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A dual-process approach to exploring the role of delay discounting in obesity

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HIGHLIGHTS

- Delay discounting for financial rewards has been inconsistently related to overeating and obesity.
- Dual-process accounts of both obesity and discounting behaviour support two-parameter models.
- A two-parameter model showed superior fit to a traditional single-parameter model in lean and obese participants.
- Both indices produced by the two-parameter model were shown to be significantly different between weight groups.
- Implications for modelling delay discounting in future obesity-related research are discussed.

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ABSTRACT

Delay discounting of financial rewards has been related to overeating and obesity. Neuropsychological evidence supports a dual-system account of both discounting and overeating behaviour where the degree of impulsive decision making is determined by the relative strength of reward desire and executive control. A dual-parameter model of discounting behaviour is consistent with this theory.

In this study, the fit of the commonly used one-parameter model was compared to a new dual-parameter model for the first time in a sample of adults with wide ranging BMI. Delay discounting data from 79 males and females (males = 26) across a wide age (M = 28.44 years (SD = 8.81)) and BMI range (M = 25.42 (SD = 5.16)) was analysed. A dual-parameter model (saturating-hyperbolic; Doya, [Doya (2008)]) was applied to the data and compared on model fit indices to the single-parameter model.

Discounting was significantly greater in the overweight/obese participants using both models, however, the two parameter model showed a superior fit to data ($p < 0.0001$). The two parameters were shown to be related yet distinct measures consistent with a dual-system account of inter-temporal choice behaviour.

The dual-parameter model showed superior fit to data and the two parameters were shown to be related yet distinct indices sensitive to differences between weight groups. Findings are discussed in terms of the impulsive reward and executive control systems that contribute to unhealthy food choice and within the context of obesity related research.

1. Introduction

The ability to delay gratification may be crucial for exerting self-control in a tempting food environment. The conflict between the delayed rewards of good health and weight maintenance versus the immediate reward of tasty foods is a dilemma well captured by the delay discounting task [1]. Typically, participants are presented with a choice between a small reward available immediately, or a larger reward available after a delay. Several trials are presented over a number of delay periods and an indifference point (IP) is calculated as the value at which the participant is indifferent to the reward being received now or after a delay. The lower the IP values, the less an individual is willing to wait for the reward, indicating a reduced ability to delay gratification. Discounting of the future on both money and food-based tasks has been related to over eating and obesity, albeit inconsistently [2–15]. A commonly used model of discounting outcomes in obesity research is the single parameter (k) hyperbolic model [16] which is fitted to data using the formula:

$$V = \frac{A}{1 + kD.}$$

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where: V is the Indifference Point (IP), A is the Larger Later Reward (LLR), D is the delay (days) and k is the free parameter for estimating steepness of temporal discounting.

As delays increase the IPs typically decrease as respondents are willing to accept less money immediately instead of waiting for the delayed reward. This decline is however time-inconsistent, being steeper when the delays are proximal (one day versus one week) and shallower when delays are more distal (six months versus nine months). This enhanced sensitivity to differences between shorter compared to longer delays may be reflecting a reduced ability to imagine distal time periods with the same clarity as the near future. For example, the greater the temporal distance to the time period being imagined, the less detail or 'pre-experiencing' of that event that is reported [17]. The ability to imagine the future varies between individuals and is considered to be an important component of executive functioning related to activity in the prefrontal cortex [18].

Most reports of delay discounting applied to obesity have cited Mazur's original paper to justify using the single parameter hyperbolic model [16], in which the model provided the best fit to data. However, Mazur examined discounting behaviour in rats, over very short delays (usually seconds or minutes), and the question arises of whether it is a suitable model for describing human discounting behaviour over longer delay periods.

A number of psychological theories support a dual-process account of the ability to inhibit impulsive responses in favour of long-term gain [19]. Koffarnus and colleagues [20] reviewed delay discounting research in different impulsive populations, exploring the plausibility of a 'Competing Neurobehavioural Decision Systems' (CNDS) explanation of inter-temporal choice. The authors suggest that behaviours related to a reduced ability to delay rewards (including drug use, gambling and over eating) may be the result of a common underlying trait predisposing a person to choose immediate rewards over long term benefits. They discuss evidence favouring a role for two neural systems in trans-disease choice behaviour: an executive decision system correlating with lateral pre-frontal cortex (PFC) activation; and an impulsive system correlating with limbic reward activity. The CNDS model predicts that individual differences in one or both of these systems, determines choice behaviour. For example, it has been reported that that obese women gained more weight over the subsequent year if they showed reduced activation in brain areas associated with executive function when completing difficult discounting trials, compared to easy trials [21]. This supports the idea that sub-optimal functioning of executive areas leads to reduced self-control and overeating behaviour. However, it has been found that a 'dual-hit' of reduced executive control *and* increased desire for food cues reflected in nucleus accumbens (NAcc) reactivity, determined a vulnerability to over eating and higher BMI [22]. Hence, outcome behaviour in the delay discounting task may relate to activity in the reward system *and* the executive system. In support of this idea, Lopez et al [23] reported that NAcc activity in response to food cues predicted subsequent food desire and consumption over a week long period, but this was moderated by inferior frontal gyrus activity in a self-control task. Reward sensitive individuals displaying greater activity in this frontal region at baseline were more able to resist strong food temptations than those who showed lower activity. This evidence supports a dual-process approach to overeating and obesity [24].Consistent with this, neuroscientific evidence indicates that discounting is sensitive to two separate considerations – time delay and reward magnitude, corresponding to PFC and Ventral Striatum (in particular NAcc) activity respectively [25–27]. Thus the one parameter hyperbolic model may not be as appropriate as a dual-parameter model, which is more in line with obesity related empirical research evidence and neuropsychological theory.

In behavioural economics and addiction research, two-parameter models have been applied to discounting data and compared favourably to single parameter models [28–30]. For example, McKercher and colleagues [28] showed that in a general undergraduate student sample, two hyperboloid models fitted with an additional power function showed superior fit to discounting data compared to one parameter exponential and hyperbolic models. However, as both two-parameter models showed equally good fit to data, the authors advise that model selection should be based on theoretical, rather than just empirical reasons in any given population. A two-parameter model which has two parameters that distinguish between immediately available and delayed rewards is the βδ model [31]. However, Kable and Glimcher [32] have suggested that it is more likely that there is a single system underpinning desire for reward as soon as possible rather than a separate system for immediate versus delayed reward.

Therefore a novel two-parameter model that is consistent with evidence and theory is put forward. The saturating-hyperbolic model [33] is based on the premise that everyday decision making is difficult because decisions can result in rewards of different amounts at different timings. Within a delay discounting paradigm, the choice outcome behaviour is therefore dependent upon both temporal discounting and reward utility. This model has two free outcome parameters, k and Q, proposed to represent these processes respectively and is calculated using the equation:

$$V = A * \left(\frac{A}{A+Q}\right) * \left(\frac{1}{1+kd}\right)$$

where: V = Indifference Point (IP); A = Larger later reward; k = hyperbolic temporal discounting parameter; d = delay (days); Q = reward utility parameter.

The k parameter reflects the extent to which an individual discounts rewards over time. This is identical to the single parameter hyperbolic function k and represents the relative steepness of discounting at proximal versus distal delays. It is theorised to represent the ability to imagine the future which relies on activity in executive decision systems [18]. The Q parameter is called the reward utility function. This is typically a nonlinear function with a sigmoid shape with a threshold and saturation point [33,34]. It is hypothesised to represent impulsive needs and desires, with variation in Q values indicating variation in nonlinear valuation [33]. A larger Q value indicates a shallow reward utility curve and signals that the reward is less appealing, whereas a smaller Q value indicates a steep reward curve and signals that the reward is more appealing. When combined with the hyperbolic function k, the Q parameter reflects the overall utility of the reward after a delay. If the reward is desired as soon as possible then the Q value will be large, indicating that any delay very rapidly devalues the reward. Therefore, the curve becomes saturated by enhanced proximal reward utility and the value of Q describes the extent of this saturation. In descriptive terms this is seen as a 'flattening' of the discounting curve where there is an immediate drop in where the curve starts on the y-axis. The larger the Q value, the larger the 'drop' and therefore the greater the emphasis on receiving the reward immediately.

To sum up, Q is theorised as a related yet distinct process to k, where the k parameter is a measure of 'temporal discounting' and is theorised to represent the ability to imagine the future and the Q parameter is a measure of reward utility, theorised to represent the impulsive need and desire for reward. When combined into a single model, the Q value represents the utility of the rewards as a function of delay, with higher values representing an emphasis on receiving that reward as soon as possible. Therefore, Q affects the overall valuation of the delayed reward being examined, contrasting with the single parameter model which only considers the steepness of discounting across indifference points. The saturating-hyperbolic model was selected because 1) it is directly comparable with the commonly used (nested) one parameter hyperbolic model, and 2) it is consistent with dual-process theories and neuropsychological evidence emphasising the importance of separate