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Exercise as a reward: Self-paced exercise perception and delay discounting in comparison with food and money

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ABSTRACT

Exercise is an important health behavior. Expressed reasons for participation are often delayed outcomes i.e. health threats and benefits, but also enjoyment. However, we do not know how people evaluate exercise as a reward. The value of rewards diminish the longer we have to wait for them and the discounting effect can undermine decision-making. Here, we investigated delay-discounting of exercise perception and its valuation with time delays; we conducted self-paced exercise sessions on treadmill and compared the discounting rates of exercise (k_{ex}) with those of established rewards of food (k_{fo}) and money (k_m). Outcomes show, that young, moderately active participants (n = 70) preferred walking/running intensity with low to moderate cardiovascular strain and light perceived exertion. Delay discounting rates (k) indicated that exercise was discounted like other consumable rewards at the same rate as food and more rapidly than monetary rewards. Significant associations were detected of k_{ex} with preferred speed and with extrinsic exercise motivation. Exercise training (n = 16) reduced k_{ex} specifically, not affecting k_{fo}. Our studies show, that participants perceived and discounted self-paced walking/running like a consumable reward. Exercise discounting was quicker in individuals who preferred lower speeds being less physically active and exercise training reduced the decay rate of exercise specifically.

1. Introduction

Exercise is widely acknowledged as a highly important health behaviour, which reduces the risk of death by 25–35% arising from cardiovascular disease, diabetes and cancer [94]. However, 31% of the worldwide population are physically inactive and only a minority of the population complete the recommended daily amount of physical activity [37]. While most people are well informed about the health benefits of exercise, various barriers reduce exercise participation; 'time' and 'motivation' are the most prevalent reasons for reduced physical activity [43,80].

Several behavioural theories have been applied to exercise participation [4], while the theory of planned behaviour is the most frequently used [1,3,35,39]. Most theories highlight cognitive processes related to knowledge about benefits and threats and developed attitudes, as well as behavioural control as important factors for exercise behaviour. Cognitive evaluation theory, however, puts more emphasis on motivation to perform a behaviour in relation to its value as a reward [20] and its relevance was, for example, shown for physical activity participation of pupils [56]. However, it is less clear whether exercise is perceived as a reward per se and in comparison with established rewards like food or money. Animal models provide overwhelming evidence that exercise might be perceived as rewarding; rats and mice choose to run spontaneously on running wheels and learn to work for access to running wheels [34]. Whereas wheel running is a stereotypical behaviour, even wild mice in natural habitat select wheel running as elected behaviour [61]. Moreover, mice emitted specific calls during and in anticipation of exercise known only in connection with palatable food rewards and social play [42]. Indeed, voluntary running can promote neuroplastic adaptation in the corticolimbic reward circuits of the brain [40].

In humans, even in face of mass participation in sports, it is difficult to say whether mice and man are similar in relation to exercise perception. Though, indirect evidence may help to understand whether exercise is perceived and valuated as a reward in humans.

The value of rewards typically diminish with the delays animals and people have to wait for their delivery; i.e. their values are time-discounted. In contrast, the perceived value of costs and punishments are much more stable over time [52,63].

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Delay discounting (DD) is the term typically used to describe the devaluation of rewards over time [47,90]. In general, immediate rewards are preferred over later rewards, and larger rewards are preferred over smaller rewards. However, choice options are more complex if they differ in more than one dimension; for example, a choice between a smaller reward available sooner and a larger reward available later [33]. Measuring the rate of discounting involves presenting a series of forced-choices between a smaller reward available immediately and a larger delayed reward. Over the course of the choice options, the smaller sooner reward value is adjusted incrementally to identify the point at which the individual "switches" from choosing the larger delayed reward value to choosing the smaller, sooner value [33]. This value, termed the "indifference point" (IP), represents the current subjective value of the larger reward. Preference reversals occur because the subjective value of smaller, sooner rewards increases more than that of larger, later rewards when there is an equivalent decrease in the delays to the two rewards. The rate of decline (k) in the reward value at IP over delays is commonly derived using a hyperbolic function [59] and k for a particular person depends on the type of the reward, its sign (loss or gain), and size. Consequently, k values can give us information about the relative time-dependence of different kinds of rewards; a frequent finding being that several rewards (foods and cigarettes for smokers) are discounted more rapidly than money [66].

k values are also related to a person's sensitivity to reward delay and it is shown that steeper discounters are more impulsive [65]; and people who engage in negative health behaviours (smoking, gambling, alcohol consumption, drug use) generally discount rewards steeper than controls [53,96]. Additionally, percent body fat was a significant and consistent predictor of discounting rates for food in adult participants [74]. Indeed, higher body mass was found to be strongly related to choosing a more immediate monetary reward using the Monetary Choice Questionnaire (MCQ) [46].

Exercise, similar to other health behaviours, seems to pose a conflict between short-term and long-term consequences of one's actions. For example, exercise could require people to sacrifice things that give them short-term pleasure such as eating highly palatable caloric foods or watching television for the long-term benefits of physical fitness. However, this thought would already assume that exercise in itself would be less rewarding for the individual than food intake and watching television.

van Beek and colleagues [91] have shown that behaviour-specific time orientation differentially predicts eating and exercising behaviour using an adopted exercise version of the Consideration of Future Consequences Scale (CFC-Exercise). Discounting rate of money can improve the prediction of exercise frequency [19]. Moreover, Garza and colleagues [30] demonstrated a significant association between high k values of money discounting with fewer health behaviours, including weekly vigorous physical activity. However, to date, there have been no studies investigating the DD of exercise as a tested commodity. Here, we investigated DD of exercise in comparison with food and money in healthy adults to establish whether exercise is discounted like rewards such as food and money. Moreover, we investigated whether body characteristics, physical activity, and selected physiological and psychometric measures were associated with k values of exercise, food and money. Due to the possibility of variable former positive or negative experiences with exercise, the participants took part in two exercise trials before the discounting tasks to establish the most pleasant exercise based on self-selection of intensity in locomotion on a treadmill. Locomotion (walking/running) was selected based on the assumption that this kind of physical activity should be more likely to be perceived as pleasant due to evolutional selection (hunter/gatherers, herders) [55] and being, in this case, void of social components which could influence perception. Moreover, self-selected exercise has been shown to be perceived as more pleasant and enjoyable than imposed settings [78]. In a second study, we investigated the influence of 3 weeks exercise training on discounting of exercise and food, as well as on self-selected exercise intensity.

For the first study, we hypothesized that the newly validated exercise experience would be discounted similarly to established rewards of food and money; the value of k for exercise would be quantitatively similar to the k for food being a consumable reward rather than of a transferrable reward like money.

Exercise motivation is an important factor for exercise participation [45]. However, some exercise motives e.g. enjoyment and social play, being defined as internal motives, can be also seen as immediate rewards, while others like fitness, weight, and health, being defined as external motives [22], are delayed in goal attainment. It was shown earlier that exercise participation was positively associated with future temporal perspective [87] and negatively associated with temporal discounting of money [89]. Consequently, we hypothesized that elevated exercise motivation should report more exercise participation, while individuals with higher proportion of external exercise motivation should show smaller k exercise values due to higher contribution of delayed outcomes (i.e. 'fitness', 'health') in their exercise valuation. Accordingly, individuals with higher physical activity would select higher exercise intensities due to improved exercise tolerance. For the second study, we hypothesized that exercise training, emphasizing delayed goals ('fitness'), would have a specific effect, e.g. reducing k value for exercise, on exercise discounting rather than a generalized effect of reward discounting. We also expected participants to self-select higher exercise intensity after the training.

2. Materials & methods

2.1. Study 1

2.1.1. Participants

After ethical approval by the ethics committee of the School of Sport, Health and Exercise Science, Bangor University (ethics number: S/PhD02-15/16), 73 subjects (38 males and 35 females) were recruited in Bangor area, UK. In study 1, university students formed 92% of the sample; while in study 2, 11 out of 16 were students (68%). They were invited to come to the PAWB laboratory, Bangor University, on 4 occasions within a period 2 weeks. Participants received £40 as a reimbursement for their time. The sample size for this study was based on a power analysis, aimed to detect a significant difference in discounting rates between money and food [18], and no significant difference between food and exercise, using G*Power 3.1.9.2, Wilcoxon Signed Rank Test and (matched pairs) assuming a two-sided significance level of 5%, a sample size of 18 would have 80% power to detect an effect size of 0.948 between the food and money. For correlation analysis, based on the correlation found between money and food discount rates ($r = 0.33$ $p < 0.001$) in [18], using α (two-tailes) = 0.05, $\beta = 0.20$ according to [49], a sample size of 70 was calculated to find moderate correlations between commodities.

2.1.2. Physical characteristics

Weight and body composition (e.g. percent body fat) was assessed via bioelectrical impedance measurement using Tanita BC-418 MA system. Participants' height was measured using a standard stadiometer. Additionally, a standard sphygmomanometer was used to measure seated brachial arterial blood pressure for health screening before each exercise session.

2.1.3. Self-report measures

Participants were asked to fill out the following questionnaires:

Monetary Choice Questionnaire (MCQ) [48], is a 27-item questionnaire which assesses delay discounting of money using a set of choices between hypothetical monetary rewards of different magnitudes/values delivered at different delays; Cronbach's alpha (CRα): 0.98 [21].

Food Craving Questionnaire-Trait (FCQ-T) [12] measures craving for foods, without confining them to certain categories, and covers

behavioural, cognitive and physiological aspects of cravings with 39-items. The overall CRα for the FCQ-T in this study was 0.871.

Exercise motivation Inventory (EMI 2) [57] assesses exercise participation motives applicable to both exercisers and non-exercisers. EMI-2 consists of 14 domains, which are Stress Management, Revitalization, Enjoyment, Challenge, Social Recognition, Affiliation, Competition, Health Pressures, Ill-Health Avoidance, Positive Health, Weight Management, Appearance, Strength and Endurance, and Nimbleness. Each subscale includes 3–4 questions, of which the scores mean is calculated. We used the items challenge, affiliation, revitalization, and enjoyment as intrinsic factors (this study, Crα: 0.788), and appearance, weight management, positive health, health pressure, ill-health avoidance, and strength/endurance as extrinsic factors (this study, Crα: 0.713), according to Egli et al. [22]. Further motives (e.g., social recognition, stress management) are more difficult to classify along dichotomous categories and were included in the total exercise motivation score (this study, Crα: 0.825).

Barrat Impulsivity Scale (BIS II) [68] measures the personality/behavioural construct of impulsiveness based on scaling frequencies of common impulsive or non-impulsive behaviours and preferences. CRα was reported to be between 0.71 and 0.83 [93].

Physical Activity Readiness Questionnaire (PAR-Q) [14,83] for assessment of potential health risks in association with physical activity participation.

International Physical Activity Questionnaire (IPAQ) [26] is a standardised self-report measure of habitual physical activity. Reliability was tested over 12 countries: Spearman's *rho* 0.81 [15].

Lark or Owl Questionnaire: a self-assessment Morningness-Eveningness questionnaire [44] for estimation of sleep-wake cycles and preferred peak time for cognitive and physical performance. CRα for our age group: 0.87 [73].

General Positive and Negative Affect Schedule PANAS-G [54] to assess average mood state using two 10-item scales; CRα: 0.88 [11]; this study, CRα: 0.688.

General Health Questionnaire (Bangor University) for assessing general health status.

2.1.4. Procedure

2.1.4.1. First visit. Participants were informed to wear comfortable clothing that allows exercising on all visits. They were introduced to the protocol, consent was given, and asked to fill out self-report questionnaires (see *self-reported measures*), followed by measuring body characteristics. Then, participants were asked to walk for about 3 to 5 min on the treadmill (h/p/cosmos®) to be familiarised with the exercise and manual settings of the treadmill for the further visits.

2.1.4.2. Second visit. The goal for the exercise trials (2nd to 3rd visit) was to establish the most pleasant/enjoyable exercise intensity possible for each participant in order to establish a specific exercise experience that could serve as an exercise reward for the DD task. The exercise intensity was set by repetitively self-adjusting the treadmill speed during the trials (see below). Social desirability and demand characteristics were minimized by emphasizing the aim to find the optimal exercise intensity for the participant's enjoyment using the same verbal protocol for all assessments and involving four different experimenters for reduction of bias and interpersonal contact.

All trials were performed using the same treadmill; during the exercise period, a nature soundtrack consisting of bird and forest sounds was played through speakers while the participants were facing a natural scenery through a wide window. This was performed to reduce possible negative effects of the technical environment on participants' perception. The heart rate (HR) was monitored throughout and after the end of the exercise sessions with a HR monitor (Polar RS800CX). Exercise trials were terminated after 30 min or whenever the participant chose to end it earlier. The sessions were separated by at least 48 h and maximally by one week. Before each exercise trial, the participants were asked to fill in the State Food Cravings Questionnaire (FCQ—S) [12] and the PANAS-moment [54] followed by a warm-up on a cycler ergometer (Lode Excalibur) for 3 min before stepping on the treadmill.

For the first exercise trial, participants started walking on the treadmill at 3 km/h; display of speed and time was disclosed from individuals in all trials. They were instructed to find the most pleasant exercise intensity they could adjust by modifying the speed of the treadmill using the control panel; it was emphasized that the experiment was not about fitness or performance. Participants were told that the exercise duration was up to 30 min maximally. After 2 min of exercise, participants were asked to rate the pleasantness of exercise using the 11-point Likert Feeling Scale (FS) that ranges from −5 to 5; anchors are provided at zero ('Neutral') and at all odd integers, ranging from 'Very Good' (5) to 'Very Bad' (−5) [38]. For the rating, the participants were asked 'How do you rate the current exercise of being pleasant?'. Participants could modify the treadmill speed every two minutes in order to optimise pleasantness, e.g. increasing or decreasing the speed (selection could be made during the first 30 s of the two minutes). Rating of current pleasantness was requested after the two-minute period elapsed; any set values were not visible for participants. Participants were cooling down after 30 min exercise before leaving.

2.1.4.3. Third visit. The second exercise trial had the goal to reconfirm the setting and experience of the self-selected exercise. After filling in state questionnaires and warm up (see above), participants walked on the treadmill at 3 km/h and the speed was elevated gradually to the preferred speed selected in the first exercise trial by the experimenter and held for further 2 min. The researcher then manipulated the speed by increasing and decreasing it by 10% of the preferred speed level, each period for 2 min, while pleasantness was rated every 2 min to confirm optimal setting of the preferred speed [23]. Thereafter, a 5 min rest was given and participants performed a further 5–10 min bout at the preferred speed to validate perception and to reinforce the feeling regarding this exercise bout.

After a resting period of about 10 min, participants were introduced to the DD task on the computer.

2.1.4.3.1. Delay discounting (DD) tasks. Each participant was verbally introduced to the task and also read the introductions and followed instructions on the computer screen. The DD tasks were generated using a specially designed computer programme based on the paradigm described by [76] using Inquisit™ program (developed by Milliseconds Software). The indifference points (IP) for each time delay of rewards for the modalities money, food and exercise were obtained by randomization between delays and amount of rewards. The sooner, smaller hypothetical reward was offered 'at the end of this session' (closest time point) and after 1, 7, 30, 60 and 180 days delay. The values of the three commodity rewards were adjusted between the three commodities based on their monetary value [13,74]. The adjustment of the rewards was masked by randomization between delays and amount of rewards, and with the progression of the test, distractors were displayed to prevent the subject from predicting the questions and unmasking the underlying technique of the test as recommended by [76]. The program terminated automatically and saved the experimental data after predetermined IP criteria had been achieved. Each computer task took about 4–6 min to be finished.

Money DD task:

For the money rewards, the amounts were (£2–£7-£12-£17-£22-£27-£32-£37-£42-£47 and £50).

Food DD task.

For the reward of food, the offered amounts were 5, 10, 15, 20 and 30 bites (1 plate); 60 bites (2 plates), 90 bites (3 plates), 120 bites (4 plates), and 150 bites (5 plates) of food as the largest reward.

Exercise DD task

For the exercise, the offered hypothetical exercises sessions were based on the formerly established treadmill exercise sessions (see above) and were fragmented into (5, 10, 15, 20, and 30 minutes (1 gym

session), 60 minutes (2 gym sessions), 90 minutes (3 gym sessions), 120 minutes (4 gym sessions) and 150 minutes (5 gym sessions); assuming that 1 gym session = 30 minutes of exercise. Participants were introduced to the exercise DD task including the following statement: "*In the following task, you will be asked to choose between two combinations of durations of your favourite exercise session and time delays; the questions will be displayed on the monitor. The exercise session will be exactly what you have enjoyed most, as established in the previous exercise trials. If you choose the delayed option, the imaginary exercise sessions will be available to you, but imagine that you don't have to perform the offered sessions in one go, and you have to imagine that other exercises will not affect the enjoyment of the offered favourite exercise session.*"

2.1.4.4. Fourth visit. The purpose of this exercise trial was to explore perception of perceived exertion at preferred exercise speed. This was not introduced during the previous two trials to avoid any cross-over effects between the two perceptual modalities. After the warm up, participants started walking on the treadmill and then the speed was gradually increased to the formerly self-selected preferred exercise speed by the experimenter; the speed as increased, as well as decreased, according to protocol of visit 3. Participants were asked to rate their perception of exertion every 2 min using Rate of Perceived Exertion scale [8] which starts from 6 (no exertion at all) to 20 (maximal exertion). The scale was appropriately anchored in the introduction before starting the exercise.

2.2. Study 2

2.2.1. Participants

After ethical approval by the ethics committee of the School of Sport, Health and Exercise Science, Bangor University (ethics number: P05–16/17), 18 subjects (9 females) were recruited from students and general public in Bangor, UK. Participants received £100 as a reimbursement for their time. For study 2, because of a lack of previous studies, we designed our a priori sample size calculation based on data from [84], which reported reduced discounting rates of money after a physical activity intervention. Based on their data, for finding a significant difference of k after training, sample size was calculated for a paired *t*-test (G*Power 3.1.9.2), alpha = 0.05, beta = 0.2; E = 0.48, SΔ = 0.69 with a sample size of 16.

The first phase of study 2 protocol was identical to study 1 (see above), however, after fourth visit participants started a running training on treadmill. Training consisted of 3 sessions per week of exercise training over three weeks. The exercise training was performed using an interval training protocol on treadmill [31] consisting of progressive peak training intensities between 65 and 85% of estimated maximal heart rate (HR_{max}). HR_{max} was calculated via 220 – age = HR_{max} which is suitable for our age group [88]. Target velocities for the treadmill were calculated by using heart rate / treadmill speed relationship from the assessment trials for preferred speed. Speed was adjusted manually if target heart rate was not achieved.

After a warm-up for 3 min, treadmill speed was gradually increased to participants' preferred speed (baseline). This was followed by intervals ramped from baseline to 65% HRmax over ~10 s, then held for 2 min, followed by slowing down to baseline speed over ~10 s; baseline speed was then held for further 2 min followed by the next cycle increasing intensity by 5% of HRmax. Five cycles were performed per training session (i.e. 65%, 70%, 75%, 80%, 85% of HRmax), exercise time ~30 min, followed by a cool-down at walking speed. All participants attended the nine training sessions over three weeks.

After the last training session, participants were asked to come to the laboratory within two days for further two visits. Both visits were identical to visit two and four of study 1 with the exception that only the discounting computer tasks for the modalities exercise and food where repeated and self-report questionnaires were not repeated.

3. Analysis

Mazur's equation [59] was used as a model to fit participants IPs data to nonlinear hyperbolic functions using least square fit method with Microsoft Excel Solver programme to obtain an individual representation for k values for each commodity. One participant's data was removed based on multiple outliers in exercise data; 15 participants' data were removed due to poor-fit of hyperbolic model ($R^2 < 0.7$). Cognitive demand of answering choice questions with parameters changing in two dimensions can lead to stereotypical answering causing poor hyperbolic fit of IPs; similar rates of data exclusion have been observed earlier [48,64]. Because most outcome variables were not normally distributed and could not be successfully transformed, non-parametric analysis was performed if not otherwise indicated. For repeated measures and multiple comparisons, Kruskal-Wallis test was used followed by Mann & Whitney *U* test with Bonferroni correction for multiple comparisons. Moreover, Mood's Median test was performed if more appropriate for data type, as indicated. For single comparisons, Mann & Whitney U test and Wilcoxon's Signed Rank tests were used, as indicated. Correlation analysis was performed using Spearman's correlation analysis. Data are displayed in median and 25 and 75 percentiles plus mean and standard deviation. Data were analysed using Statistical Package for the Social Science (IBM SPSS) version 24.

4. Results

4.1. 1. Study 1: Body characteristics and physical data

70 participants completed the study (35 males and 35 females); three participants withdrew from the study, two due health reasons and one without further explanation. Body characteristics and psychological self-report data are presented in Table 1; weight and percentage of body fat showed a significant effect of gender with females being lighter but having higher body fat, as expected. Participants were mostly young adults (24.9 (9.5) yrs.) of eutrophic BMI (24.09 (3.93) kg/m^2) and the majority reported high to moderate physical activity in the IPAQ: high (37), moderate (29) and low (5). Participants scored moderate levels of impulsivity questionnaire (BIS II), and the monetary choice questionnaire (MCQ) resulted in a median of $k_{Kirby} = 0.06$. The PANAS-PA and PANAS-NA (Table 1) revealed medium scores for positive affect and less than medium scores for negative affect. Furthermore, the cravings questionnaire (FCQ-T) reported medium cravings scores for the group (Table 1). Additionally, all participants were of a neutral type in the Lark and Owl questionnaire (not shown).

Table 1
Body characteristics and psychometric self-reports.

N = 70 (35 females)	Mean	STD (±)	
Age (yrs)	24.9	(9.5)	
Weight (kg)	72.46*	(13.27)	
BMI (kg/m^2)	24.09	(3.93)	
Percentage of body fat (%)	20.92*	(8.87)	
			Range of scores
BIS II	69.81	(8.08)	30–120
FCQ-T	125.15	(25.59)	39–234
PANAS-G-PA	35.94	(6.06)	10–50
PANAS-G-NA	17.66	(5.79)	10–50
MCQ-k_{Kirby}	0.041 Median	(0.074) 25th percentile	75th percentile
	0.006	0.0025	0.0256
IPAQ	high = 37	moderate = 29	low = 5

* significant ($p < 0.05$) effect of gender (independent t-test).

Table 2
Exercise motivation and exercise characteristics.

N = 70	Mean	STD (±)	Median	25th Percentile	75th Percentile
EMI 2 (Range: 0–5)					
Intrinsic Exercise Motivation	3.33	(1.00)	3.53	2.79	3.97
Extrinsic Exercise Motivation	3.12	(0.78)	3.12	2.66	3.63
Intrinsic Plus Extrinsic Exercise Motivation	3.32	(0.82)	3.29	2.68	3.97
Exercise Motivation	3.26	(0.74)	3.29	2.78	3.73
Preferred Speed (km/h)	5.60	(2.25)	5.00	3.90	6.20
Average HR (bpm)	120.73	(23.50)	112.00	103.00	135.50
RPE (range: 6–20)	10.13	(2.06)	10.00	9.00	12.00
Feeling Scale (Range: −5/0/5)	4.47	(0.78)			
1st Exercise Trial			5.00	4.00	5.00
2nd Exercise Trial	4.41	(0.84)	5.00	4.00	5.00

4.1.1. Exercise motivation and self-selected exercise data

Baseline EMI-2 scores showed generally moderate exercise motivation. Integrating the domains into groups of intrinsic, extrinsic, extrinsic plus extrinsic, and overall exercise motivation showed that motivation domains were not significantly different in scores (Kruskal-Wallis test).

In the trials for self-selection of exercise intensity on the treadmill, the average feeling scores were above four (4.47 (0.78) and 4.41 (0.84)) in both trials (5 = 'Very Good'; Table 2) showing that participants successfully adjusted the treadmill to an intensity which they could enjoy. Preferred speed of the locomotion was median: 5.0 km/h, and mean (SD): 5.60 (2.25) km/h; the heart rate revealed low to moderate cardiovascular strain (median: 112 min^{-1} and mean (SD): 120.73 (23.50) min^{-1}). Moreover, rate of perceived exertion scores (RPE) showed preference for a perceived exertion during exercise described as being between 'very light' and 'light' (RPE: median: 10.00; mean (SD): 10.13 (2.06)), (Table 2).

4.1.2. DD of money, food and exercise

The computer based DD tasks generated indifference points for the tested modalities of money, food, and the formerly established exercise on treadmill. Fifty-five complete sets across all three commodities of the 70 participants were included in the analyses due poor fits; however, n-numbers for the specific sets of variables are higher and given in the table (Table 3). Curves for the three modalities using the hyperbolic fit are shown in Fig. 1. Non-parametric statistical analysis using Kruskal-Wallis test showed a significant difference between k values (Chi-Square = 59.85, df = 2, asymptotic significance < 0.001); pairwise follow up tests, using Mann-Whitney *U* tests, revealed a significant difference between k_m and k_{ex}, (U = 641.0, asymptotic significance < 0.001) and k_m and k_{fo} (U = 669.5, asymptotic significance < 0.001), respectively. However, no difference between k_{fo} and k_{ex} were reported (U = 1749.5, asymptotic significance = 0.267), Bonferroni critical value: p = 0.017, Table 3.

4.1.3. Correlation analysis

Spearman's correlation analysis reported significant association between the DD rates k_m of the computer task and k_{Kirby} of the MCQ [48], *rho* = 0.301, p = 0.015, *n* = 65; k_{fo} and k_{ex} were not significantly associated with k_{Kirby}. However, k_m of our study was positively correlated with k_{ex} (*rho* = 0.364, p = 0.006, *n* = 56) but not with k_{fo}. Associations between participants' body characteristics and k values were

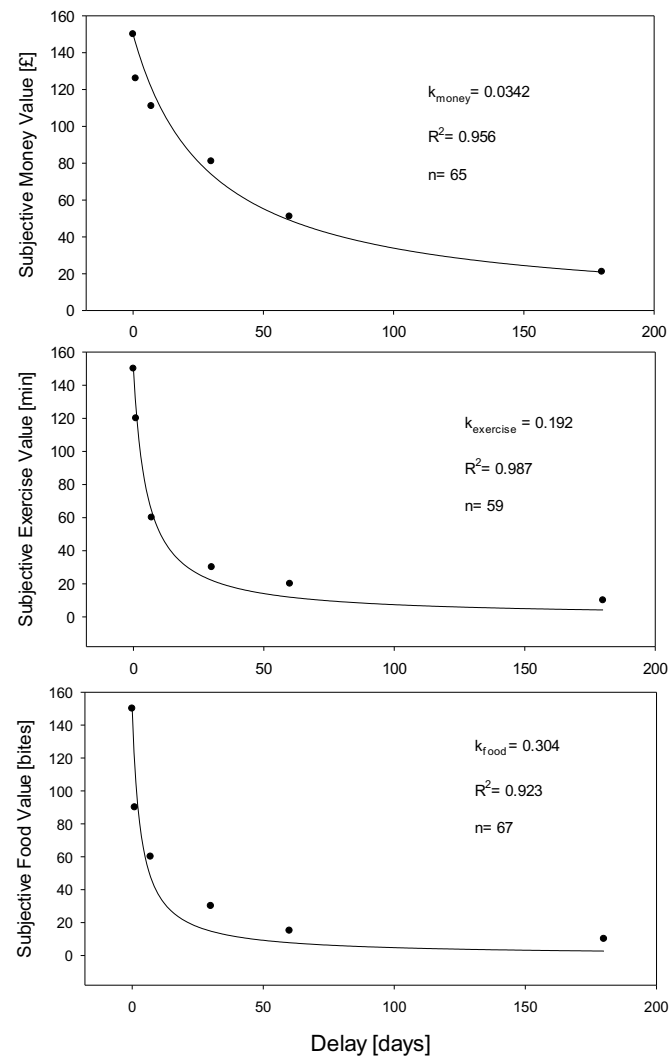

Fig. 1. Median indifference values from delay discounting of modalities money, exercise and food with fit lines using Mazur's hyperbolic discounting model (1987). Notice that values in graphs do not match values in Table 3 due to differences in data processing.

Table 3
DD constants (k) of money, exercise, and food.

	Mean	STD (±)	Median	25th percentile	75th percentile	R^2 mean	STD (±)
k_m (*n* = 65)	0.078	(0.13)	0.021*	0.009	0.088	0.852	(0.148)
k_{ex} (*n* = 59)	0.281	(0.285)	0.144	0.079	0.421	0.820	(0.111)
k_{fo} (*n* = 67)	0.339	(0.299)	0.208	0.100	0.586	0.886	(0.115)

* significant different from k_{ex} and k_{fo}, asymp. Sig. < 0.001. k_m: k money, k_{ex}: k exercise, k_{fo}: k food.

Table 4
Correlations between DD k values and exercise characteristics and motivation.

	k_m	k_{ex}	k_{fo}	Preferred Speed (km/h)	Average HR (min^{-1})	RPE	Activity Level
k_{ex}	0.364*						
	0.006						
	56						
k_{fo}	0.159	0.262					
	0.209	0.052					
	64	56					
Preferred Speed (km/h)	−0.115	−0.285*	−0.245*				
	0.361	0.029	0.046				
	65	59	67				
Average HR (min^{-1})	−0.257*	0.114	−0.205	0.559*			
	0.038	0.389	0.096	0.000			
	65	59	67	70			
RPE	−0.019	−0.178	−0.225	0.424*	0.377*		
	0.882	0.176	0.067	0.000	0.001		
	65	59	67	70	70		
Activity Level	−0.173	−0.233	−0.020	0.385*	0.107	0.129	
	0.169	0.076	0.874	0.001	0.380	0.287	
	65	59	67	70	70	70	
EMI Intrinsic	−0.008	−0.112	0.044	0.248*	0.243*	0.193	0.294*
	0.947	0.397	0.724	0.038	0.043	0.109	0.013
	65	59	67	70	70	70	70
EMI Extrinsic	−0.206	−0.334*	−0.279*	0.284*	0.292	0.202	0.403*
	0.099	0.010	0.022	0.038	0.014	0.094	0.001
	65	59	67	70	70	70	70
EMI Intrinsic Plus Extrinsic	−0.195	−0.261*	−0.123	0.269*	0.277*	0.150	0.420*
	0.120	0.045	0.320	0.024	0.020	0.216	0.000
	65	59	67	70	70	70	70
EMI Mean Score	−0.158	−0.266*	−0.153	0.296*	0.289*	0.186	0.445*
	0.208	0.042	0.216	0.013	0.015	0124	0.000
	65	59	67	70	70	70	70

Numbers in boxes: Spearman's *rho* over *p*-value over n-number.
* significant $p < 0.05$.

all not significant. Correlation analysis between k values and self-selected exercise characteristics and exercise motivation reported several significant associations (Table 4). Indeed, k_{ex} showed negative associations with preferred speed and exercise motivation domains; participants who discounted the self- selected exercise faster selected a lower speed on the treadmill and reported lower exercise motivation (with exception of the intrinsic domain). Additionally, associations between physical activity levels and exercise motivation were moderate, showing that participants with higher exercise motivation were more physically active (Table 4).

Moreover, overall exercise motivation was lower in individuals with higher body fat percentage (*rho* = −0.305, p = 0.01, n = 70), while the intrinsic domain, as well as the intrinsic plus extrinsic domain had significant weak to moderate negative associations with body fat percentage and BMI (not shown). There were no significant associations between k values and other self-reported questionnaires.

4.2. Study 2

Sixteen participants finished the 3 weeks training study; two participants withdrew from the study due to personal reasons. Body and self-report characteristics are shown in Table 5.

All participants' characteristics were similar to the characteristics of participants in study 1.

As in Study 1, participants' baseline discounting rates (k values) showed faster discounting for food and exercise than money (Table 6); (Kruskal-Wallis test: Chi squared = 22.320, df = 2, Asymp. Sig. < 0.0001; Mann-Whitney U test: k_m versus k_{ex}, U = 23.00, Asymp. Sig. < 0.001; k_m versus k_{fo}, U = 17.00, Asymp. Sig. < 0.001). Exercise training for three weeks altered delayed discounting rate for k_{ex} specifically (Table 6). Wilcoxon's Signed Rank test showed significant reduction of k_{ex} from median: 0.315 (mean (SD): 0.365 (0.280)) at baseline to median: 0.107 (mean (SD): 0.170 (0.177)) after training; pre-post k_{ex}, Z = −3.206, Asymp.Sig. (2-tailed) = 0.001. However, k_{fo} values were unchanged after the training period (Table 6). Moreover, exercise characteristics showed that exercise training significantly altered the preferred speed exercising on the treadmill from pre, median: 4.60 km/h (mean (SD): 5.04 (1.16) km/h) to post, median: 5.75 km/h (mean (SD): 6.13 (0.98) km/h); Wilcoxon's Signed Rank Test, Z = −3.521, Asymp.Sig. (2-tailed) < 0.001. Other parameters remained unaltered (Table 6).

Table 5
Body characteristics and psychometric self-reports.

N = 16 (9 females)	Mean	STD (±)			
Age (yrs.)	23.19	(3.49)			
Weight (kg)	67.77	(12.27)			
BMI (kg/m^2)	24.09	(3.93)			
Percentage of body fat (%)	25.38	(9.07)			
					Range of scores
BIS II	72.50	(14.00)			30–120
FCQ-T	131.06	(29.02)			39–234
PANAS-G-PA	38.56	(7.70)			10–50
PANAS-G-NA	13.25	(3.38)			10–50
MCQ-k_{Kirby}	0.058	(0.083)	Median	25th percentile	75th percentile
			0.016	0.006	0.0813
IPAQ	high = 4	mod. = 10	low = 2		
EMI 2	Mean	STD	Median	25th percentile	75th percentile
Intrinsic	3.32	(0.93)	3.50	2.45	3.94
Extrinsic	3.28	(0.81)	3.26	2.52	4.10
Intrinsic plus extrinsic	3.10	(0.75)	3.28	2.52	3.67
Exercise motivation	3.23	(0.75)	3.30	2.56	3.80

Table 6
DD rate constants and exercise characteristics pre and post training.

$N = 16$	Mean	STD (±)	Median	25th Percentile	75th Percentile
k_m	0.043	0.073	0.018[b]	0.010	0.040
k_{ex} pre	0.365	(0.280)	0.315	0.104	0.570
k_{ex} post	0.170	(0.177)	0.107[a]	0.040	0.302
k_{fo} pre	0.408	(0.391)	0.369	0.107	0.476
k_{fo} post	0.464	(0.350)	0.397	0.175	0.732
Preferred Speed (km/h) Pre	5.04	(1.16)	4.60	4.30	5.45
Preferred Speed (km/h) Post	6.13	(0.98)	5.75[a]	5.50	6.58
Average HR (bpm) Pre	124.38	(14.48)	124.50	113.00	134.00
Average HR (bpm) Post	121.63	(10.70)	123.00	111.00	131.25
RPE (range: 6–20) Pre	10.44	(1.50)	11.00	9.00	11.00
RPE (range: 6–20) Post	10.56	(1.15)	11.00	9.25	11.75
Feeling Scale (Range: −5/0/5) Exercise trial 1 Pre	4.00	(1.03)	4.00	3.00	5.00
Feeling Scale (Range: −5/0/5) Exercise trial 1 Post	4.25	(0.93)	4.50	4.00	5.00

[a] depicts significant differences between pre and post training k_{ex} values.
[b] depicts significant difference between k_m and both, k_{ex} and k_{fo} at baseline.

5. Discussion

In agreement with our first hypothesis, we found that predetermined self-selected exercise was discounted like a non-transferrable reward (i.e. food), while the subjective value of the transferrable reward (i.e. money) revealed slower decay in time; k_{ex} was not significantly different from k_{fo} but both were significantly larger than k_m. Indeed, it is suggestive from the values of k_{ex} that the exercise task at self-selected intensity seems not to be valuated as a cost or punishment; those modalities are shown to be much more stable over time with very low k values [52,63]. However, the fast decay of exercise valuation in time poses the question whether participants discounted exercise specifically, or only a non-transferrable hypothetical reward. Certainly, various commodities have been shown to be discounted with similar decay times (books, CDs) [13], which are unquestionably items that could be perceived as a reward having an objective monetary value. This could be questioned for our exercise task; the task is rather to perform than to receive. However, the pleasantness scores during the exercise task performance were high for all participants, which suggest that participants' positive affective response to the exercise task may have contributed to the faster discounting being an immediate response. Indeed, affective processes have been suggested to be integrated with cognitive processes for decision making during discounting [82]. In support of a specificity of reward discounting of exercise, in our second study, exercise training altered the value of k_{ex} specifically, which was not found for the k for food. Consequently, it is unlikely that exercise discounting was solely driven by its non-transferrable property.

The rapid decay of some modalities, unlike money, has been investigated before and was suggested to be related to specific theoretical aspects of those modalities [67]. They could be seen as primary reinforcers rather than conditioned reinforcers (money) [66], however, it could be shown that the difference in k values between money and fast decaying modalities disappears in probability discounting paradigms, which weakens this argument [24]. In terms of food, a further reason was suggested – the influence of visceral [51,92] perspective and therefore, in case of food, being influenced by the physiological state (satiation and hunger) of the individual. However, this seems unlikely for exercise in our case because participants were neither tired nor hungry (both states were excluded by participant information and hunger was assessed on trials). On the other hand, if we consider that exercise behaviour is part of other behaviours, the idea that there might be a visceral perspective is not entirely impossible. Exercise or physical activity, in its most basic function (locomotion), is certainly part of various behaviours, as example in foraging, hunting, social interaction, exploration. Exercise training can promote explorative behaviour in animal models [6]. Indeed, reduction in anxiety and depressive symptoms after exercise training are reported [9,41]. Positive effects of aerobic exercise on mood are well known and the involvement of endorphins and endocannabinoids were addressed in research studies [7,29,72]. Moreover, it was shown that exercise deprivation increases negative affect in humans [2]. Consequently, a visceral perspective for the valuation of exercise seems highly likely on closer inspection. The effect of visceral factors has been shown to be asymmetric over time and impact the immediate option much stronger than the delayed option in delay discounting trials [51]. Therefore, it is suggestive that k_{ex} is quantitatively similar to k_{fo} but both much larger than k_m for money, like it is apparent in our study.

A further influencing factor on k values has been shown to be the level of motivation for maximizing a reward [67]. For money, it is obvious that the motivation to maximize the reward is high due to its transferability; however, for food the motivation for maximizing reward was shown to be weak even in hungry individuals [77]. Clearly, in terms of evolution this makes sense because in a hungry/starved state any food will relieve from the negative state hunger and will enable survival instead of maximizing reward with large delays. This may be also true for exercise; we could assume that motivation for maximizing the discounted exercise session was similar to food due to the shared quality of being non-transferrable, and that exercise may act as a reward or relieves from a negative state based on a visceral component. The volume of exercise to induce a positive visceral effect may be well below what has been offered at maximum, which would make the preference for the immediate option more likely. In our study, we tried to match the objective monetary value of maximal food and exercise with that of money for avoidance of size effects, however, effects that are based on the modality of the rewards cannot be controlled for.

Certainly, motivation plays a large role for evaluation of commodities [67]. Exercise motivation has been investigated with varied instruments [62,70]; for our study we used the EMI-2, which enabled us to separate potential motives for exercise [58]. Based on our hypothesis of an influencing factor of exercise motivation for the discounting of exercise, we could show in our first study that there was a significant negative association between k_{ex} and self-reported exercise motivation (general, internal and external motivation) (EMI2). The stronger association of k_{ex} with external motives suggests that participants who were more motivated by external motives (like appearance, weight, and health) discounted exercise less steeply than people who were less motivated by those. External and internal motives for exercise

participation have been frequently investigated; internal motives related to enjoyment, competence, and social interaction were stronger than external motives, like appearance, health and weight motives, in people who had a high exercise participation [28,75]. Additionally, enjoyment motives were stronger in people who participated in sports with social component, and appearance motives stronger in gym goers [75]. According to the self-determination theory [79], appearance, health, and weight motives would be mainly extrinsic, while enjoyment and social engagement motives would be mainly intrinsic [22]. Besides the role of internal and external motives in relation to self-determination theory, evidently, internal motives of enjoyment and social engagement could also be interpreted as more immediate rewards, and appearance, health and weight as delayed rewards. Consequently, these motives gain relevance for discounting by looking at their time perspective and reported associations of k_{ex} with motives, in particular external motives, are therefore understandable. However, our tested population was young and moderately active, scoring generally high on the EMI and the external motivation scores were positively associated with general exercise motivation. These characteristic limit the generalizability of our findings to other population groups. Additionally, a differentiation between internal and external motives is not always clear; in particular, external motives can be internalized [79]. Indeed, positive association of health/fitness and body related motives with exercise participation have been published earlier [10,27,28,45].

Hypothetically, valuation of exercise could be driven by two systems, one visceral/affective which evaluates based on perceptual responses to intensity, duration and social components of exercise being immediate, and the other cognitive, integrating values of delayed outcomes (like appearance, weight, and health) into exercise valuation. Certainly, the systems involved, i.e. brain areas, should be similar to those described being involved in discounting of other modalities [32,60], However, contribution of delayed outcomes for the valuation of exercise should also depend on the type of exercise. In our example, the self-selected, low intensity walking on treadmill is certainly unlikely to be reinforcing motives related to delayed outcomes like health, weight and appearance. Indeed, higher intensities, as we have used in our training study, are well known to have properties that enable beneficial changes in delayed outcomes (fitness, health, weight, and appearance) [94], while being far above the preferred intensity. It is possible, in our training study, that attention towards delayed outcome motives may have been reinforced by the type of exercise training, which may have led to the observed shift in k values for exercise to lower values seen in our data; a mechanism suggested in discounting changes of other modalities [71]. In support of this, in our first study, k_{ex} was negatively associated with self-selected speed, and self-selected speed was positively associated with physical activity, showing that participants, who were more physically active, selected a higher speed and discounted the exercise more slowly. Indeed, physical activity was positively correlated with delayed external motives in the EMI2 questionnaire. However, in study 2, we did not retest exercise motives after the training to support this suggestion and due to the missing control group, former interpretations are conjectural and remain to be tested. Effects of exercise training on reward discounting was reported before, in other work, time perspective and money discounting was affected towards higher appreciation of delayed outcomes with reduction of k values, however, no specific exercise modality was assessed [84,87,89]. Additionally, the reverse relation was also found with altering the time perspective towards delayed outcomes improved physical activity in young adults [36].

The preference for a low to moderate intensity of exercise in self-selection tasks is known for a longer time [16]. In our study, the selected treadmill speed was close to the formerly reported speeds in other studies; additionally, RPE values and heart rate matched other reports [17,50]. Williams and Raynor [95] highlighted the importance of affective response for the selection of speed. Associations with body characteristics and physical activity, as well as exercise motivation are expected and have been formerly reported [23,69,78]. Preference for walking over running could depend on the lower energy costs for walking [5] and optimization of energy costs are shown to be automatically selected in humans during walking [81]. Positive affective response connected with the preference for lower speed, in this study and others [95] may be seen as an evolutional advantage for minimizing energy costs for locomotion [85].

5.1. Practical insights

In our studies, we showed that our healthy young participants preferred exercise intensities at the lower end of the recommended intensity for exercise adaptation even for clinical population [25]; however, our selection of exercise type (walking/running) certainly limits the generalization towards other types of exercise, where motivation to compete or perform might play a major role. A very important point from our investigation is that self-paced walking/running shows properties in a discounting paradigm that clearly support the notion that it is perceived as a reward. However, the fast discounting of exercise, similar to that of food, reveals a problem of our current environment. Food cues and foods are readily available and accessible everywhere, while exercise needs planning and is often connected with time delays due to transportation (driving to gym or sports venue). Consequently, exercise is bound to lose in a choice situation where food is present and exercise is delayed (e.g. for transportation) with k values of the modalities being similar. Clearly, based on the notion that k values have meaning for behavioural choices [86], changes in physical activity participation could be achieved if accessibility of exercise is improved (implementation in workspaces) and food accessibility is reduced (no sales of unhealthy foods on and close to school grounds and workspace). However, our data also suggest an important contribution of delayed external motives for discounting of exercise in our tested population; therefore, information about positive effects of exercise may still to be a valuable strategy and not without response.

In conclusion, our study shows, for the first time, that self-selected exercise on treadmill is discounted like an established non-transferrable reward (i.e. food) but faster than money using a delay discounting paradigm. Discounting of exercise was specific and was associated with exercise motivation and was sensitive to training, e.g. reduction of k_{ex} value. This can be interpreted as an indirect evidence that exercise is perceived as a reward in humans, while various exercise motives influence the valuation of exercise towards faster or slower discounting in time.

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Declarations of interest

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