limited use. The most common tests involving subjective ratings of liking are brief exposure tests and fixed quantity tests. Although easy to conduct, these tests are considerably different to free-living eating situations where much larger quantities of food are eaten and in combination with other foods and drinks. Bellisle et al. (1984), Lucas & Bellisle (1987), Monneuse et al. (1991), Perez et al. (1994) and Zandstra et al. (1999) have all found brief exposure tests to give a biased estimation of the optimal palatability of a food. Zandstra et al. (1999) found consumption to correlate best with ad libitum tests and worst with taste-and-spit tests. This finding gains support from several other studies who find liking ratings alone insufficient to predict subsequent intake (Bellisle & Le Magnen, 1980; 1981; Helleman & Tuorila, 1991). This point has been explored elsewhere (Mook & Votaw

1991): By asking college students to rank or choose from a list of reasons for terminating a meal, the authors found hedonic factors to be of little perceived importance. They cautioned that studies employing subjective ratings may enhance the perceived importance of the hedonic properties of test foods that otherwise might not be considered. For instance, one study investigated repeated within meal interruptions (in order to make subjective appetite and hedonic ratings) and their effect on intake (Yeomans et al. 1997). Surprisingly, when meals were interrupted at every 50g interval of intake, overall consumption was significantly greater compared to one continuous bout of feeding. It is possible that by repeatedly eliciting a conscious, subjective evaluation of liking for available foods, the incentive salience of the food may also have been inadvertently enhanced.

#### Dual-component contributions to the study of reward in human appetite

With a dual-process model of reward, retrospective evaluation of the literature may help to throw light on the relationship between food reward, appetite and ingestive behaviour. More recently, researchers are beginning to consider liking and wanting interpretations of their own study findings and some are specifically tuning their methodologies to allow for separations of motivation and affective responding to food. These studies provide examples of how liking and wanting may be operationally defined in human appetite research.

In one study (Zandstra et al. 2000), three levels of palatable food were consumed as open sandwiches each day for three weeks (5 days repeated exposure per level of palatability). As well as measuring ad libitum food intake and subjective appetite on each day, change in rated pleasantness of the food and change in rated desire-to-eat were assessed by subtracting post-meal ratings from ratings taken after the first bite. The study found that intake on the first two days reflected the manipulated palatability of the foods, with proportional differences between low, medium and high levels. On the third day of repeated exposure, intake between the medium and high levels was equivalent, and on the fifth day, intake did not vary between any of the conditions. Similarly, ratings of fullness suggested that satiety following the low palatability food was increasing with time. On examination of ratings of pleasantness and desire-to-eat, an interesting dissociation was observed. After a considerable reduction in desire-to-eat on the first day of exposure for the low palatability food relative to the other levels, this decline dissipated after a few days and ratings for all foods became

equivalent. In contrast, the change in rated pleasantness for each level of palatability was stable over time. Therefore, the convergence of intake and satiety for three levels of palatability brought about over five days of repeated exposure was associated with changes in desire to eat (explicit wanting) and not rated pleasantness (explicit liking) for the foods. More recently, these explicit processes have also been dissociated by manipulating expectations by labelling or withholding information about fresh versus processed food (Zandstra et al. 2004). When consumed blind, foods were desired and liked similarly. However, when labelled as fresh or processed, desire for the fresh food was greater, with no change in liking. The findings of both studies may justify the importance of differentiating questions of liking and desire (explicit wanting) for foods. The authors suggested that without the opportunity to rate liking and wanting aspects of the foods separately, subjects' ratings may have contained elements of both. In other words, they thought the explicit components of each underlying process may have been interpreted as single subjective feeling.

Another study compared lean and obese subjects on their liking for an array of food products (sandwiches or snacks) in hungry and satiated states (Snoek et al. 2004). Subjects tested and rated a selection of foods before consuming one food item to fullness as an ad libitum meal. Ratings of appetite that were specific (e.g. "appetite for a meal", "appetite for something sweet", "appetite for a snack" etc.) as well as non-specific (e.g. hunger, fullness) were recorded immediately before and after a sandwich or snack 'meal'. Results showed that obese and lean subjects did not rate the pleasantness of any of the food items differently after consuming the meal. However, differences were apparent in some of the appetite ratings; specifically "appetite for a snack" and "appetite for a meal" following consumption of either snacks or sandwiches, and also "appetite for something savoury" after snack consumption. The authors speculated that obese-lean differences referred to differences in wanting and not liking, on the basis of higher perceived energy needs of obese subjects. The authors were careful however, to point out that their measures "reflect conscious, rationalised liking and wanting" (p.830). They suggested that to study the differences in obese and lean humans will require improved more objective techniques to measure liking and wanting, for example through neuroimaging techniques, or indirect methods that do not rely on subjective ratings.

One neuroimaging study (Small et al. 2001) used consecutive PET scans to track changes in brain activity as subjects consumed chocolate to beyond satiety. In this

design, subjects ate one piece of chocolate at a time, followed by a rating of how pleasant or unpleasant they found it (explicit liking), and how much they would like or not like to have another piece of chocolate (explicit wanting). Each feeding period – with a scan followed by a rest period – was determined by the amount of chocolate it took to produce a two unit decrease in rated liking. Thus, as subjects ate chocolate from a state where it was highly motivating and pleasurable, to a state where motivation to stop eating was high and chocolate consumption unpleasant, it was possible to observe the differential recruitment of brain regions as the reward value of the chocolate decreased. The study found that subjects ratings of wanting decreased faster and to a greater extent than ratings of liking, suggesting that some separation of these constructs was occurring. In order to see if these processes could be identified physically in the brain, scan order was controlled for and regional cerebral blood flow was regressed against subjective ratings of liking and wanting. It was found that activity in a region of the retrosplenial cortex correlated to a greater extent to ratings of wanting than ratings of liking. The authors suggested that this region may form part of the substrate for a dissociation between liking and wanting. Indeed, studies that incorporate objective measures of brain activity in conjunction with sensory and motivational challenges may help to further characterise separable processes of reward. As these techniques become more sophisticated it is likely that more will be understood about the connection between implicit and explicit components of reward and their influence on ingestive behaviour in more complex scenarios.

One way to overcome the difficulties of extracting reliable subjective responses may be to find alternative indirect measures of motivation or affect. For example, Saelens & Epstein (1996) assessed the reinforcing value of food using a slot-machine-like progressive ratio computer task. In this paradigm, subjects' commitment to the task was rewarded with points that could be exchanged for amounts of tasty snack food or allotments of time that could be spent playing an enjoyable computer game. The reinforcing value of the tasty food was calibrated as the willingness to work for amounts of the food relative to the time playing the game. In a study comparing obese and lean subjects, the authors found that subjective ratings of liking for snack food items – including the most preferred item used in the progressive ratio task – did not differ; however, the obese subjects were found to work harder for food relative to playing the game, and this corresponded to the amount of calories consumed. These findings confirmed earlier research associating obesity with willingness to work for

food in the presence of food cues (Johnson, 1974). These findings may also demonstrate important differences in reward-driven behaviour in these populations. Although liking for rewards may be involved in establishing their reinforcing value, it is possible for wanting to become a more significant factor in influencing ingestive behaviour (e.g. Robinson & Berridge, 1993). Furthermore, the lack of differences in subjective hunger ratings suggests that the differences in reward-driven behaviour were somewhat independent of homeostatic processes.

Using a similar paradigm, the effects of food deprivation on hedonics (liking) and reinforcing value (wanting) of foods was assessed (Epstein et al. 2003). Subjects were assigned to satiated (i.e. fed) or hungry (i.e. unfed) conditions and the subjective pleasantness of a range of drinks as well as the reinforcement value of a preferred snack item were measured before and after a satiating meal or equivalent time abstaining from food. There were no differences in temporal profiles of pleasantness between the two conditions. In contrast, the deprived subjects responded more for food on the progressive ratio task compared to fed subjects. The authors concluded that food deprivation influenced the motivation to eat, but not the hedonics of a range of drinks. These findings are consistent with a dual-component view of reward. Wanting was shown to increase under deprived conditions while liking did not change. In passing, liking was found to decrease for the most pleasant drink in the fed state. Although non-significant, this finding may reveal certain conditions (e.g. satiated) where liking can decrease independently from wanting.

In our laboratory, some progress has been made in developing a methodology to separately assess and observe dissociation between liking and wanting (Finlayson et al. In Press). We designed a novel computer-based procedure to identify liking and wanting for the same target food stimuli through separate tasks consisting of a number of response trials. These separate procedures prevented cross-contamination in the evaluation of liking and wanting. The presentation of trials for both tasks was integrated and fully randomised into a single executable program. The stimuli were a number of photographic food items selected to vary in fat content and taste (two key dimensions associated with loss of appetite control and overconsumption). In this procedure, liking is measured explicitly using visual analogue scales combined with the prompt “how pleasant would it be to experience a mouthful of this food now?” this question was designed to carefully direct attention to the (imagined) hedonic experience in the mouth at the point of ingestion, rather than a more global rating of a

foods pleasantness. In contrast, the wanting task was designed to provide an implicit measure derived from a forced choice task whereby stimuli are presented in pairs and responded to according to which food is most wanted at the present moment. The speed with which one stimulus is chosen rather than its alternative provides a quantifiable measure (reaction time) related to relative wanting for that food item. Reaction time of each decision can convey information about the degree (on a continuous, interval unit of measurement) to which a chosen stimuli is wanted relative to an alternative. Furthermore, mean reaction time for each food category can give an indication of whether motivation is increasing or decreasing independent of the other categories – in essence an implicit measure of wanting. The forced choice paradigm carries with it several advantages as an implicit measure of wanting. The visual nature of the food stimuli means that the dimensions of the categories can be simply adapted to compare motivation for innumerable combinations of food properties or specifically selected to complement a particular experimental intervention. Perhaps most crucially, the forced choice paradigm allows the concurrent measurement of both implicit and explicit elements of food reward by using dissimilar methodology to measure each process. Using the computer task, one recent study has revealed evidence to suggest that the sensory specific satiety phenomenon brought about by consumption of a standardised, uniform test meal may implicate different roles for liking and wanting in human appetite (Finlayson et al. In Preparation). We demonstrated that liking for foods in the task was reduced more for stimuli sharing properties similar to the test meal (e.g. taste), while wanting had increased for stimuli with contrasting properties. If a wanting component to sensory specific satiety exists, it may be activated or enhanced for foods with contrasting sensory properties. We suggest that the outputs of this computer-based procedure resemble and may correspond to separate processes of liking and wanting.

The studies reviewed above provide different examples of how cross-contamination between explicit measures of liking and wanting can be circumvented. Repeated exposure ratings within a bout of eating (Small et al. 2001) or over a number of days (Zandstra et al. 2001) can track separations in changes of liking or desire for a target food. Alternatively, distinguishing general appetite from appetite for a specific food category (Snoek et al. 2004) may isolate wanting from hunger. Finally, instrumental measures of motivation (e.g. Saelens & Epstein, 1996; Finlayson et al. 2007) for

target food stimuli may provide operational definitions for the concept of implicit wanting (incentive salience).

#### Further conceptual development

Parsing reward into separable components provides a parsimonious theoretical framework within which to study ingestive behaviour. However, liking and wanting are not well understood constructs in human appetite. Berridge (1996) advocated a minimal definition of these processes, opting to focus instead on their role and function through expanding empirical study. However, as more investigations start to draw on dual component theories to tackle their research questions, and interpret their findings, there is a more pressing need to expand and develop theoretical conceptualisation of these constructs. Four recent theoretical models that – through the diversity of their approach – may help to enhance a description of liking and wanting are discussed below.

#### Homeostatic-hedonic model of hunger

In a discursive paper on the controversy over dietary restriction, Lowe and Levine (Lowe & Levine, 2005) distinguish physiological or homeostatic hunger (resulting from nutritional or energy need) from psychological or hedonic hunger (reward-driven eating when not hungry), which operates “beyond the need to counteract physiological signals of energy depletion” (p.798). Although reward-driven hunger is thought to be an important factor in passive overconsumption and obesity (Blundell, 2002; Blundell & Gillett, 2001); the authors argue that both motivations are intuitively adaptive when viewed in terms of human evolution in a climate of food scarcity. Just as physiological hunger can strongly motivate food seeking behaviour in response to declining energy stores, hunger that promotes eating in the absence of an energy deficit is protective against future energy crises. Therefore, food seeking behaviour can be motivated by the presence or availability of food (especially when energy dense or palatable) as well as by genuine homeostatic need. A further implication is that restriction of wanted foods – even in the absence of an energy deficit – can cause difficulties in suppressing further food seeking behaviours, similar to a denial of food that is genuinely required. For example, “200kcal of unflavoured hot cereal might result in short term satiation whereas 200kcal of chocolate cake might not satisfy hedonic needs” (p.799). As the authors point out, the boundary

between these two processes is unclear; the point at which hunger becomes reward-driven rather than necessity-based is subject to a host of inter and intra-individual factors. The model also provides an interesting perspective on the relationship between liking and wanting. The authors note that liking is largely a learned phenomenon, and food preferences that are learned generally retain their motivational properties independent of homeostatic needs. Hence, palatability seems to be maintained by oro-sensory factors of reward rather than the energetic delivery of the ingested nutrients and separate to their perceived energy value. It is argued that food intake behaviour is more ambiguous than other reward-driven behaviours because the need to consume food is innate. Therefore, need and reward based want are likely to interact. However, this assertion can be taken further: feeding behaviour is not alone in being innate (e.g. mating, parent-child attachment), but it is a habitual behaviour that is uniquely vital to continued survival. Therefore, the motivating processes behind feeding are likely to be different to non-essential reward driven behaviours. The authors emphasise the need to differentiate these behaviours (needing/wanting vs. liking/wanting) in the study of reward. However, this issue was potentially resolved in a recent symposium on non-homeostatic behaviour (Corwin & Hajnal, 2005). The speakers developed a collection of defining principles from which feeding could be included in an operational definition for all non-homeostatic behaviour. They proposed that over- or under-eating in response to a homeostatic drive for energy is normal and will vary within a certain regulatory range (termed 'compensated non-homeostatic eating'). When over- or under-eating becomes repetitive or excessive however, this is termed 'maladaptive non-homeostatic eating'. This distinction may represent a framework in which the reward mechanisms central to all non-homeostatic behaviours can be understood.

#### Motivating operations in human appetite

Advances in the field of behaviourism have led to an update in the theoretical principles that can be applied to the study of human appetite. In an interesting review of the literature (Tapper, 2005) the concept of 'motivating operations' (MO) was discussed. The paper examines the extent to which MOs can account for different aspects of ingestive behaviour and discusses the conceptual overlap between this and liking/wanting components of reward. An MO is a motivating event, operation or stimulus that temporarily affects an organism on two levels. Firstly there is a value-

altering effect: how reinforcing or punishing a relevant stimulus is. Secondly there is a behaviour-altering effect: whether a relevant behaviour is evoked or abated (Michael, 1993). In most circumstances, value-altering and behaviour-altering MOs occur simultaneously and independently. A straight-forward example of an MO is food deprivation. This physical state acts to increase both the reinforcing effectiveness of eating (i.e. enhances the experienced pleasure, Cabanac 1989) and evokes food seeking behaviour (i.e. increases the motivation to consume). Similarly, a state of excessive-satiety would qualify as an MO; simultaneously reducing the reinforcing effectiveness of eating and the frequency of behaviours that lead to eating. Tapper points out that through behavioural analysis, it is possible to observe the independence of an MO's separate effects. In food deprivation for example, the frequency and intensity of food seeking behaviour increases prior to any physical contact with food. Hence the actual reinforcing value of the food is still unknown and cannot factor into the observed behaviour. Once oral contact is made with the food, these seeking behaviours are sometimes observed to intensify (e.g. the 'appetiser effect'; see Yeomans, 1996). This temporary increase in responding can be seen as the impact of the value-altering MO on ingestive behaviour. The author suggests that the strength of an MO's value-altering effects may not always be proportional to its behaviour-altering effects. Moreover, an MO could have value-altering effects in the absence of behaviour-altering effects. These possibilities are reminiscent of neural dissociations of liking and wanting. For example, dopamine depletion causes available food incentives to be ignored – behaviour-altering effect – but does not reduce the hedonic reaction to food – no value-altering effect (Berridge et al. 1989). Another feature of the MO model is that MOs can influence the reward value of neutral stimuli (termed discriminative stimuli, SD) that have since become associated with the availability of a reinforcer. To adapt the author's example, through repeated association with the availability of food, a photograph of a set meal on a restaurant menu (SD) may elicit some of the behaviours previously linked only to the food itself (e.g. salivation, stomach rumbling). MOs work to influence the strength of SDs, therefore, food deprivation could increase responsivity to the food photograph. From this simple scenario it is possible to envisage a situation where the presence of an MO could raise the power of an SD above that of the availability of the reinforcer alone. Consequently, in a state of energy need, the food photograph may elicit a more intense response than the actual availability of the food and disproportionate to the

reinforcing value of consuming the food. In this way, the MO model could provide a methodological platform from which 'irrational wanting' (Wyvell and Berridge, 2000) might be simulated in humans. The MO model may also help to explain some non-homeostatic ingestive behaviour. According to the approach, it is possible for environmental factors to take on motive-like properties through repeated association with an MO. For example, stimuli paired with hunger (an MO associated with homeostatic feeding) could eventually acquire similar value and behaviour altering effects even in the absence of the MO.

#### The tonic/phasic model of DA system regulation

In a paper written to inform research on craving, Grace (2000) presented a model in which aspects of drug craving can be explained by distinguishing tonic and phasic responses in the dopamine system (see figure 2). Phasic DA release refers to the action potential ('spike') dependent release of DA into the synaptic cleft. Phasic DA release is necessary for the behaviourally relevant actions of DA system activation including reward signals (e.g. Schultz, 1997; Schultz, 1998). The phasic response causes a flood of DA to be released into the synapse which under normal conditions is quickly and efficiently dealt with by re-uptake mechanisms before it can diffuse into extra-cellular space. Tonic DA release on the other hand refers to the escape of very small concentrations of DA into extra-cellular space caused by sustained increases in DA neuron firing or presynaptic stimulation of DA terminals by glutamate. Although too low to stimulate post-synaptic targets, these levels of DA are sufficient to be detected by DA terminal auto receptors that regulate DA release from the terminal. These extra-cellular levels of DA are highly regulated by feedback systems. Through their effect on the DA auto receptors, increases in tonic DA can cause the inhibition of phasic DA release (Grace 1991; Grace 1995).

Administration of potent sources of reward (e.g. psychostimulants and alcohol) differ in their mechanism of DA transmission, but what they have in common is that repeated administration causes the overflow of DA into the synapse which can result in the escape of extra-cellular DA. Since increased levels of tonic DA can diminish phasic release, stimuli that would normally be rewarding will instead produce a blunted reinforcing signal. This imbalance between phasic and tonic systems is detected by the organism which attempts to restore the equilibrium. The tonic/phasic model has interesting implications for the conceptualisation of liking and wanting.

Firstly, it is possible to envisage at the molecular level how a ‘natural’ dissociation between these processes might occur. Chronic overstimulation of the reward commodity may cause a gradual increase of tonic DA. This disequilibrium of tonic and phasic systems could be responded to via psychological drivers such as craving (a form of wanting). Consequently, food cues become more salient and food seeking behaviours are initiated. However, due to inhibited phasic response, consumption of the desired food does not produce the expected rewarding effects. In this way, liking and wanting become separated by subtle yet significant changes in tonic DA regulation.

#### Determinants of food choice model

Mela (2001; 2006) developed a model to support the assertion that desire for food – a function of innate and learned liking, internal need state, and environmental cues – can be viewed as one of the major determinants of food choice in man. Liking is constructed as the experience or anticipation of pleasure either innately present or acquired through associative conditioning. In this way, liking is seen as an essential component contributing to desire. Desire is also influenced by environmental cues such as situation and appropriateness which may increase or decrease motivation to eat – possibly through a change in anticipated liking. In this way, it is suggested that external stimuli can become integrated into a system of cues that trigger motivation for specific foods under certain conditions. The third factor thought to influence desire is internal need state. This factor refers to psychological and/or physiological needs such as hunger, thirst and specific food cravings which may also reinforce the development of liking. The author uses this model to support the notion that food liking (as an isolated factor) is not a crucial process in weight gain and obesity, as liking is often a rather stable characteristic within an individual and less influenced by weight status (e.g. Cox et al. 1999; Snoek et al. 2004). The implication is that food intake is driven in part by the stimulation or suppression of desire that incorporates, yet remains distinguishable from liking. The presence of environmental cues, strength of internal need state and degree of liking, may all modulate the strength of desire which in turn determines what (and possibly how much) is consumed next (see figure 3).

The four models discussed here provide very different perspectives on processes of liking and wanting in reward. In the homeostatic-hedonic model, wanting is viewed

as an adaptive response to the presence of rewarding food that is closely related to physical hunger stemming from nutritional need. The motivating operations account distinguishes value-altering effects from behaviour-altering effects to account for the variable impact of reward cues on food seeking behaviour and the possible dissociation of explicit and implicit wanting. The tonic/phasic model describes a possible mechanism by which wanting can be enhanced yet subsequent reward diminished through repeated stimulation of the reward commodity. Lastly, the determinants of food choice model conceptualises liking as a component of wanting, the strength of which can determine preference. All four models are compatible with reward driven (non-homeostatic) consumption, and permit a degree of independence between processes of liking and wanting. Such theoretical accounts may help to inform our understanding of how separate components of reward should be conceptualised.

#### Implication for weight gain and obesity

Thanks in part to a better understanding of the interaction of homeostatic and hedonic processes of appetite and the phenomenon of non-homeostatic consumption, reward is growing to be viewed as an significant risk factor in weight gain leading to obesity (Nasser, 2001; Yeomans et al. 2004; Blundell & Finlayson, 2004; Erlanson-Albertsson, 2005). But what is the evidence that reward may play a role in the aetiology of obesity? Some studies have implicated individual variability in sensitivity to reward (STR) – a psychobiological trait linked to the mesolimbic dopamine pathway – in the development of obesity. Davis et al (Davis et al. 2004) used the Physical Anhedonia scale (Chapman, 1976) to measure the capacity to experience reward in normal, overweight and obese patients. The authors found an inverted U relationship, with overweight subjects scoring higher (more anhedonic) than obese and normal weight. Similarly, Franken & Muris (2005) demonstrated that STR (Torrubia et al. 2001) is associated with food cravings and BMI. More recently, the STR trait has been shown to correlate strongly with activation in relevant regions of the brain in response to appetising foods relative to bland, aversive and non-food stimuli (Beaver et al. 2006). Taken together, these findings suggest that a high STR may characterise those individuals who are at risk of weight gain due to exaggerated responding to rewarding food cues. Interestingly, because Davis et al. found no differences between normal weight and patients who had become obese, STR may

represent a risk factor for weight gain (leading to obesity) without necessarily characterising an obese person. Therefore, STR could be a factor in enhancing susceptibility to weight gain, rather than a definitive trait of obese people. There is evidence to support this proposition. For example, PET scans of normal-weight healthy subjects eating a favourite meal revealed an increase in dopamine release that correlated with the degree of experienced pleasure. Another study demonstrated that the availability of the dopamine D2 receptor was decreased in very obese subjects in proportion to their BMI (Wang et al. 2001). These studies map onto the idea that there is an optimal level or inverted U relationship between the capacity to experience reward and dopamine activation (Volkow et al. 1999). Subjects administered the dopamine agonist methylphenidate found it either pleasant or unpleasant depending on their DRD2 receptor levels. Those subjects reporting pleasant effects had significantly lower levels of the dopamine receptor than those who found it unpleasant. It can therefore be construed that potent stimuli (including palatable foods) elicit a dampened positive hedonic response through the stimulation of dopamine activity in people of an anhedonic (low STR) predisposition. One way to overcome this might simply be to consume more of the rewarding commodity. However, there is no evidence to date that tests the notion that particularly hedonic individuals respond aversively to highly palatable foods. It has been suggested that dopamine activity relating to excessive food consumption might only involve activation of brain reward circuitry within normal limits, with other psychological factors exerting stronger effects (Robinson and Berridge, 1998).

Recent investigation of behavioural phenotypes characterised by habitual diet suggests that the hedonic response to palatable food can influence appetite control via effects on both food choice and energy intake. Groups of overweight and lean young males matched for age and the habitual high consumption of fat (high-fat phenotypes) were compared (Blundell et al. 2005; Le Noury et al. 2002). Although both groups were eating a diet which theoretically favours a positive energy balance, the overweight phenotypes consumed greater amounts of the high-fat foods in a test meal and reported greater feelings of pleasantness, satisfaction, and tastiness for the foods consumed. One interpretation of these data is that, for at least this group of overweight people (susceptible to weight gain), they habitually self-select (high-fat/palatable) foods with a high probability of generating a positive energy balance (on the basis of their energy density), consume these foods in greater amounts, and

derive greater pleasure from eating these foods. This outcome also demonstrates that certain high-fat phenotypes – susceptible to weight gain – have a disposition to perceive foods as being more pleasant than their lean counterparts (who consume the same habitual high-fat diet). Interestingly, Salbe et al. (2004) found a heightened hedonic response to sweet and creamy solutions to be associated with subsequent weight gain in a sample of Pima Indians (a population highly prone to obesity). Furthermore, Drewnowski and Schwartz (1990) found higher liking for dietary fat in obese individuals compared to lean. Given this capacity to obtain a high level of pleasure from foods (and eating), it is not surprising that many obese people show a tendency to self-select high-palatability foods.

There is also evidence to suggest that obese people may differ in their motivation to eat. As mentioned previously, Saelens and Epstein (1996) found obese subjects invest more effort for liked foods on a progressive ratio task, with similar findings when a normal weight sample of subjects were food-deprived compared to fed (Epstein et al. 2003). Nasser et al. (2005) have also reported the propensity to binge eat to be associated with persistence of motivation to eat in a post-fed state. Furthermore, some neuroimaging studies have indicated greater neural activation at specific reward sites in the brain of weight gaining subjects after consumption of a meal compared to lean controls (Gautier et al. 2000; 2001). These findings were interpreted as weaker post-meal satiety signals in overweight subjects. Lastly, Tetley et al. (2006) have reported greater reactivity in overweight subjects (measured by self-estimated prospective consumption) when exposed to the sight and smell of a palatable food compared to lean controls. Cue reactivity was correlated to habitual portion size and TFEQ disinhibition. Taken together these studies provide some evidence to indicate that susceptible individuals may be characterised by a diminished ability to resist the foods they want, possibly due to greater responsiveness and motivation toward cues associated with tasty foods.

Indeed, individual differences in reward may lead to overconsumption relative to homeostasis via a number of routes. In terms of processes of liking, it is possible that some susceptible individuals may experience an exaggerated hedonic response to palatable foods, in that foods are enjoyed more and therefore eaten in greater amounts for longer periods of time. In addition to this, some people may have a diminished ability to experience pleasure from food and therefore greater consumption of palatable food is promoted to satisfy an optimum level of stimulation. Processes of

wanting may also leave some individuals vulnerable to weight gain through increased motivation (or reactivity) towards cues signalling the availability of food. Further to this, a reduced capacity to resist the motivation to eat when replete may also promote non-homeostatic eating. Finally, some individuals may simply habitually choose highly-palatable, energy-dense foods that promote overconsumption and lead to a positive energy balance. This latter possibility can be viewed as (unhealthy/weight gain promoting) preference and is a behavioural outcome likely to contain elements of both liking and wanting.

### Conclusion

Prompted by findings on the neural structure of food reward in the brain, it is possible to take a fresh look at the role of reward in human appetite and weight regulation. Research shows that hedonic processes interact with the homeostatic system of energy regulation, and that this can influence the organisation of ingestive behaviour, but less is understood about how liking and wanting components of reward might work together or separately to modulate appetite. An important consideration is how these concepts can be operationalised for use in human appetite research. Most previous research has approached these processes on an explicit (subjective) level, although there have been some more recent attempts to explore implicit processes through behavioural measures and brain imaging techniques. There is some interesting overlap between a number of recent theoretical models and the dual process modulation of food reward, and these may help to flesh out the framework from which these processes can be better understood. Processes of liking and wanting may have independent roles in characterising those susceptible to weight gain and obesity. Further research into the dissociability of these processes would help to assess the relative importance of these conceptual components of reward in appetite control and weight regulation.

### Postscript

It should not be forgotten that – strictly speaking – liking and wanting should be seen to have the logical status of theoretical constructs. Our preferred view is that liking and wanting should be viewed as intervening variables that help us to understand the role of hedonics in appetite control. Their existence should not be taken to mean that these processes are structurally embodied in a neural substrate. Rather, that different

neurochemical pathways can separately influence the events that can be measured objectively (in animals and humans) and which imply the existence of processes here referred to as liking and wanting. It is in this sense that we have used the terms in this review.

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