Relationship between monetary delay discounting and obesity: a systematic review and meta-regression


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Title page

Title:
Relationship between monetary delay discounting and obesity: A systematic review and meta-regression

Running title: Monetary Delay Discounting and Obesity

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Background and objectives: Previous studies have documented that high rates of delay discounting are associated with obesity. However, studies utilizing monetary reward experiments typically report no associations, as opposed to positive associations apparent in studies utilising food-reward experiments. Our objective was to investigate the reasons behind the mixed evidence from a methodological perspective using systematic review and meta-analytic methodologies.

Methods: Seven databases (EMBASE, MEDLINE, PsycINFO, Scopus, Web of Science, Econlit and IBSS) were systematically searched. Logistic meta-regression was applied to identify the determinants of a significant association and risk of bias was assessed using a modified form of the Newcastle Ottawa cohort scale.

Results: A total of 59 studies were identified, among which 29 studies (49.2%) found a significant positive association and 29 (49.2%) reported no association. A higher proportion of significant and positive associations was reported in those studies utilizing ‘best-practice’ methods (i.e. appropriate measurement models) to estimate monetary delay discounting (15/27; 55.6%) and incentive-compatible experiments (10/16; 62.5%) than those using non-‘best-practice’ methods (14/34; 41.2%) and hypothetical experiments (19/43; 44.2%). All five studies utilizing both ‘best-practice’ methods and incentive-compatible experiments generated a positive and significant relationship. Results from a logistic meta-regression also suggested that studies
employing incentive-compatible experiments (OR: 4.38, 95% CI = 1.05–18.33, p-value: 0.04), ‘best-practice’ methods (OR: 4.40, 95% CI = 0.88–22.99, p-value: 0.07), parametric methods (OR: 3.36, 95% CI = 0.83–13.57, p-value: 0.04), those conducted in children/adolescent populations (OR: 3.90, 95% CI = 0.85–17.88, p-value: 0.08), and those with larger sample size (OR: 1.91, 95% CI = 1.15–3.18, p-value: 0.01) tended to show positive and significant associations between delay discounting and obesity.

**Conclusions:** This review suggests that the mixed evidence to date is a result of methodological heterogeneity, and that future studies should utilise ‘best practice’ methods.

**Keywords:** Systematic review; Obesity; Delay discounting; Financial incentives; Present-bias; Incentive-compatible

**Introduction**

Obesity is a major global risk factor for morbidity and mortality [1] and entails substantial economic costs [2]. In 2013-2014, 35% of adult men and 40% adult women in the United States were obese (body mass index ≥30) [3], a figure forecasted to increase to over 50% by 2030 [4]. Accordingly, obesity represents a major current and future public health challenge. To date, traditional interventions to promote healthy dietary patterns have had modest success in reducing these trends, with weight loss maintenance rare and weight regain common [5]. Thus, there is a recognized need to explore new obesity reduction and prevention strategies [6].
While in its infancy, behavioural economics has provided new insights and sparked interest among public health researchers and the United States government [7, 8]. An increasingly popular strategy is the provision of financial incentives to aid weight-loss and encourage physical activity and dietary-related behavioral change [9, 10]. The principle behind financial incentives is to capitalize upon the notion of delay discounting, i.e. the tendency for an individual to place greater value on the present benefits of an action relative to the future benefits [7].

Delay discounting, also commonly known as discount rate, time preference, temporal discounting or time discounting, is typically elicited through a binary question (e.g. Would you choose $100 today or $150 one year from today?”), or series of binary questions, that ask an individual to choose between an immediate, smaller reward or a delayed, larger reward [11]. Individuals who choose the smaller, immediate reward are said to have a high discount rate and thus, are less likely to resist the temptation for an immediate gratification which might harm their future health [7].

There is rich literature on the role of delay discounting in shaping our health behaviours. Early research focused heavily on addictive health behaviours, where systematic reviews report positive associations between delay discounting and both smoking and drug use [12, 13]. Considering the alarming prevalence over recent years, a growing body of research has shifted attention towards unhealthy diets as well as obesity. Individuals with higher discount rates are assumed to be less likely to resist tempting yet unhealthy foods and eventually become obese. Barlow et al. concluded that there was consistent evidence of an association between delay discounting and obesity, i.e. a higher delay discounting is associated with an increased weight [14].
Interestingly, this was dependent upon the method used to elicit delay discounting: studies utilizing hypothetical and monetary reward choice tasks typically reported no associations as opposed to positive associations apparent in studies using food choice tasks. In contrast, a systematic review by Story et al. [15], albeit focusing on a range of health behaviours, reported strong evidence of an association between monetary elicited temporal discounting and unhealthy behaviours, noting an emerging relationship with obesity. This mixed finding, where obesity was commonly associated with delay discounting elicited from food choice tasks but not with monetary-based methods, requires further exploration.

We hypothesize that this is a result of the largely heterogeneous methods used to elicit monetary delay discounting. For example, various studies have either unjustifiably assumed a parametric form of discount function or used hypothetical rather than real rewards in their choice tasks, possibly biasing their delay discounting estimates. Various studies have employed the Mazur-hyperbolic functional form [16], which does not necessarily characterise individual discount behaviours and other flexible hyperbolic discount functions have rarely been adopted [17]. Further, a valuable and more valid technique is to use real rather than hypothetical rewards when possible, because real monetary rewards are familiar, fungible and have potential to deal with hypothetical bias, and thus likely eliciting more reflective discount rates [18]. Thus, the null findings reported with monetary delay discounting by Barlow et al. [14], as noted by the authors themselves, should be interpreted with caution as only two out of the 41 included studies used incentive-compatible designs, i.e. real monies were actually paid to participants depending on their chosen
immediate or future rewards. Further, methodological heterogeneity was not taken into consideration.

Therefore, in light of the above issues, the aim of the current systematic review was to investigate whether the previously reported null association between obesity and monetary delay discounting may be explained by methodological heterogeneity, with a particular focus on *inter alia* whether the studies utilized incentive-compatible experiments and ‘best-practice’ methods, i.e. appropriate methods to estimate monetary delay discounting. Using systematic review, meta-regression and risk of bias methodologies, evidence was synthesized both numerically and empirically to draw robust conclusions.

**Methods**

**Search Strategy and Eligibility Criteria**

The protocol is registered on PROSPERO (registration number CRD42015026786).

Seven electronic databases (EconLit, EMBASE, International Bibliography of the Social Sciences, Medline, PsycINFO, Scopus and Web of Science) were searched for studies published since inception to May 2017. A combination of key terms relating to ‘delay discounting’ and ‘obesity’ was searched (Supplementary Information S1). Inclusion criteria were:

i. Used a monetary measure of ‘delay discounting’

ii. Reported a measure of ‘obesity’ (i.e. body mass index; body fat percentage)

iii. Tested for a direct association between ‘delay discounting’ and ‘obesity’
iv. Involved a non-clinical (i.e. no current clinically diagnosed condition or disease) population

v. Retrospective or prospective cohort, cross-sectional study design or randomized control trial (RCT)

vi. English language

vii. Full-text available

RCTs were included only if the association between delay discounting and obesity was analyzed at baseline to prevent any confounding effects of the intervention on the association. Studies that did not report the health status of participants were assumed to be non-clinical and were included. Where studies also involved a clinical population group, the data utilized in the paper was only that which tested the association for a non-clinical population group. All age ranges were included. Studies that used non-monetary measures of delay discounting were excluded.

Identified records were screened against the eligibility criteria independently by two researchers (XX) in two phases: (1) titles and abstracts; then, (2) full texts. Any disagreements were resolved by discussion between members of the research team. Reference lists of included studies were manually searched for further eligible papers.

**Data Extraction**

Data was extracted by one reviewer (XX) and then independently cross checked by two other reviewers (XX and XX). Key study characteristics and outcome(s) of interest were extracted and tabulated for each study including sample size, population group, measure of delay discounting and obesity, primary statistical analysis conducted for
Evidence Synthesis

In studies that measured both monetary and non-monetary measures of delay discounting, only data that used monetary elicited delay discounting were extracted and analyzed. Methods to elicit an individual’s monetary delay discounting were classified and ranked according to whether discount rates were estimated by ‘best practice’ methods and whether real or hypothetical payments were used. The methods were described as ‘best practice’ if: (i) either the non-parametric method, Area Under Curve (AUC), or, the parametric methods assuming dual-parameter discount functions, e.g. Quasi-hyperbolic, Fixed-cost hyperbolic, Generalized-hyperbolic, and Saturating-hyperbolic) and (ii) incentive-compatible tasks when respondents had chances to be paid for real, depending on their own choices to these tasks (Supplementary Information S2). Studies that referred to a group as ‘normal weight’ or control group are referred to as ‘healthy weight’. A statistically significant delay discounting-obesity association was defined as a p-value less than 0.05. To quantitatively identify the determinants of a significant association, a logistic meta-regression analysis using STATA was conducted (version 13.0; Stata Corp., College Station, TX, USA). To test the robustness of the meta-regression results, a backward stepwise procedure was followed such that the insignificant predictor variables in the initial model were deleted one by one starting from the factor with the highest p-value until the p-values of all remaining predictor variables were below 0.10 (final model).
However, as the delay discounting estimates had different metrics resulting from the heterogeneous methods, a meta-analysis was not appropriate.

**Assessment of risk of bias**

Risks of bias were assessed independently by two reviewers (XX and XX) using a modified form of the Newcastle Ottawa cohort scale for cross-sectional studies [20] (Supplementary Information S3).

**Results**

The PRISMA flow diagram [21] depicted in Figure 1 shows the results of the literature search. In summary, 1005 records were identified following database searching and 59 studies were included in the review. Study characteristics and main findings are reported in Table 1. Large heterogeneity existed among the studies, especially for the type of monetary tasks used to elicit delay discounting, the statistical analysis applied and sample sizes (ranging from 28 [22] to 42,863 [23] participants). The majority of studies were conducted in the USA (n=34), followed by Europe (n=16), Asia (n=6), Canada (n=1), Australia (n=1) and multiple countries (n=1). Fifty-eight studies were based on cross-sectional analysis of the association between delay discounting and obesity, and one was a longitudinal study [24]. Forty-seven (79.7%) studies were conducted in adults and twelve (20.3%) in children.

Overall the quality of statistical tests and reporting tended to be high with a mean score of 5.03 (S.D. 1.47, range = 1–8). Ten (16.9%) studies were classified as ‘high’ quality (more than 6 stars), forty (67.8%) ‘medium’ quality (4-6 stars) and nine (15.3%)
‘low’ quality (less than 4 stars). For the complete risk of bias analysis conducted using the Newcastle-Ottawa Scale, see Supplementary Information S3 and S4.

Heterogeneity of methods in the elicitation of monetary delay discounting

A range of different methods was used to elicit monetary delay discounting (Supplementary Information S2) and to analyze its association with obesity. Only a small proportion of studies (16/59; 27%) made their inter-temporal choice tasks incentive-compatible so that participants had a chance to be paid (often) for one randomly determined choice they made [25-38].

Two studies [39, 40] conducted both parametric and non-parametric analysis taking the total number of analyzes to 61. Among the 25 parametric studies, 2 studies elicited delay discounting through Exponential discounting [25, 41] and 23 utilized hyperbolic discounting (Mazur-hyperbolic, n=18, [26, 28, 31, 39, 40, 42-52]; Quasi-hyperbolic, n=2, [34, 53]; Generalized-hyperbolic, n=1, [54]; Saturating-hyperbolic, n=1, [17]; and Fixed-cost hyperbolic, n=1, [32]). Among the 36 non-parametric studies, 21 studies utilized the Area Under Curve (AUC) method [22, 29, 30, 36, 39, 40, 55-69] and 15 used proxy measures [23, 24, 27, 33, 35, 37, 38, 70-77]. Among those using proxy measures, five studies were based on a single multiple-choice trade-off question [23, 24, 27, 72, 77], five used indifference points [33, 71, 73, 75, 76], two used an open-ended future equivalent question [35, 74], and three used the number of patient choices [37, 38, 70].

Overall association
Among the 59 included studies, 29 studies (49%) found a significant positive association between delay discounting and obesity, 29 (49%) reported no association and 1 (2%) found a significant negative association (Table 1).

[Insert Table 1 about here]

‘best-practice’ vs. non-‘best-practice’ analysis

Studies utilizing ‘best-practice’ methods tended to reveal a higher proportion of significant associations than those using non-‘best-practice’ methods (Table 1).

Among the 27 studies utilizing ‘best-practice’ methods, 15 (55.6%) studies produced a significant positive association and 12 (44.4%) reported no association. In comparison, non-‘best-practice’ methods resulted in a lower proportion of positive associations (14/34; 41.2%), a higher proportion with no association (19/34; 55.9%), and one (2.9%) significant negative association.

Parametric Mazur-hyperbolic discounting vs. non-parametric AUC

Mazur-hyperbolic discounting is the main parametric method used whereas AUC is the main non-parametrical method. Among the 18 studies that applied the Mazur-hyperbolic discount function, eight (44.4%) produced a significant positive association and 10 (55.6%) found no association. In the 21 studies that used the AUC method, a significant positive association was evident in nine (42.9%) and no association was apparent in 12 (57.1%) studies. Two studies reported results from both the Mazur-hyperbolic and non-parametric AUC methods and found no association between delay discounting and obesity, irrespective of the method used [39, 40].
Incentive-compatible vs. hypothetical monetary rewards

Among the 16 studies that used real monetary rewards, ten (62.5%) found a significant positive association between delay discounting and obesity, five reported no association (31.2%) and one (6.3%) produced a significant negative association. In contrast, 19 (44.2%) out of the 43 studies that used hypothetical monetary rewards found an overall significant positive association between delay discounting and obesity, and 24 (55.8%) reported no association.

In summary, from the above a trend is observed to support the conjecture that either ‘best-practice’ methods or real rewards resulted in a somewhat higher proportion of positive and significant associations between obesity and delay discounting than their counterpart non-‘best-practice’ or hypothetical rewards analysis. Further, it is noteworthy that the five real reward studies employing ‘best-practice’ methods exceptionally generated a positive and significant relationship [29, 30, 32, 34, 36]. If the five real reward studies using Mazur-hyperbolic [26, 28, 31] are also included, the same trend holds for 9 out of 10 studies. Conversely, it should be noted that a ‘best-practice’ method or a real reward design alone does not lead to many significant and positive results. Studies utilizing ‘best-practice’ methods but hypothetical rewards produced positive and significant relationships in only 10 (45.5%) out of 22 studies. In a similar vein, the real rewards studies that did not adopt a ‘best-practice’ approach (e.g. used Proxy and Exponential etc.) produced significant results in 5 (45.5%) out of 11 studies. Thus, ‘best-practice’ methods and incentive-compatible environments seem to be the two necessary conditions for a positive and significant relationship.

Objective vs. subjective measures of obesity
All included studies assessed obesity through BMI. Twelve studies (20.3%) did not state whether their measures of BMI were objectively or subjectively reported. Among the 29 studies that have used objectively measured BMI, 12 (41.4%) reported a significant positive association and 17 (58.6%) found no association. By contrast, 12 (66.7%) out of 18 studies with self-reported BMI found a significant positive association and 6 (33.3%) reported no association.

Quantitative analysis

The logistic meta-regression model (Table 2) shows that none of the factors were robust and significant predictors of a significant and positive association in both initial and final models, albeit those studies employing incentive-compatible experiments (OR = 3.86, 95% CI = 0.81, 18.43; OR = 4.38, 95% CI = 1.05, 18.33), ‘best-practice’ methods (OR = 6.54, 95% CI = 0.87, 49.28; OR = 4.40, 95% CI = 0.88, 22.99), parametric methods (OR = 5.38, 95% CI = 1.01, 28.73; OR = 3.36, 95% CI = 0.83, 13.57), those conducted in children/adolescent populations (OR = 4.54, 95% CI = 0.85, 24.34; OR = 3.90, 95% CI = 0.85, 17.88), and those with larger sample size (OR = 1.67, 95% CI = 0.89, 3.13; OR = 1.91, 95% CI = 1.15, 3.18) tended to reveal a positive significant association, echoing the earlier finding that ‘best-practice’ methods or real rewards alone do not lead to many significant and positive results. However, when ten “low” quality studies were excluded from the analysis, those studies utilizing ‘best-practice’ methods and parametric methods are more likely to report a positive and significant association (Supplementary Information S5).
Methodological moderators

The association between delay discounting and obesity was not moderated by specific trial/time delay, reward size and weight status threshold used (Supplementary Information S6).

Discussion

In summary, this study demonstrates that monetary elicited delay discounting was only associated with obesity in the studies in which incentive-compatible experiments were used and ‘best-practice’ methods to estimate delay discounting were employed.

Looking broadly at the associations found in all included studies, an equal number of studies found positive or no associations between monetary-elicited delay discounting and obesity. This is consistent with the overall conclusion of Barlow et al. [14] who stated that there was a lack of evidence that a monetary-elicited delay discounting was associated with obesity. This lack of clear association is not aligned with the predictions of theoretical concepts of delay discounting and the prevailing hypothesis commonly held by many researchers from the field [11, 78]. Nor is it in line with the fact that delay discounting elicited from food-based tasks strongly relate to consuming unhealthy foods and obesity as observed by Barlow et al. However, the trend becomes much clearer if the studies are rated according to methodological appropriateness and incentive-compatibility. We found that studies where real rewards were at stake and ‘best-practice’ methods were used to estimate delay discounting, consistently
reported positive and significant relationships. Furthermore, these two conditions are complementary but seem not to act alone (i.e. studies adopting ‘best-practice’ methods or real reward alone result in fewer identified associations). Thus we conjecture that the broadly null relationship between monetary delay discounting and obesity reported by Barlow et al. is conflated by critical methodological issues. We suggest that findings should be interpreted with caution in studies which fail to adopt the ‘best-practice’ methods, or which use hypothetical choice tasks.

Considerable heterogeneity was evident across all of the included studies on the basis of various methodological issues, echoing previous discussions in the literature [14, 52, 61]. Regarding whether the method applied was parametric or non-parametric, the present results revealed that the former method tends to reveal a higher proportion of positive associations between delay discounting and obesity than non-parametric methods. The parametric Mazur-hyperbolic discount function and non-parametric AUC methods were the most commonly identified types of analysis and when compared, no substantial differences in the number of significant associations is evident between the two methods. Interestingly, two studies conducted both methods (i.e. Mazur-hyperbolic and AUC) and both reported no differences between the two analyses. However, we observed a significantly higher proportion of significant delay discounting-obesity associations in studies using more flexible discount functions which nest both exponential and hyperbolic discounting, e.g. Fixed-cost hyperbolic, Quasi-hyperbolic, Generalized-hyperbolic, and Saturating-hyperbolic. All the five included studies that assumed these specifications have reported positive associations.
The basic advantage over the typically-modelled Mazur-hyperbolic function of the more flexible hyperbolic functional forms, e.g. Fixed-cost hyperbolic and Quasi-hyperbolic etc., is that they incorporate two parameters each of which represents the two elements of delay discounting: 1) a conventional discount rate which refers to the extent to which future rewards are discounted; and (2) time-inconsistency which means the relative discount rate between two proximal delays is higher than the relative discount rate between two distal delays. It is intriguing that advances in neuroeconomics have provided novel insights into the neural mechanisms associated with the discounting of delayed rewards where two distinguishable brain regions are involved, with one associated with time-inconsistency (also referring to present-bias, i.e. sensitivity to the immediacy of rewards irrespective of reward magnitude) and the other related to discount rate (the long-run delay of the absolute magnitude of rewards irrespective of delay immediacy) [79, 80]. In addition, one should be aware that present-bias is not universally observed in all subjects, while discounting is an inherent phenomenon (detailed discussions see Andersen et al. [18]). Six of the included studies conducted analyses relating to the two elements, although not all applied the parametric methods per se [27, 32, 34, 53, 54, 73]. Three studies found that a higher discount rate and greater present-bias were both significantly associated with higher BMI, respectively [17, 53, 54]. By contrast, Simmank et al. [34] found that only discount rate but not present bias was related to BMI. Instead of a parametric estimation, Ikeda et al. [73] constructed a dummy for present-bias and again found that only discount rate (not present bias) was related to BMI. As mentioned earlier, very few studies took account of the two related yet distinct elements of delay discounting. We conjecture that the majority of the included parametric studies
assuming a Mazur-hyperbolic function and the non-parametric AUC method failed to disentangle the two differentiated elements, resulting in pseudo non-associations between monetary delay discounting and obesity.

Strengths of this study included the addition of numerous studies with hypothetical monetary tasks, and with delay discounting elicited from real-monetary rewards, which facilitated investigation of why a monetary-elicited delay discounting was not associated with obesity. To our knowledge, this is the first systematic review that has attempted to elucidate the methodological implications.

Implications for public health research and practice

In times of economic hardship and spiraling healthcare costs, return on investment is a high priority for governments, especially with regards to the potential for interventions to change behavior that use financial rewards. With the concern that policy makers might ‘jump the gun’ by implementing interventions before convincing evidence exists [7, 81], studies based on ‘best-practice’ will help direct and develop future delay discounting and obesity research to ensure studies are methodologically robust. This will allow more definitive conclusions to be drawn, helping policy makers to make balanced, evidence-based decisions. The decomposition of delay discounting into its two components suggests that incentive strategies derived from each of the two elements differ in that the discount rate determines the overall level of incentives whereas the time-inconstancy factor determines whether incentives should be changed to match the decreasing discount rates over time.

Future directions
Firstly, there is a need for future research to validate the conditions for eliciting monetary delay discounting, with regards to both the real rewards utilized and the ‘best-practice’ methods applied. This will allow stronger and more comparable study designs, which will ultimately provide greater clarity on the association between delay discounting and obesity. As highlighted by Barlow et al. [14] and Story et al. [15], there is a need for longitudinal study designs and to control for risk aversion. All but one study included in the current systematic review was cross-sectional, preventing any information on causality, if a potential association exists. Few studies controlled for risk aversion, now considered to avoid upward-biases to the discount rate estimates [18]. Secondly, given the fact that financial incentives are increasingly used in weight loss intervention programs, how to design incentive levels to match the two related yet distinct underlying processes of delay discounting, i.e. level of discounting and time-inconsistency, are open questions for future research. This may have important implications for the applicability of delay discounting in weight loss interventions, especially when incentives are contingent on achieving a future weight loss target. Lastly, a previously overlooked area is to test for demographic differences in the association between delay discounting and obesity. Among the very few studies to date which investigated this, the majority found no evidence of moderation effects from demographic factors such as gender, age. While this finding should be interpreted with caution due to the small numbers of studies, the potential demographic moderators are highly relevant for the incorporation of delay discounting into the design and implementation of obesity strategies, highlighting the need to consider them in future research.
Conclusions

In research conducted to date on the association between monetary-elicited delay discounting and obesity, there have been an equal number of significant positive and insignificant positive associations. This study revealed that only the studies adopting ‘best-practices’ and incentive-compatible tasks have reported a significant association between delay discounting and obesity. This conclusion may be relevant to studies which link delay discounting to other real-world health behaviors in general. Given the heterogeneous methods adopted in the literature, the current evidence suggests a need for future studies to utilize ‘best-practice’ methods and incentive-compatible designs to more validly discern the association between monetary delay discounting and obesity, allowing policy makers to draw definitive conclusions based on methodologically robust evidence. Prior to the implementation of behavioral change programs, the investigation of delay discounting of the target population and the decomposition into its two components, i.e. discount rate and time-inconsistency, could provide insights into designing incentive strategies to improve effectiveness of these programs.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

SUPPLEMENTARY INFORMATION
Supplementary information is available at International Journal of Obesity’s website.

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