**QUEEN'S
UNIVERSITY
BELFAST**

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

Tang, J., Chrzanowski-Smith, O. J., Hutchinson, G., Kee, F., & Hunter, R. F. (2018). Relationship between monetary delay discounting and obesity: a systematic review and meta-regression. *International Journal of Obesity*. <https://doi.org/10.1038/s41366-018-0265-0>

Published in:
International Journal of Obesity

Document Version:
Peer reviewed version

Queen's University Belfast - Research Portal:
[Link to publication record in Queen's University Belfast Research Portal](#)

Publisher rights
© 2018 Springer Nature Limited.
This work is made available online in accordance with the publisher's policies. Please refer to any applicable terms of use of the publisher.

General rights
Copyright for the publications made accessible via the Queen's University Belfast Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy
The Research Portal is Queen's institutional repository that provides access to Queen's research output. Every effort has been made to ensure that content in the Research Portal does not infringe any person's rights, or applicable UK laws. If you discover content in the Research Portal that you believe breaches copyright or violates any law, please contact openaccess@qub.ac.uk.

Title page

Title:

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

Running title: Monetary Delay Discounting and Obesity

Authors:

Jianjun Tang^{1,2,*}, Oliver Chrzanowski-Smith³, George Hutchinson^{2,4}, Frank Kee², Ruth F. Hunter²

Affiliations:

¹ School of Agricultural Economics and Rural Development, Renmin University of China, Beijing 100872, China

² Centre for Public Health/UKCRC Centre of Excellence for Public Health (NI), Queen's University Belfast, Belfast, Northern Ireland, UK

³ Department for Health, University of Bath, Bath, UK

⁴ Gibson Institute for Land, Food and Environment, School of Biological Sciences, Queen's University Belfast, Belfast, Northern Ireland, UK

Email addresses:

Jianjun Tang (j.tang@qub.ac.uk)

Oliver Chrzanowski-Smith (O.J.Chrzanowski-Smith@bath.ac.uk)

George Hutchinson (g.hutchinson@qub.ac.uk)

Frank Kee (f.kee@qub.ac.uk)

Ruth F. Hunter (ruth.hunter@qub.ac.uk)

* Corresponding author:

Dr. Jianjun Tang, School of Agricultural Economics and Rural Development, Renmin University of China, 59 Zhongguancun Ave., Beijing 100872, CHINA; E-mail: j.tang@qub.ac.uk; Tel: +86 (0)10-62511061.

Conflicts of interest: The authors have no conflicts of interest.

1   **Relationship between monetary delay discounting and obesity: A**

2   **systematic review and meta-regression**

3

4   **Background and objectives:** Previous studies have documented that high rates of

5   delay discounting are associated with obesity. However, studies utilizing monetary

6   reward experiments typically report no associations, as opposed to positive

7   associations apparent in studies utilising food-reward experiments. Our objective was

8   to investigate the reasons behind the mixed evidence from a methodological

9   perspective using systematic review and meta-analytic methodologies.

10   **Methods:** Seven databases (EMBASE, MEDLINE, PsycINFO, Scopus, Web of Science,

11   Econlit and IBSS) were systematically searched. Logistic meta-regression was applied

12   to identify the determinants of a significant association and risk of bias was assessed

13   using a modified form of the Newcastle Ottawa cohort scale.

14   **Results:** A total of 59 studies were identified, among which 29 studies (49.2%) found

15   a significant positive association and 29 (49.2%) reported no association. A higher

16   proportion of significant and positive associations was reported in those studies

17   utilizing ‘best-practice’ methods (i.e. appropriate measurement models) to estimate

18   monetary delay discounting (15/27; 55.6%) and incentive-compatible experiments

19   (10/16; 62.5%) than those using non-‘best-practice’ methods (14/34; 41.2%) and

20   hypothetical experiments (19/43; 44.2%). All five studies utilizing both ‘best-practice’

21   methods and incentive-compatible experiments generated a positive and significant

22   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].

44 While in its infancy, behavioural economics has provided new insights and sparked
45 interest among public health researchers and the United States government [7, 8]. An
46 increasingly popular strategy is the provision of financial incentives to aid weight-loss
47 and encourage physical activity and dietary-related behavioral change [9, 10]. The
48 principle behind financial incentives is to capitalize upon the notion of delay
49 discounting, i.e. the tendency for an individual to place greater value on the present
50 benefits of an action relative to the future benefits [7].

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

58 There is rich literature on the role of delay discounting in shaping our health
59 behaviours. Early research focused heavily on addictive health behaviours, where
60 systematic reviews report positive associations between delay discounting and both
61 smoking and drug use [12, 13]. Considering the alarming prevalence over recent years,
62 a growing body of research has shifted attention towards unhealthy diets as well as
63 obesity. Individuals with higher discount rates are assumed to be less likely to resist
64 tempting yet unhealthy foods and eventually become obese. Barlow et al. concluded
65 that there was consistent evidence of an association between delay discounting and
66 obesity, i.e. a higher delay discounting is associated with an increased weight [14].

67 Interestingly, this was dependent upon the method used to elicit delay discounting:
68 studies utilizing hypothetical and monetary reward choice tasks typically reported no
69 associations as opposed to positive associations apparent in studies using food choice
70 tasks. In contrast, a systematic review by Story et al. [15], albeit focusing on a range
71 of health behaviours, reported strong evidence of an association between monetary
72 elicited temporal discounting and unhealthy behaviours, noting an emerging
73 relationship with obesity. This mixed finding, where obesity was commonly associated
74 with delay discounting elicited from food choice tasks but not with monetary-based
75 methods, requires further exploration.

76 We hypothesize that this is a result of the largely heterogeneous methods used to
77 elicit monetary delay discounting. For example, various studies have either
78 unjustifiably assumed a parametric form of discount function or used hypothetical
79 rather than real rewards in their choice tasks, possibly biasing their delay discounting
80 estimates. Various studies have employed the Mazur-hyperbolic functional form [16],
81 which does not necessarily characterise individual discount behaviours and other
82 flexible hyperbolic discount functions have rarely been adopted [17]. Further, a
83 valuable and more valid technique is to use real rather than hypothetical rewards
84 when possible, because real monetary rewards are familiar, fungible and have
85 potential to deal with hypothetical bias, and thus likely eliciting more reflective
86 discount rates [18]. Thus, the null findings reported with monetary delay discounting
87 by Barlow et al. [14], as noted by the authors themselves, should be interpreted with
88 caution as only two out of the 41 included studies used incentive-compatible designs,
89 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

delay discounting-obesity association, results (p-values, standard errors, and 95% confidence intervals) and summary/main finding(s).

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)

[19]. 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).

[Insert Table 2 about here]

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.

310 The basic advantage over the typically-modelled Mazur-hyperbolic function of the
311 more flexible hyperbolic functional forms, e.g. Fixed-cost hyperbolic and Quasi-
312 hyperbolic etc., is that they incorporate two parameters each of which represents the
313 two elements of delay discounting: 1) a conventional *discount rate* which refers to the
314 extent to which future rewards are discounted; and (2) *time-inconsistency* which
315 means the relative discount rate between two proximal delays is higher than the
316 relative discount rate between two distal delays. It is intriguing that advances in
317 neuroeconomics have provided novel insights into the neural mechanisms associated
318 with the discounting of delayed rewards where two distinguishable brain regions are
319 involved, with one associated with *time-inconsistency* (also referring to present-bias,
320 i.e. sensitivity to the immediacy of rewards irrespective of reward magnitude) and the
321 other related to *discount rate* (the long-run delay of the absolute magnitude of
322 rewards irrespective of delay immediacy) [79, 80]. In addition, one should be aware
323 that present-bias is not universally observed in all subjects, while discounting is an
324 inherent phenomenon (detailed discussions see Andersen et al. [18]). Six of the
325 included studies conducted analyses relating to the two elements, although not all
326 applied the parametric methods per se [27, 32, 34, 53, 54, 73]. Three studies found
327 that a higher discount rate and greater present-bias were both significantly associated
328 with higher BMI, respectively [17, 53, 54]. By contrast, Simmank et al. [34] found that
329 only discount rate but not present bias was related to BMI. Instead of a parametric
330 estimation, Ikeda et al. [73] constructed a dummy for present-bias and again found
331 that only discount rate (not present bias) was related to BMI. As mentioned earlier,
332 very few studies took account of the two related yet distinct elements of delay
333 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

356 Firstly, there is a need for future research to validate the conditions for eliciting
357 monetary delay discounting, with regards to both the real rewards utilized and the
358 'best-practice' methods applied. This will allow stronger and more comparable study
359 designs, which will ultimately provide greater clarity on the association between delay
360 discounting and obesity. As highlighted by Barlow et al. [14] and Story et al. [15], there
361 is a need for longitudinal study designs and to control for risk aversion. All but one
362 study included in the current systematic review was cross-sectional, preventing any
363 information on causality, if a potential association exists. Few studies controlled for
364 risk aversion, now considered to avoid upward-biases to the discount rate estimates
365 [18]. Secondly, given the fact that financial incentives are increasingly used in weight
366 loss intervention programs, how to design incentive levels to match the two related
367 yet distinct underlying processes of delay discounting, i.e. level of discounting and
368 time-inconsistency, are open questions for future research. This may have important
369 implications for the applicability of delay discounting in weight loss interventions,
370 especially when incentives are contingent on achieving a future weight loss target.
371 Lastly, a previously overlooked area is to test for demographic differences in the
372 association between delay discounting and obesity. Among the very few studies to
373 date which investigated this, the majority found no evidence of moderation effects
374 from demographic factors such as gender, age. While this finding should be
375 interpreted with caution due to the small numbers of studies, the potential
376 demographic moderators are highly relevant for the incorporation of delay
377 discounting into the design and implementation of obesity strategies, highlighting the
378 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.

References

1. Forouzanfar MH, Alexander L, Anderson HR, Bachman VF, Biryukov S, Brauer M, et al. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990-2013: A systematic analysis for the Global Burden of Disease Study 2013. *Lancet*. 2015;**386**(10010):2287-323.
2. Ulijaszek SJ, McLennan AK. Framing obesity in UK policy from the Blair years, 1997-2015: the persistence of individualistic approaches despite overwhelming evidence of societal and economic factors, and the need for collective responsibility. *Obes Rev*. 2016;**17**(5):397-411.
3. Flegal KM, Kruszon-Moran D, Carroll MD, Fryar CD, Ogden CL. Trends in obesity among adults in the united states, 2005 to 2014. *JAMA*. 2016;**315**(21):2284-91.
4. Wang Y, McPherson K, Marsh T, Gortmaker SL, Brown M. Obesity 2 Health and economic burden of the projected obesity trends in the USA and the UK. *Lancet*. 2011;**378**(9793):815-25.
5. Dombrowski SU, Knittle K, Avenell A, Araujo-Soares V, Sniehotta FF. Long term maintenance of weight loss with non-surgical interventions in obese adults: Systematic review and meta-analyses of randomised controlled trials. *Bmj-Brit Med J*. 2014;**348**.

- 421 6. Davies S. Annual report of the chief medical officer, 2014 - The health of the 51%:
422 women 2015 [March 7, 2018]. Available from:
423 [https://www.gov.uk/government/publications/chief-medical-officer-annual-report-2014-](https://www.gov.uk/government/publications/chief-medical-officer-annual-report-2014-womens-health)
424 [womens-health](https://www.gov.uk/government/publications/chief-medical-officer-annual-report-2014-womens-health).
- 425 7. Loewenstein G, Asch DA, Friedman JY, Melichar LA, Volpp KG. Can behavioural
426 economics make us healthier? *Brit Med J.* 2012;**344**.
- 427 8. Obama B. Executive order - using behavioral science insights to better serve the
428 American people 2015 [07/03/2018]. Available from:
429 [https://obamawhitehouse.archives.gov/the-press-office/2015/09/15/executive-order-using-](https://obamawhitehouse.archives.gov/the-press-office/2015/09/15/executive-order-using-behavioral-science-insights-better-serve-american)
430 [behavioral-science-insights-better-serve-american](https://obamawhitehouse.archives.gov/the-press-office/2015/09/15/executive-order-using-behavioral-science-insights-better-serve-american).
- 431 9. Mantzari E, Vogt F, Shemilt I, Wei YH, Higgins JPT, Marteau TM. Personal financial
432 incentives for changing habitual health-related behaviors: A systematic review and meta-
433 analysis. *Prev Med.* 2015;**75**:75-85.
- 434 10. Adams J, Giles EL, McColl E, Sniehotta FF. Carrots, sticks and health behaviours: A
435 framework for documenting the complexity of financial incentive interventions to change
436 health behaviours. *Health Psychol Rev.* 2014;**8**(3):286-95.
- 437 11. Lawless LD, A.C.; Nayga Jr, R.M. Time preferences and health behaviour: A review.
438 *Agricultural and Food Economics.* 2013;**1**(1):19.
- 439 12. Reynolds B. A review of delay-discounting research with humans: relations to drug
440 use and gambling. *Behav Pharmacol.* 2006;**17**(8):651-67.

- 441 13. Barlow P, Mckee M, Reeves A, Galea G, Stuckler D. Time-discounting and tobacco
442 smoking: A systematic review and network analysis. *Int J Epidemiol.* 2017;**46**(3):869-.
- 443 14. Barlow P, Reeves A, McKee M, Galea G, Stuckler D. Unhealthy diets, obesity and time
444 discounting: A systematic literature review and network analysis. *Obes Rev.* 2016;**17**(9):810-
445 9.
- 446 15. Story GW, Vlaev I, Seymour B, Darzi A, Dolan RJ. Does temporal discounting explain
447 unhealthy behavior? A systematic review and reinforcement learning perspective. *Front*
448 *Behav Neurosci.* 2014;**8**.
- 449 16. Mazur JE. Tests of an equivalence rule for fixed and variable reinforcer delays. *J Exp*
450 *Psychol Anim B.* 1984;**10**(4):426-36.
- 451 17. Price M, Higgs S, Maw J, Lee M. A dual-process approach to exploring the role of
452 delay discounting in obesity. *Physiology & Behavior.* 2016;**162**:46-51.
- 453 18. Andersen S, Harrison GW, Lau MI, Rutstrom EE. Discounting behavior: A
454 reconsideration. *Eur Econ Rev.* 2014;**71**:15-33.
- 455 19. Wooldridge JM. *Introductory econometrics: A modern approach.* Boston: Cengage
456 Learning; 2015.
- 457 20. Herzog R, Alvarez-Pasquin MJ, Diaz C, Del Barrio JL, Estrada JM, Gil A. Are healthcare
458 workers' intentions to vaccinate related to their knowledge, beliefs and attitudes? A
459 systematic review. *Bmc Public Health.* 2013;**13**.

- 460 21. Moher D, Liberati A, Tetzlaff J, Altman DG, Grp P. Preferred reporting items for
461 systematic reviews and meta-Analyses: The PRISMA statement. *Ann Intern Med*.
462 2009;**151**(4):264-W64.
- 463 22. Feda DM, Roemmich JN, Roberts A, Epstein LH. Food reinforcement and delay
464 discounting in zBMI-discordant siblings. *Appetite*. 2015;**85**:185-9.
- 465 23. Reimers S, Maylor EA, Stewart N, Chater N. Associations between a one-shot delay
466 discounting measure and age, income, education and real-world impulsive behavior. *Pers*
467 *Indiv Differ*. 2009;**47**(8):973-8.
- 468 24. Golsteyn BHH, Gronqvist H, Lindahl L. Adolescent time preferences predict lifetime
469 outcomes. *Econ J*. 2014;**124**(580):F739-F61.
- 470 25. Budria S, Lacomba JA, Lagos F, Swedberg P. When obese people are more patient
471 than non-obese people a study of post-surgery individuals in a weight loss association. *Rev*
472 *Int Sociol*. 2012;**70**:83-98.
- 473 26. Chabris CF, Laibson D, Morris CL, Schuldt JP, Taubinsky D. Individual laboratory-
474 measured discount rates predict field behavior. *J Risk Uncertainty*. 2008;**37**(2-3):237-69.
- 475 27. Conell-Price L, Jamison J. Predicting health behaviors with economic preferences &
476 locus of control. *J Behav Exp Econ*. 2015;**54**:1-9.
- 477 28. Epstein LH, Richards JB, Saad FG, Paluch RA, Roemmich JN, Lerman C. Comparison
478 between two measures of delay discounting in smokers. *Exp Clin Psychopharm*.
479 2003;**11**(2):131-8.

- 480 29. Fields SA, Sabet M, Peal A, Reynolds B. Relationship between weight status and
481 delay discounting in a sample of adolescent cigarette smokers. *Behav Pharmacol*.
482 2011;**22**(3):266-8.
- 483 30. Fields SA, Sabet M, Reynolds B. Dimensions of impulsive behavior in obese,
484 overweight, and healthy-weight adolescents. *Appetite*. 2013;**70**:60-6.
- 485 31. Kulendran M, Vlaev I, Sugden C, King D, Ashrafian H, Gately P, et al.
486 Neuropsychological assessment as a predictor of weight loss in obese adolescents. *Int J*
487 *Obesity*. 2014;**38**(4):507-12.
- 488 32. Richards TJ, Hamilton SF. Obesity and hyperbolic discounting: An experimental
489 analysis. *J Agr Resour Econ*. 2012;**37**(2):181-98.
- 490 33. Rieger M. Risk aversion, time preference and health production: Theory and
491 empirical evidence from Cambodia. *Econ Hum Biol*. 2015;**17**:1-15.
- 492 34. Simmank J, Murawski C, Bode S, Horstmann A. Incidental rewarding cues influence
493 economic decisions in people with obesity. *Front Behav Neurosci*. 2015;**9**.
- 494 35. Sutter M, Kocher MG, Glatzle-Rutzler D, Trautmann ST. Impatience and uncertainty:
495 Experimental decisions predict adolescents' field behavior. *Am Econ Rev*. 2013;**103**(1):510-
496 31.
- 497 36. Sabet M. Impulsivity and obesity in adolescents: The Ohio State University; 2011.
- 498 37. de Oliveira ACM, Leonard TCM, Shuval K, Skinner CS, Eckel C, Murdoch JC. Economic
499 preferences and obesity among a low-income African American community. *Journal of*
500 *Economic Behavior & Organization*. 2016;**131**:196-208.

- 501 38. Rustichini A, DeYoung CG, Anderson JE, Burks SV. Toward the integration of
502 personality theory and decision theory in explaining economic behavior: An experimental
503 investigation. *J Behav Exp Econ.* 2016;**64**:122-37.
- 504 39. Hendrickson KL, Rasmussen EB. Effects of mindful eating training on delay and
505 probability discounting for food and money in obese and healthy-weight individuals. *Behav*
506 *Res Ther.* 2013;**51**(7):399-409.
- 507 40. Hendrickson KL, Rasmussen EB, Lawyer SR. Measurement and validation of
508 measures for impulsive food choice across obese and healthy-weight individuals. *Appetite.*
509 2015;**90**:254-63.
- 510 41. Booij AS, van Praag BMS. A simultaneous approach to the estimation of risk aversion
511 and the subjective time discount rate. *Journal of Economic Behavior & Organization.*
512 2009;**70**(1-2):374-88.
- 513 42. Adams J, Nettle D. Time perspective, personality and smoking, body mass, and
514 physical activity: An empirical study. *Brit J Health Psych.* 2009;**14**:83-105.
- 515 43. Bickel WK, Wilson AG, Franck CT, Mueller ET, Jarmolowicz DP, Koffarnus MN, et al.
516 Using crowdsourcing to compare temporal, social temporal, and probability discounting
517 among obese and non-obese individuals. *Appetite.* 2014;**75**:82-9.
- 518 44. Dassen FCM, Houben K, Jansen A. Time orientation and eating behavior: Unhealthy
519 eaters consider immediate consequences, while healthy eaters focus on future health.
520 *Appetite.* 2015;**91**:13-9.

- 521 45. Lawyer SR, Boomhower SR, Rasmussen EB. Differential associations between obesity
522 and behavioral measures of impulsivity. *Appetite*. 2015;**95**:375-82.
- 523 46. Nederkoorn C, Smulders FTY, Havermans RC, Roefs A, Jansen A. Impulsivity in obese
524 women. *Appetite*. 2006;**47**(2):253-6.
- 525 47. Yeomans MR, Leitch M, Mobini S. Impulsivity is associated with the disinhibition but
526 not restraint factor from the Three Factor Eating Questionnaire. *Appetite*. 2008;**50**(2-3):469-
527 76.
- 528 48. Verdejo-Garcia A, Perez-Exposito M, Schmidt-Rio-Valle J, Fernandez-Serrano MJ,
529 Cruz F, Perez-Garcia M, et al. Selective alterations within executive functions in adolescents
530 with excess weight. *Obesity*. 2010;**18**(8):1572-8.
- 531 49. Chan WS. Delay discounting and response disinhibition moderate associations
532 between actigraphically measured sleep parameters and body mass index. *Journal of Sleep*
533 *Research*. 2017;**26**(1):21-9.
- 534 50. Hendrickson KL, Rasmussen EB. Mindful eating reduces impulsive food choice in
535 adolescents and adults. *Health Psychology*. 2017;**36**(3):226-35.
- 536 51. VanderBroek-Stice L, Stojek MK, Beach SRH, VanDellen MR, MacKillop J.
537 Multidimensional assessment of impulsivity in relation to obesity and food addiction.
538 *Appetite*. 2017;**112**:59-68.
- 539 52. Jarmolowicz DP, Cherry JBC, Reed DD, Bruce JM, Crespi JM, Lusk JL, et al. Robust
540 relation between temporal discounting rates and body mass. *Appetite*. 2014;**78**:63-7.

- 541 53. Courtemanche C, Heutel G, McAlvanah P. Impatience, incentives and obesity. *Econ J.*
542 2015;**125**(582):1-31.
- 543 54. Kang MI, Ikeda S. Time discounting, present biases, and health-related behaviors:
544 Evidence from Japan. *Econ Hum Biol.* 2016;**21**:122-36.
- 545 55. Appelhans BM, Woolf K, Pagoto SL, Schneider KL, Whited MC, Liebman R. Inhibiting
546 food reward: Delay discounting, food reward sensitivity, and palatable food intake in
547 overweight and obese women. *Obesity.* 2011;**19**(11):2175-82.
- 548 56. Appelhans BM, Waring ME, Schneider KL, Pagoto SL, DeBiasse MA, Whited MC, et al.
549 Delay discounting and intake of ready-to-eat and away-from-home foods in overweight and
550 obese women. *Appetite.* 2012;**59**(2):576-84.
- 551 57. Bongers P, van de Giessen E, Roefs A, Nederkoorn C, Booij J, van den Brink W, et al.
552 Being impulsive and obese increases susceptibility to speeded detection of high-calorie
553 foods. *Health Psychology.* 2015;**34**(6):677-85.
- 554 58. Buono FDW, Seth W.; Sprong, Matthew E. Decision-making deficient in overweight
555 and obese adolescents: Evidence from door open and delay discounting tasks. *Behavior*
556 *Analysis: Research and Practice.* 2015;**15**(2):9.
- 557 59. Chen GC, Tai-sheng; Li, Zhi-hua; Liu, Wen-li. Decision-making deficient in overweight
558 and obese adolescents: Evidence from door open and delay discounting tasks. *Chinese*
559 *Journal of Clinical Psychology.* 2015;**23**(1):10.

- 560 60. Eisenstein SA, Gredysa DM, Antenor-Dorsey JA, Green L, Arbelaez AM, Koller JM, et
561 al. Insulin, central dopamine D2 receptors, and monetary reward discounting in obesity. Plos
562 One. 2015;**10**(7).
- 563 61. Epstein LH, Jankowiak N, Fletcher KD, Carr KA, Nederkoorn C, Raynor HA, et al.
564 Women who are motivated to eat and discount the future are more obese. Obesity.
565 2014;**22**(6):1394-9.
- 566 62. Garza KB, Harris CV, Bolding MS. Examination of value of the future and health
567 beliefs to explain dietary and physical activity behaviors. Res Soc Admin Pharm.
568 2013;**9**(6):851-62.
- 569 63. Garza KB, Ding M, Owensby JK, Zizza CA. Impulsivity and fast-food consumption: A
570 cross-sectional study among working adults. Journal of the Academy of Nutrition and
571 Dietetics. 2016;**116**(1):61-8.
- 572 64. Hsu AS, Vlaev I. Monetary cost for time spent in everyday physical activities. Soc Sci
573 Med. 2014;**108**:74-80.
- 574 65. Lu QY, Tao FB, Hou FL, Zhang ZC, Sun Y, Xu YY, et al. Cortisol reactivity, delay
575 discounting and percent body fat in Chinese urban young adolescents. Appetite. 2014;**72**:13-
576 20.
- 577 66. Manwaring JL, Green L, Myerson J, Strube MJ, Wilfley DE. Discounting of various
578 types of rewards by women with and without binge eating disorder: Evidence for general
579 rather than specific differences. Psychol Rec. 2011;**61**(4):561-82.

- 580 67. Rasmussen EB, Lawyer SR, Reilly W. Percent body fat is related to delay and
581 probability discounting for food in humans. *Behav Process.* 2010;**83**(1):23-30.
- 582 68. Weller RE, Cook EW, Avsar KB, Cox JE. Obese women show greater delay discounting
583 than healthy-weight women. *Appetite.* 2008;**51**(3):563-9.
- 584 69. Thamotharan S, Lange K, Ramos A, Fields S. Examining weight concern and delay
585 discounting in adolescent females. *Eating Behaviors.* 2016;**21**:228-31.
- 586 70. Borghans L, Golsteyn BHH. Time discounting and the body mass index: Evidence
587 from the Netherlands. *Econ Hum Biol.* 2006;**4**(1):39-61.
- 588 71. Davis C, Patte K, Curtis C, Reid C. Immediate pleasures and future consequences. A
589 neuropsychological study of binge eating and obesity. *Appetite.* 2010;**54**(1):208-13.
- 590 72. Dodd MC. Intertemporal discounting as a risk factor for high BMI: Evidence from
591 Australia, 2008. *Econ Hum Biol.* 2014;**12**:83-97.
- 592 73. Ikeda S, Kang MI, Ohtake F. Hyperbolic discounting, the sign effect, and the body
593 mass index. *J Health Econ.* 2010;**29**(2):268-84.
- 594 74. Tu Q, Donkers B, Melenberg B, van Soest A. The time preference of gains and losses
595 2004 [March 7, 2018]. Available from:
596 https://www.researchgate.net/publication/265893119_The_Time_Preference_of_Gains_and_Losses.
597 [d Losses](https://www.researchgate.net/publication/265893119_The_Time_Preference_of_Gains_and_Losses).
- 598 75. Schiff S, Amodio P, Testa G, Nardi M, Montagnese S, Caregaro L, et al. Impulsivity
599 toward food reward is related to BMI: Evidence from intertemporal choice in obese and
600 normal-weight individuals. *Brain and Cognition.* 2016;**110**:112-9.

601 76. Takagi D, Kondo N, Takada M, Hashimoto H. Educational attainment, time
602 preference, and health-related behaviors: A mediation analysis from the J-SHINE survey. Soc
603 Sci Med. 2016;**153**:116-22.

604 77. Wang M, Rieger MO, Hens T. How time preferences differ: Evidence from 53
605 countries. Journal of Economic Psychology. 2016;**52**:115-35.

606 78. Bickel WK, Moody L, Higgins ST. Some current dimensions of the behavioral
607 economics of health-related behavior change. Prev Med. 2016;**92**:16-23.

608 79. Bickel WK, Miller ML, Yi R, Kowal BP, Lindquist DM, Pitcock JA. Behavioral and
609 neuroeconomics of drug addiction: Competing neural systems and temporal discounting
610 processes. Drug Alcohol Depen. 2007;**90**:S85-S91.

611 80. Koffarnus MN, Jarmolowicz DP, Mueller ET, Bickel WK. Changing delay discounting in
612 the light of the competing neurobehavioral decision systems theory: A review. J Exp Anal
613 Behav. 2013;**99**(1):32-57.

614 81. Matjasko JL, Cawley JH, Baker-Goering MM, Yokum DV. Applying behavioral
615 economics to public health policy illustrative examples and promising directions. Am J Prev
616 Med. 2016;**50**(5):S13-S9.

617