Behavioral Economics and Exercise Reinforcement

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Behavioral Economics Theory

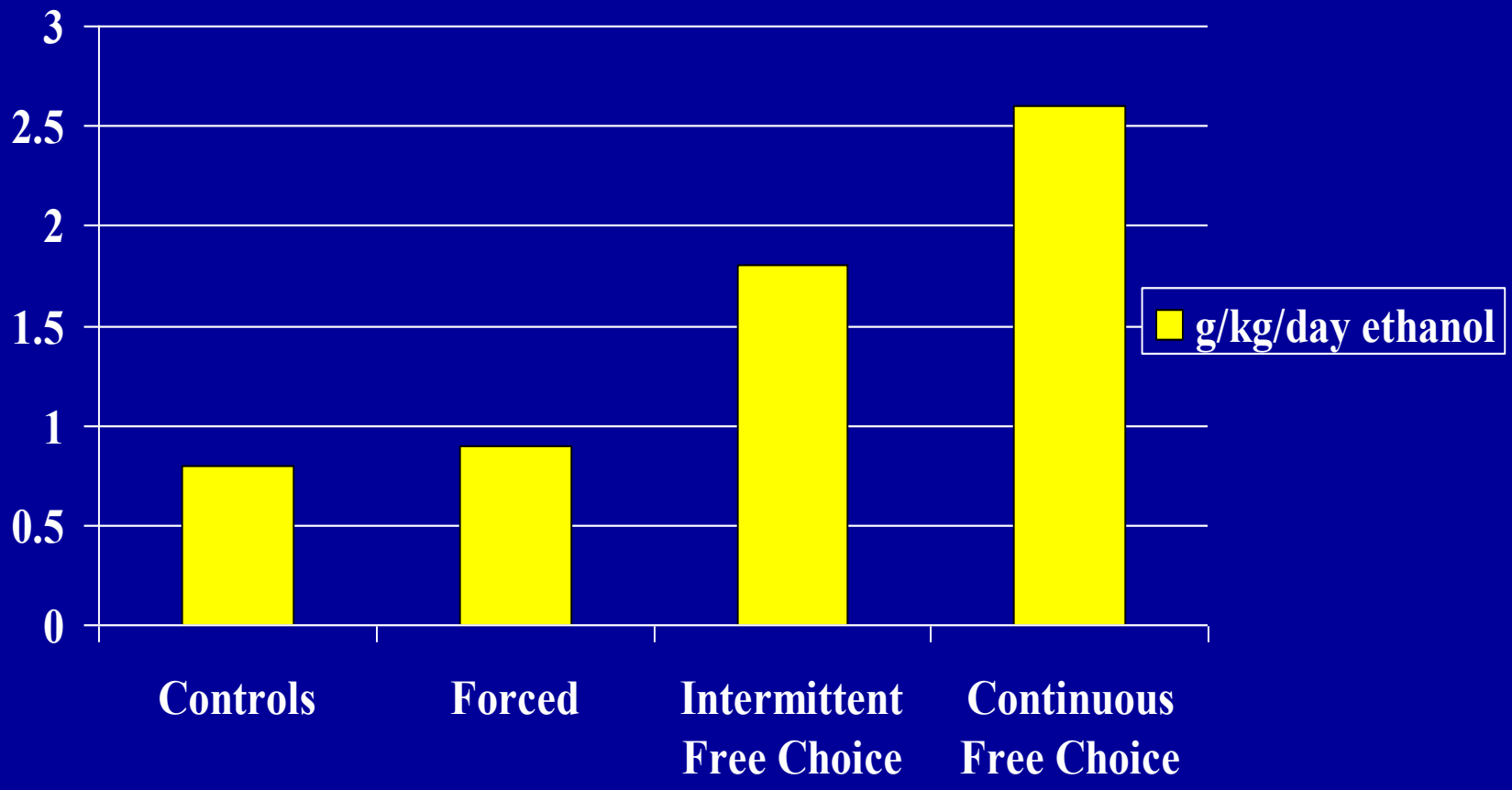
- Behavioral choice theory, or behavioral economics involves understanding processes that influence choice between two or more alternatives
- Based on extensive research from
  - Behavioral psychology
  - Cognitive psychology
  - Economics
  - Behavioral neuroscience

Importance of choice

Experimental Design: Alcohol Dependence

- Rats randomized to control, intermittent free choice (once per week), continuous free choice, or forced intake of ethanol
- Became dependent on ethanol over 32 weeks of drug administration
- Animals kept ethanol-abstinent for 3 months, during which time they showed withdrawal (change in pain threshold, hyperthermia, inactivity)
- Animals then provided self-administration test

Wolffgramm, J., Heyne, A. (1995). From controlled drug intake to loss of control: the irreversible development of drug addiction in the rat. Behavioural Brain Research, 70, 77-94.

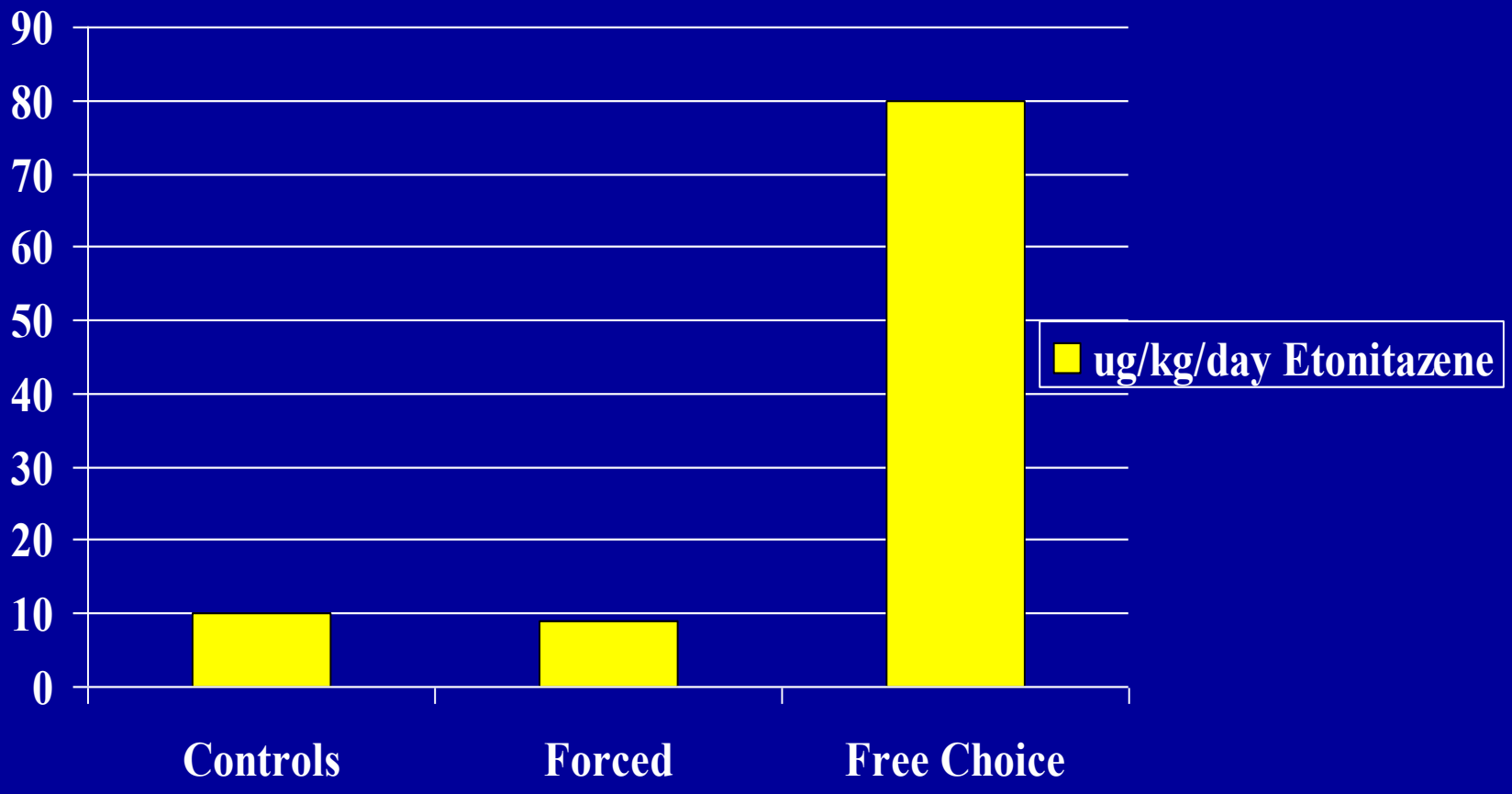


Wolffgramm, J., Heyne, A. (1995). From controlled drug intake to loss of control: the irreversible development of drug addiction in the rat Behavioural Brain Research, 70, 77-94.

Experimental Design : Opiate Dependence

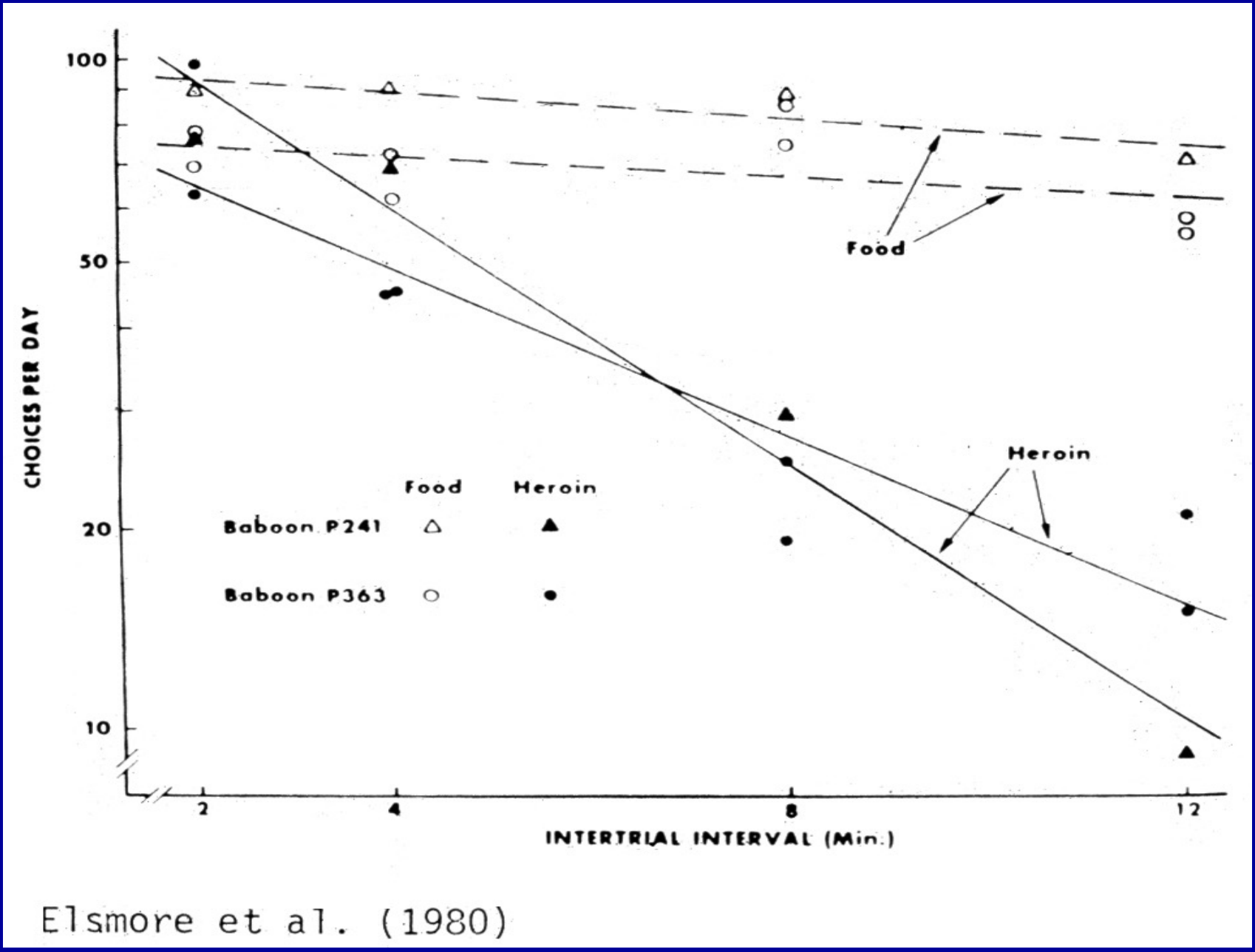
- Rats randomized to control, choice or forced intake of etonitazene
- Became dependent on opiate over 30 weeks of drug administration
- Animals kept opiate-abstinent for 19 weeks, during which time they showed withdrawal (change in pain threshold)
- Animals then provided self-administration test

Wolffgramm, J., Heyne, A. (1995). From controlled drug intake to loss of control: the irreversible development of drug addiction in the rat. Behavioural Brain Research, 70, 77-94.



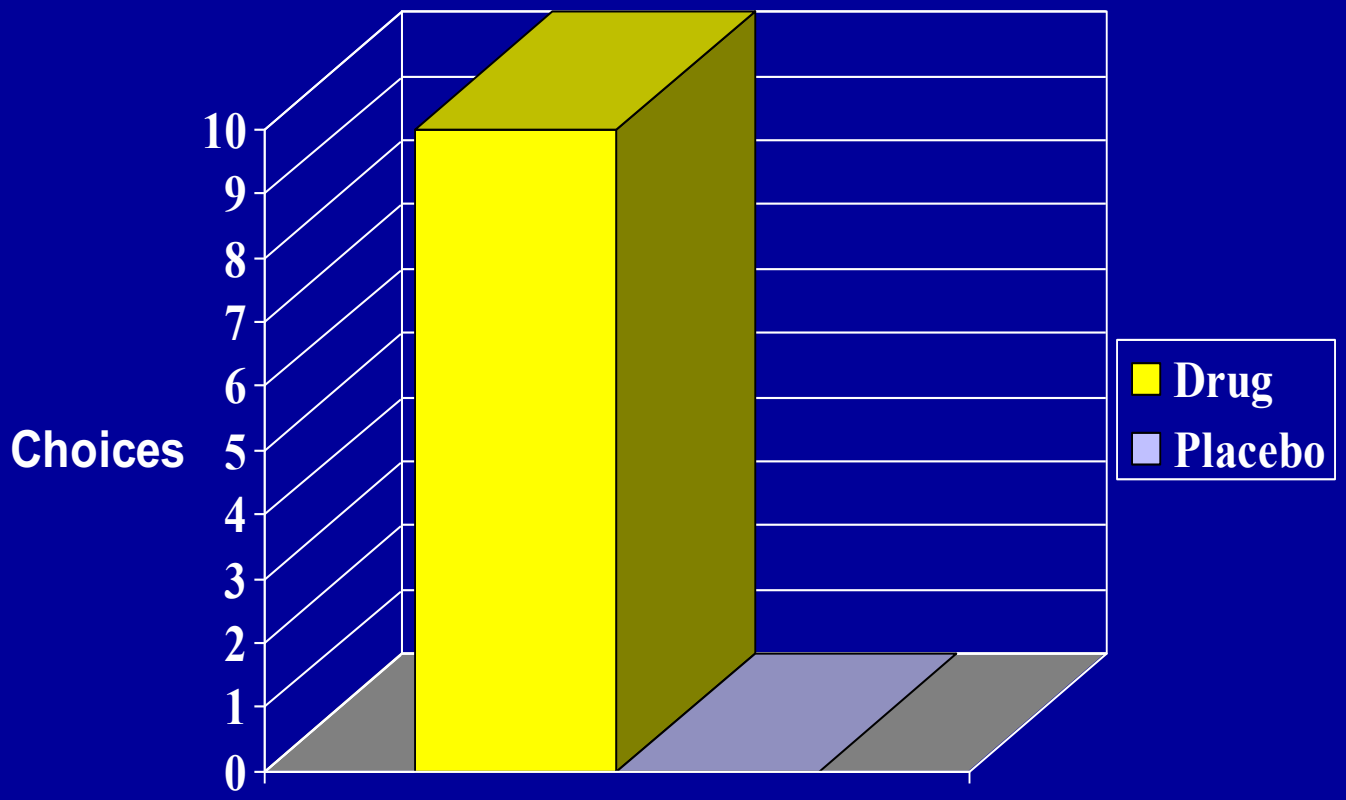
Wolffgramm, J., Heyne, A. (1995). From controlled drug intake to loss of control: the irreversible development of drug addiction in the rat Behavioural Brain Research, 70, 77-94.

Importance of alternatives



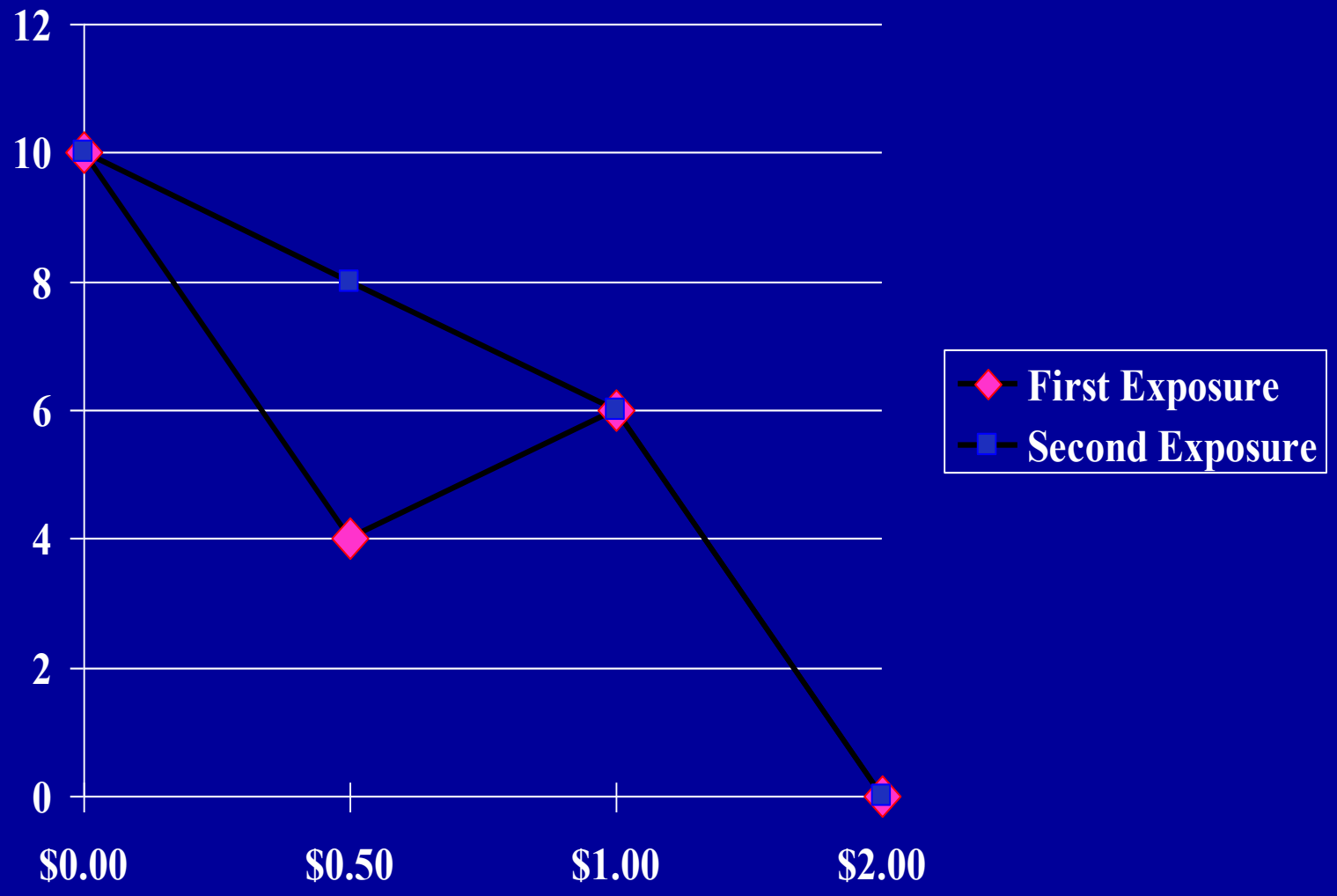
Elsmore, T. F., Fletcher, G. V., Conrad, D. G., & Sodetz, F. J. (1980). Reduction of heroin intake in baboons by an economic constraint. *Pharmacology, Biochemistry and Behavior, 13*, 729-731.

Choices for cocaine or placebo



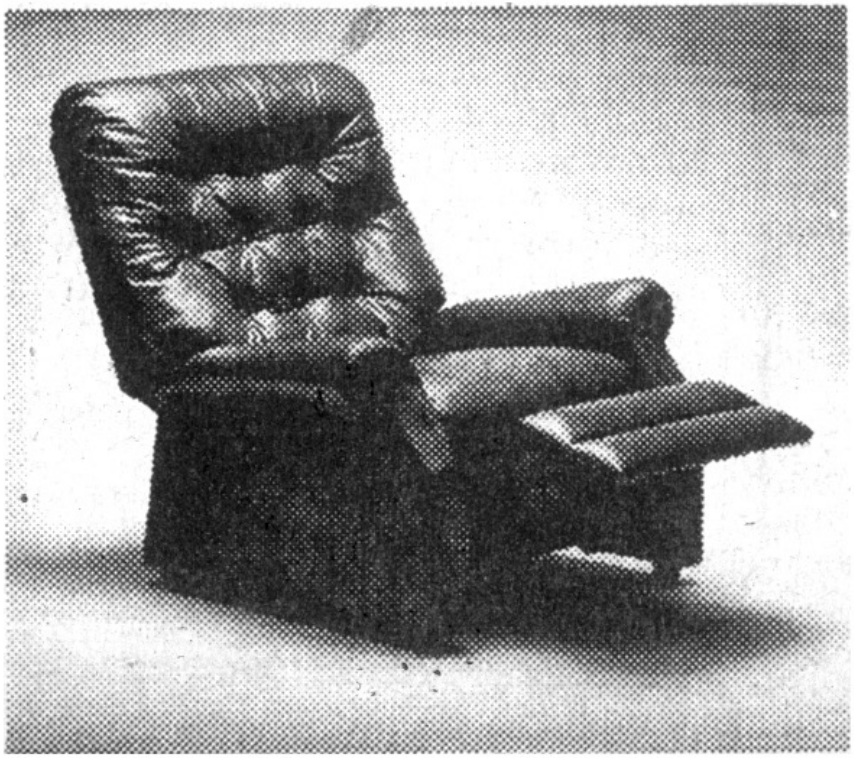
Higgins, Bickel & Hughes. (1994). Influence of an alternative reinforcer on human cocaine self-administration. Life Sciences, 55, 179-187.

Choices for cocaine or placebo



Higgins, Bickel & Hughes. (1994). Influence of an alternative reinforcer on human cocaine self-administration. Life Sciences, 55, 179-187.

It could be worse for your heart than cholesterol.



Behavioral economic relationships

- Relative reinforcing value
  - Determined by reinforcing value of the alternatives and the cost of the alternatives
- Elasticity
  - The relationship between cost and consumption
    - » Elasticity = consumption decreases when price increases
    - » Inelastic = consumption does not decrease when price increases
- Complements and Substitutes
  - A complement is when changes in behavior A are associated with changes in the **same** direction in Behavior B
    - » Increase vigorous physical activity, increase showers
  - A substitute is when changes in behavior A are associated with changes in the **opposite** direction in Behavior B
    - » Increase TV watching, decrease social interaction


I THINK I'LL TAKE A WALK


YOU'RE NOT GETTING ME TONIGHT


WHAT HAPPENED ?
IT GOT ME
DAN BUNG 7-8

Exercise/Activity Reinforcement

- The reinforcing value of exercise/physical activity describes how hard someone will work to get access to activity.
- Studied using progressive ratio schedules of reinforcement
  - Work progressively increases
- Participants do not exercise prior to assessment
- Work is on computer tasks that provide the reinforcer after the person meets response criteria
- Relative reinforcing value compares value of exercise versus alternative reinforcers
- Other related (but not the same) concepts include reward, incentive salience, hedonics, wanting
  - What would you do for a Klondike bar?

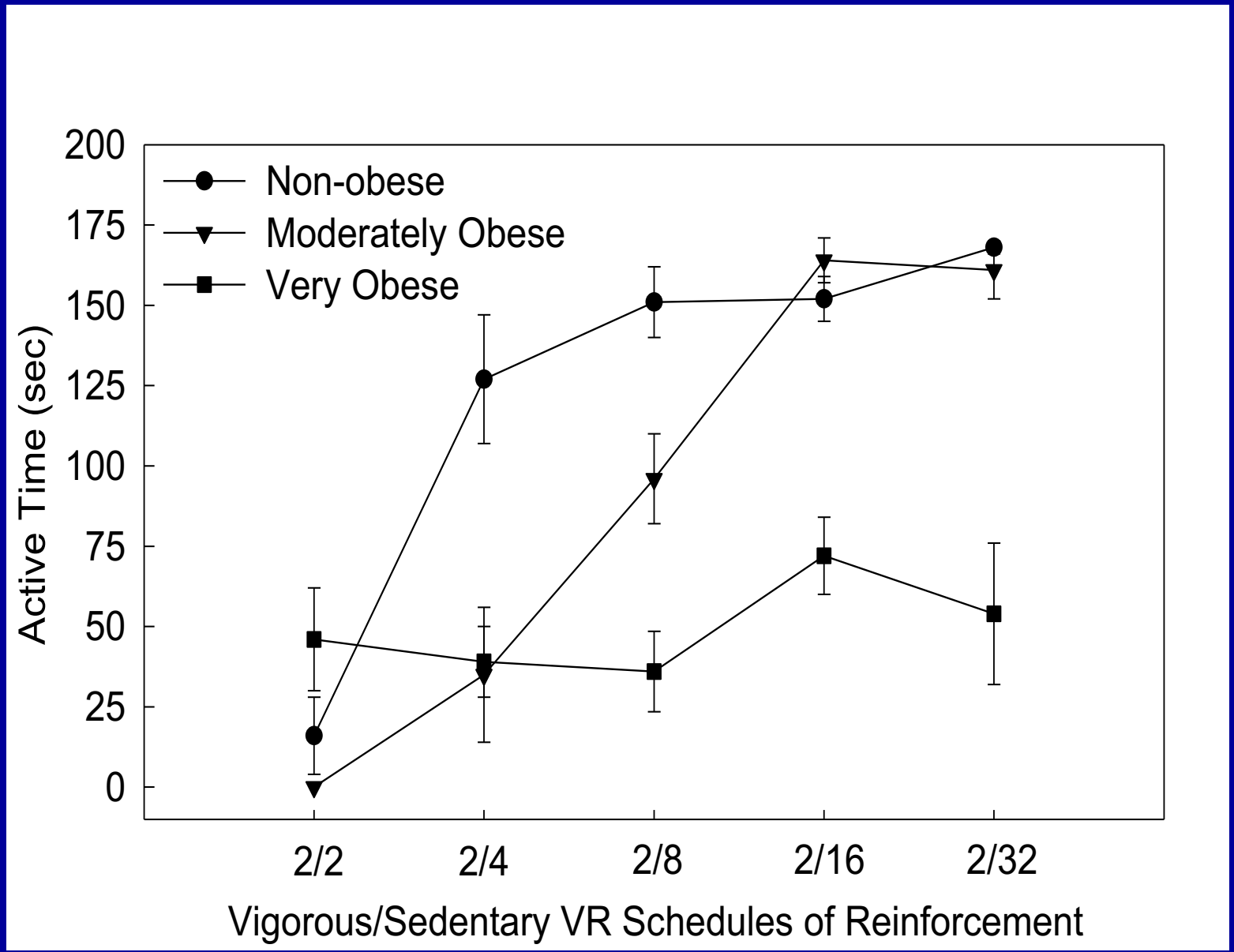
Exercise Reinforcement

- Both animals and humans will work to gain access to exercise
- Exercise activates mesolimbic reward pathways, increases dopamine in the striatum, hypothalamus, midbrain and brainstem, as well as showing conditioned place preference
- Behavioral genetic research suggests phenotypes associated with a reduction in DRD2 receptors (taqA1 allele) are predictive of increases in both food and exercise reinforcement

Reinforcing value of physical activity: Design

- Children in three categories:
  - Non-obese (<20% overweight)
  - Moderately obese (20-80% overweight)
  - Very obese (>80% overweight)
- Provided access to a moderately liked vigorous activity at a constant variable ratio (VR2) reinforcement schedule versus a highly liked sedentary activity with the schedule varied from VR2 to VR32.

Epstein, Smith, Vara, & Rodefer. (1991). Behavioral economic analysis of activity choice in obese children. Health Psychology, 10, 311-316.



Epstein, Smith, Vara, & Rodefer. (1991). Behavioral economic analysis of activity choice in obese children. Health Psychology, 10, 311-316.

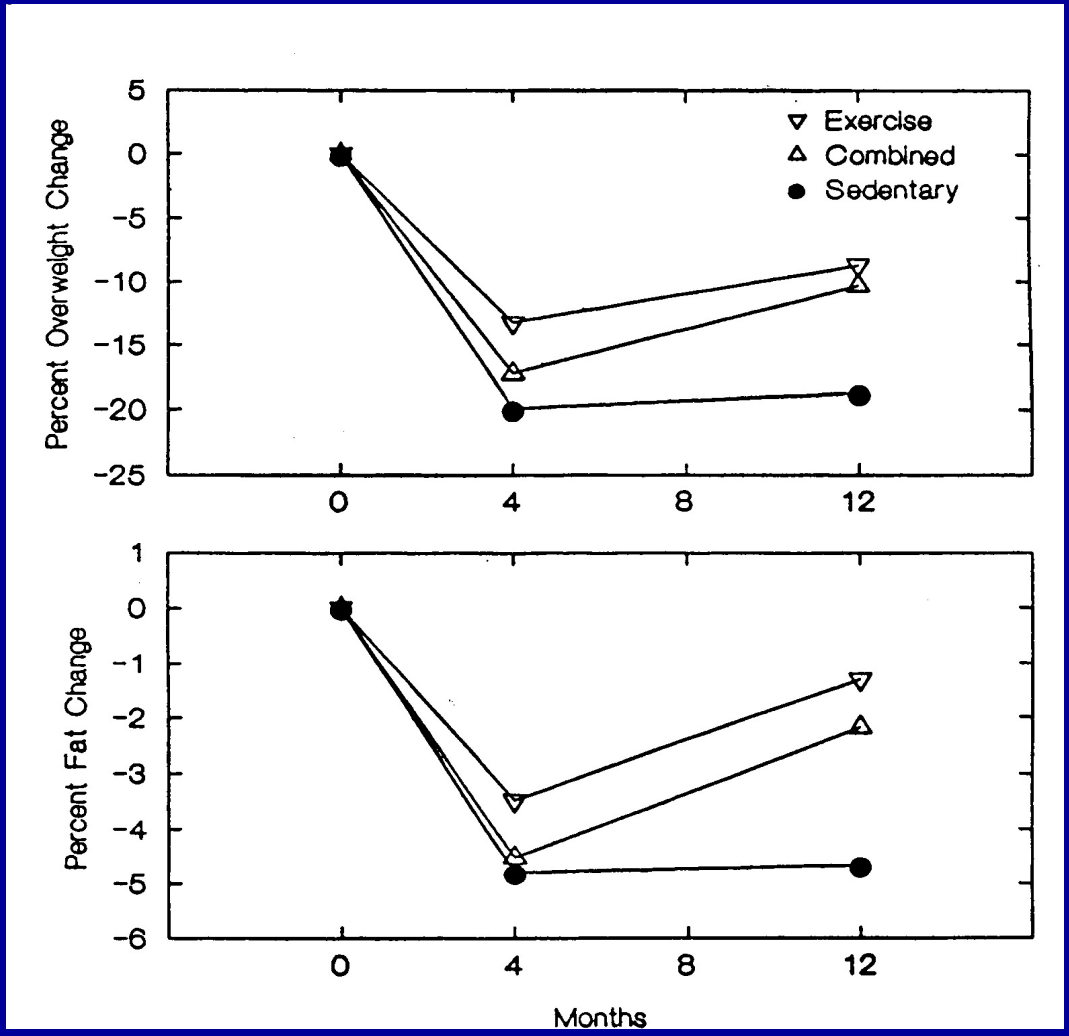
Role of reducing reinforcing sedentary alternatives

Effects of decreasing sedentary behavior versus increasing activity on weight change in obese children

- Obese 8-12 year-old children from 61 families randomized to groups that targeted:
  - Increased physical activity
  - Decreased sedentary behavior
  - Combined increased physical activity, decreased sedentary behavior
- Provided 4-month intensive treatment, followed at 12-month post randomization

Effects of decreasing sedentary behavior versus increasing activity on weight change in obese children

- Traffic light diet used for reducing calories, increasing nutrient density and balancing nutrient intake
- Increase activity goals from 30-150 points/week
  - 300-1500 kcal/week for a 150 lb person
- Decrease sedentary from 35 hours/week to goal of 15 hours/week
  - decreases in 5 hour increments



Epstein et al. (1995). Effects of decreasing sedentary behavior and increasing physical activity on weight change in obese children. Health Psychology, 14, 109-115.

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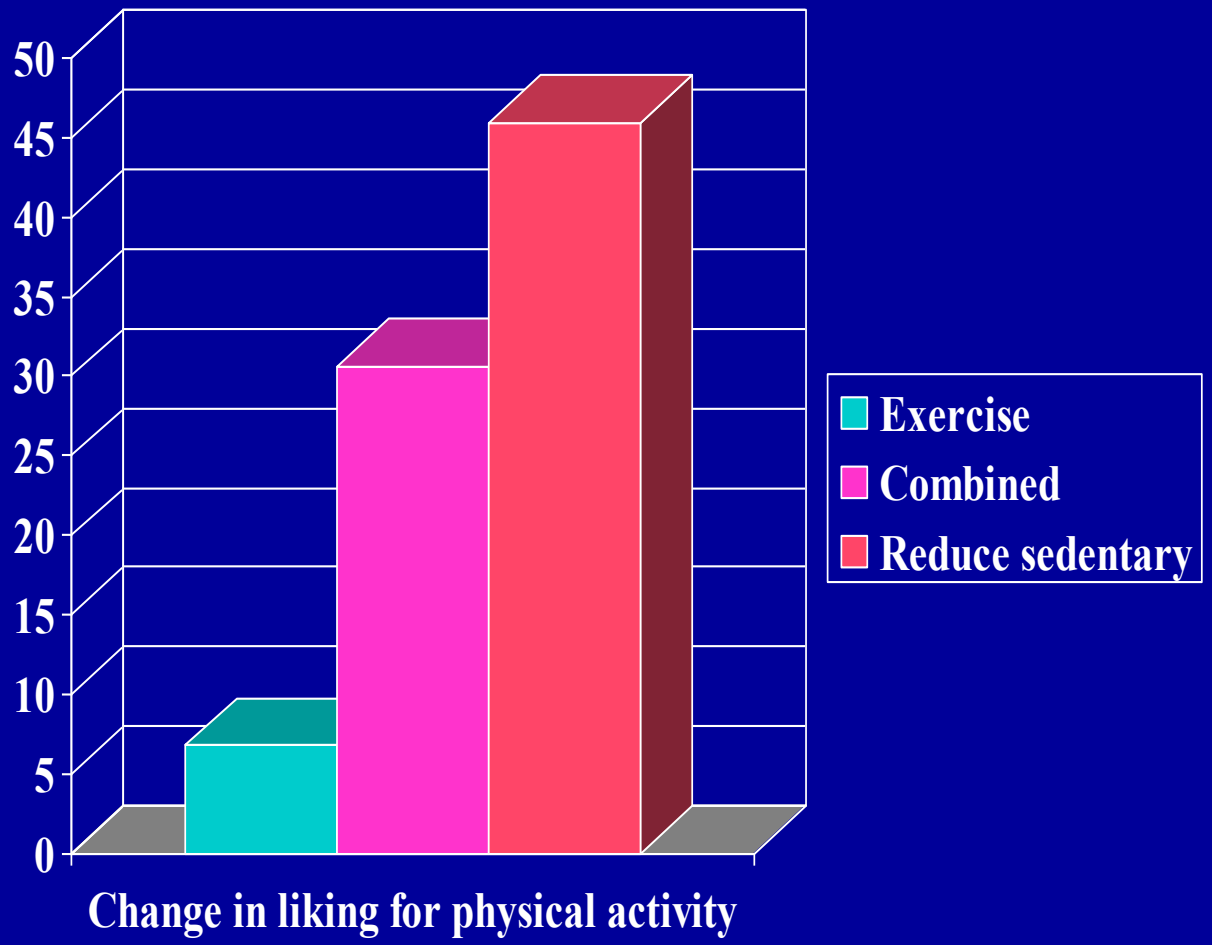


Can reducing television watching modify z-BMI in 4-7 year-old youth?

- Most programs to change body weight involve combinations of programs to decrease energy intake and increase physical activity
  - Reducing television watching may have an impact on body weight since the effects on reducing energy intake are potentially so strong
  - Even if the effects on physical activity are more limited

Epstein, et al, A randomized trial of the effects of reducing television viewing and computer use on body mass index in young children. Archives of Pediatric and Adolescent Medicine, 2008, 162, 239-245.

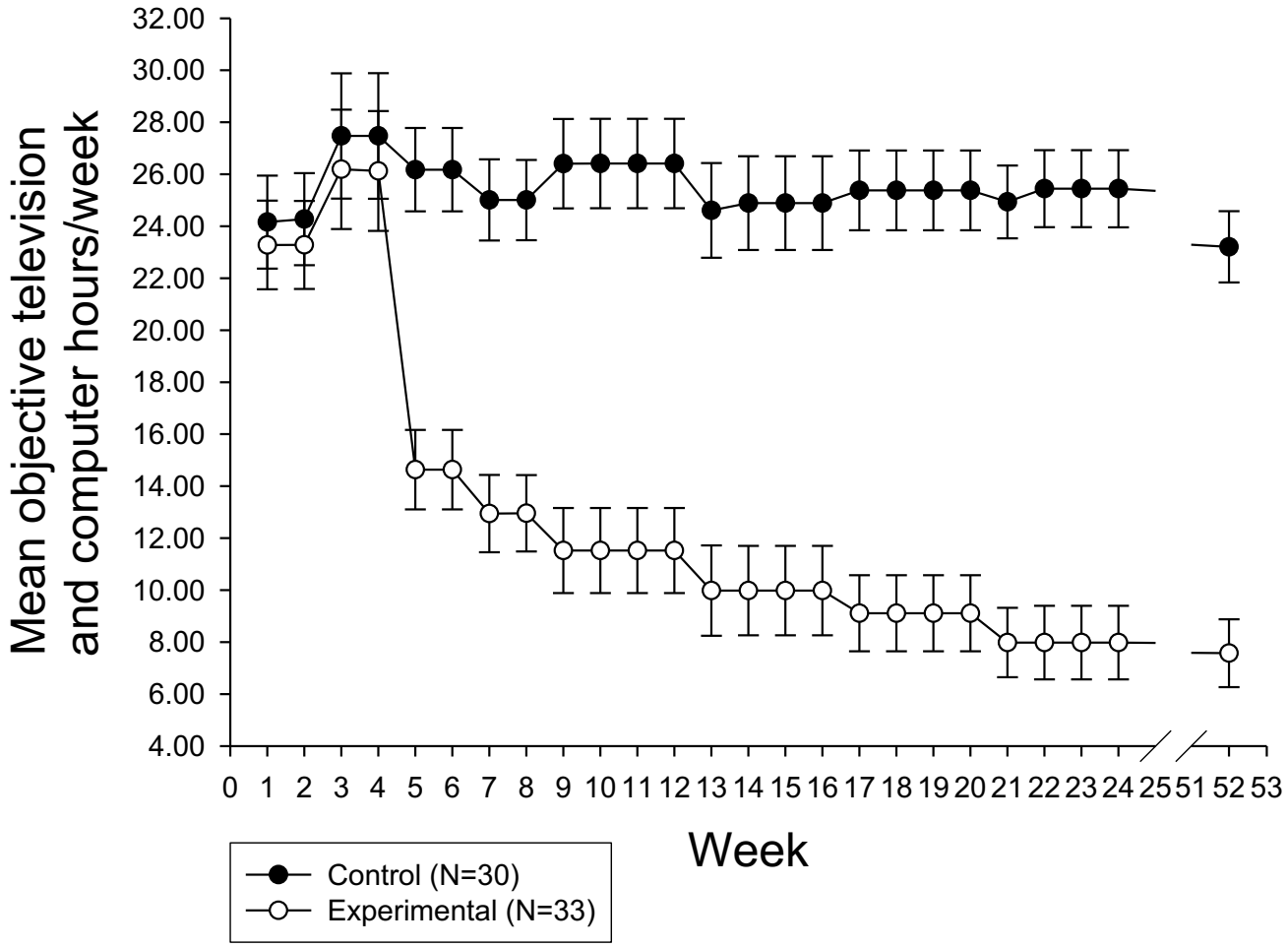


Figure 1. Child television and computer hours per week by group over one year.

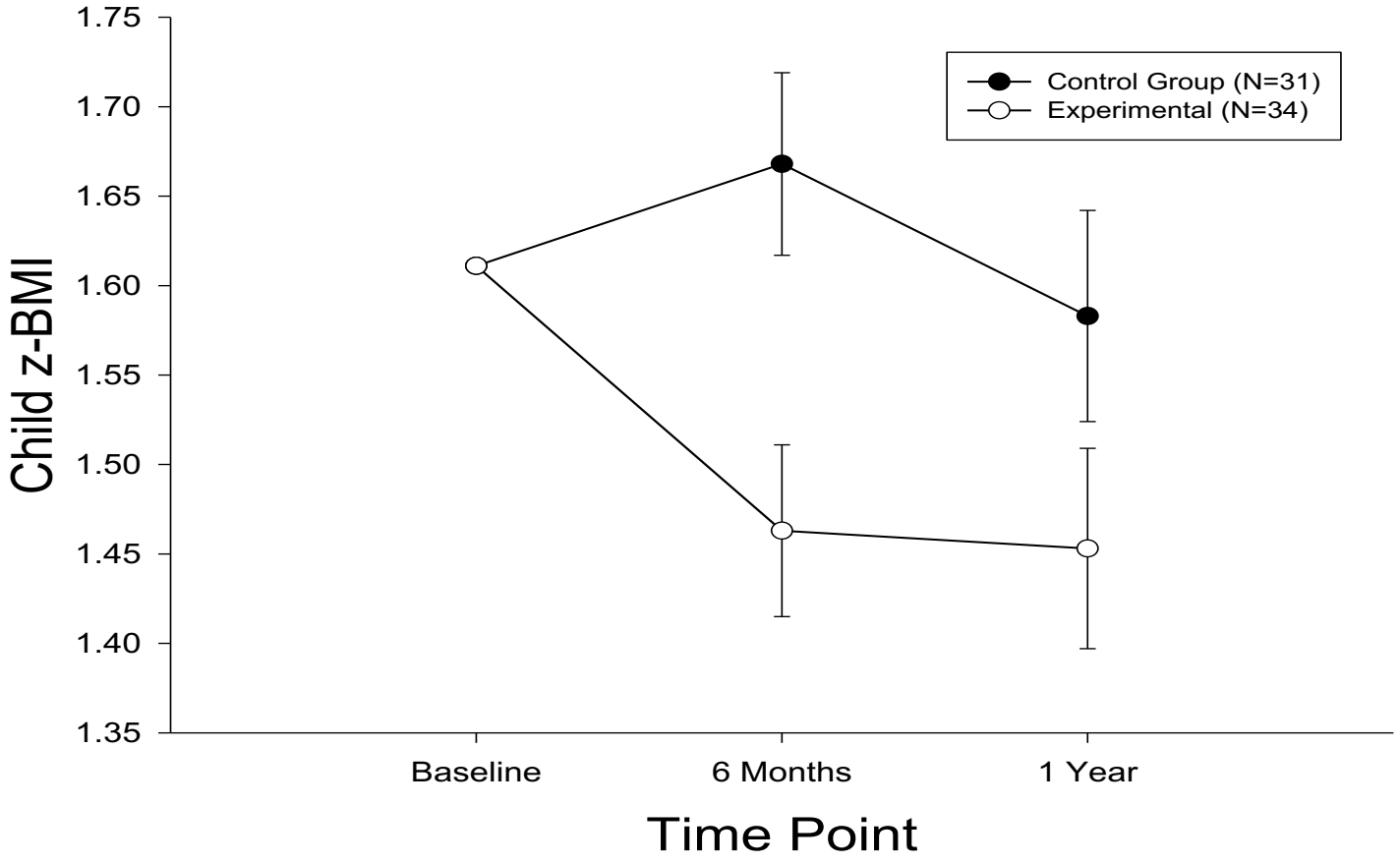


Figure 2. Child z-BMI at 0, 6, and 12 months by group.

Increasing the reinforcing value of exercise: Exercise sensitization

Increasing the motivation to be active

- If reducing sedentary behavior does not reliably increase physical activity in sedentary youth, then the other alternative is to increase the reinforcing value of exercise
- Reinforcement is a dynamic process, and reinforcing value can increase over time
  - This is called sensitization (Robinson and Berridge)
  - Sensitization is observed for many drugs of abuse, and for many palatable, high energy dense foods
  - Initiation of sensitization involves ventral tegmental area (VTA) while expression involves the nucleus accumbens
  - Increased wanting (motivation) related to brain dopaminergic activity
- Sensitization is generally related to large doses of a drug (or food), and intermittent presentation of the drug

Do people who find exercise more reinforcing engage in more exercise?

- Relationships between reinforcing value of exercise and activity levels have been shown for children (Epstein, 1999; Barkley, 2009)

- 88 people were studied
- Measures
  - RRV
  - Liking
  - Preference and tolerance of the Intensity of Exercise
  - Accelerometer measured activity
  - Yale Physical Activity Survey (resistance activity)

Flack, et al. The reinforcing value and liking of resistance training and aerobic exercise as predictors of adult's physical activity. 2017, Physiology & Behavior 179, 284-289.

Flack, et al. Aerobic and resistance exercise reinforcement and discomfort tolerance predict meeting activity guidelines. 2017, Physiology & Behavior, 180, 32-36.

Relationships with aerobic exercise

Table 2
Hierarchical regression results of the association of liking of aerobic exercise and the relative reinforcing value of aerobic exercise with weekly minutes of vigorous physical activity.[a]

Effect	Coefficient	SE	Standardized coefficient	R^b	ΔR^b
Step one (control variables)				0.024	
Intercept	1.62	0.69	0.00		
Age (years)	0.02	0.02	0.10		
Gender[c]	− 0.17	0.22	− 0.09		
BMI (kg/m^2)[d]	− 0.02	0.02	− 0.14		
Step two				0.027	0.002
$Liking_{AT}$[e]	0.05	0.10	0.05		
Step three				0.134*	0.101*
RRV_{AT}[f]	0.15	0.05	0.37		

Relationships with resistance exercise

Table 3
Hierarchical regression results of the association of liking of resistance training and the relative reinforcing value of resistance training with weekly minutes of vigorous physical activity.[a]

Effect	Coefficient	SE	Standardized coefficient	R^b	ΔR^b
Step one (control variables)				0.016	
Intercept	1.43	0.67	0.00		
Age (years)	0.13	0.02	0.09		
Gender[c]	− 0.18	0.22	− 0.09		
BMI (kg/m^b)[d]	− 0.02	0.02	− 0.09		
Step two				0.020	0.004
$Liking_{RT}$[e]	0.05	0.08	0.06		
Step three				0.174*	0.154*
RRV_{RT}[f]	0.19	0.05	0.46		

Can we increase the reinforcing value of exercise? I

- 104 sedentary men and women randomized, 89 people completed (86%)
- Randomized to 50 or 300 kcal/session, 3 sessions/wk or control
- 6 weeks of training, 4 weeks follow-up
- Train at self-selected intensity, monitored by Sense Wear monitor that monitored activity and estimated energy expenditure
- Measures
  - RRV
  - Liking
  - Preference and tolerance of the Intensity of Exercise
  - Accelerometer measured activity/sedentary behavior

Flack, et al. Inducing incentive sensitization of exercise reinforcement among adults who do not regularly exercise – A randomized controlled trial. PLoS ONE, 14, e0216355.

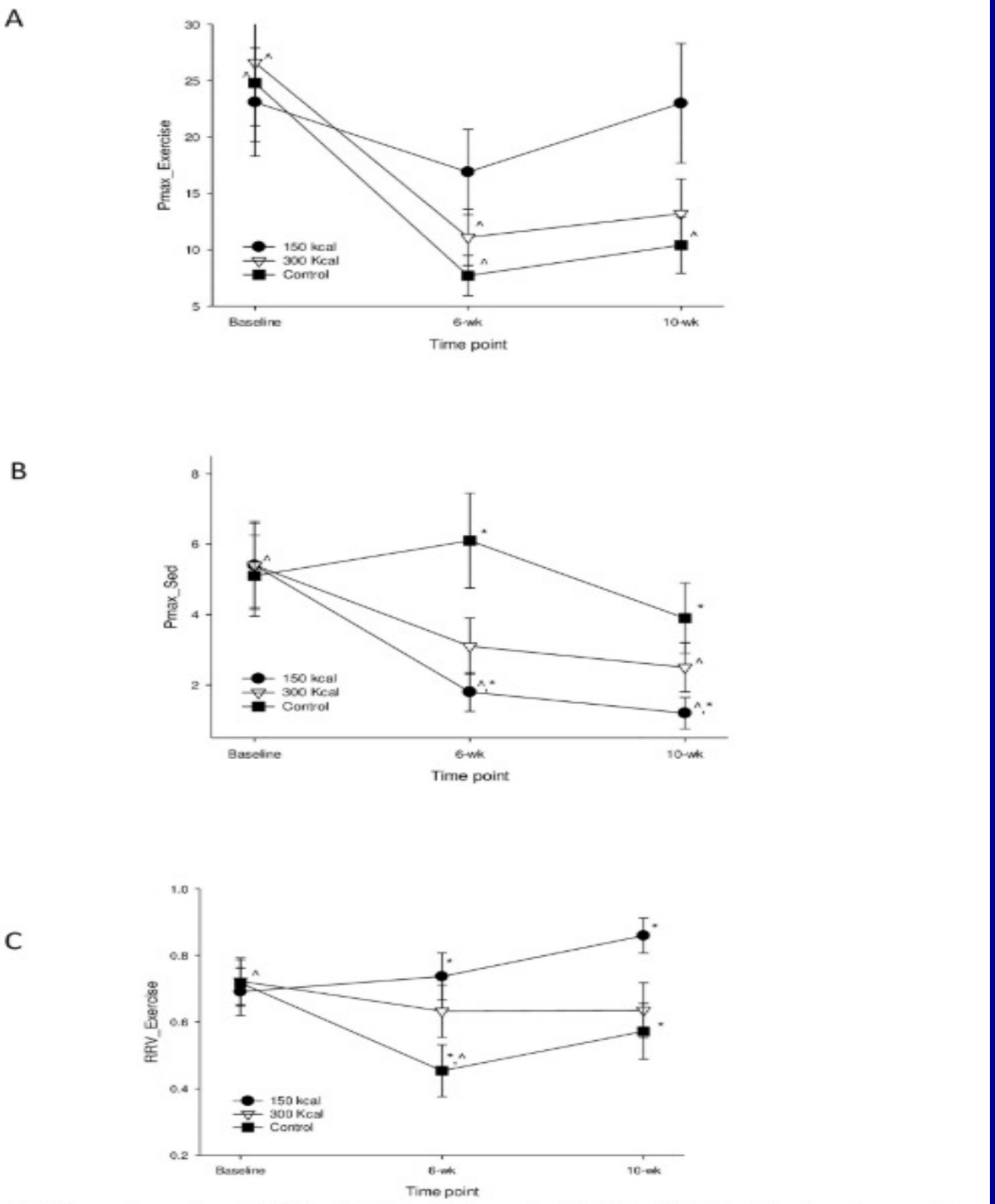


Fig 2. Changes in exercise and sedentary behavior reinforcement and relative reinforcing value of exercise over 10 weeks. Reinforcing value of exercise (Pmax of exercise, A), Pmax of sedentary activities (B), and relative reinforcing

- People randomized to exercise groups reduced reinforcing value of sedentary behaviors

- People in 300 kcal/session reduced their sedentary time during 6 weeks by about 50 min, went back to baseline by 10 weeks

Can we increase the reinforcing value of exercise? II

- 52 people were randomized, 44 completed the study (85%) studied
- Randomized to 2 or 6 days/week or a control for 12 weeks
  - 2 days/week expend 1000 kcal/session
  - 6 days/week expend 400 kcal/session
  - Polar HR monitors were used to monitor energy expenditure
    - » People self-selected their exercise intensity
- Measures
  - RRV
  - Liking
  - PRETIE-Q
  - Accelerometer measured activity
  - Body composition

Flack, et al. Incentive sensitization for exercise reinforcement to increase exercise behaviors. Journal of Health Psychology, 2020, 26, 2487-2504.

Table 1. Demographics, vigorous physical activity, and resistance exercise training behavior of the study participants at baseline, all participants randomized included.

	6-day / week group N = 19	2-day / week group N = 20	Control N = 14
Exercise reinforcement[a]	25.12 ± 9.74	21.84 ± 8.27	16.0 ± 6.65
Sedentary reinforcement[b]	2.78 ± 1.0*	9.21 ± 2.76*	29.86 ± 7.91*
Minutes of MVPA[c]	290.74 ± 48.34	243.01 ± 29.12	329.47 ± 44.56
Minutes of VPA[d]	9.01 ± 2.96	8.57 ± 3.90	12.91 ± 5.31
Minutes of sedentary[e]	4490.4 ± 363.16	4301.0 ± 167.51	3880.8 ± 257.69
MVPA bouts[f]	4.26 ± 1.12	3.30 ± 0.99*	7.14 ± 1.68*
Body fat (%)	36.52 ± 1.61*	41.06 ± 1.08*	39.68 ± 1.14
Liking of exercise[g]	74.83 ± 2.79	73.68 ± 2.73	69.36 ± 5.68
Liking of sedentary[g]	74.33 ± 3.08	71.26 ± 3.82	68.64 ± 5.72
Preference for exercise intensity[h]	23.68 ± 2.26	22.9 ± 2.31	23.29 ± 2.14
Tolerance for exercise intensity[h]	25.79 ± 1.93	24.15 ± 2.52	25.54 ± 3.23

While people reported being sedentary, they Engaged in at least 240 minutes/week of MVPA (>34 min/day)

Table 2. Changes in outcome variables (exercise and sedentary behavior reinforcement, MVPA bouts, percent change of body fat mass) between groups randomized based on exercise frequency in addition to participants retrospectively split into groups expending greater or less than 2000 kcal per week through exercise during the intervention and into groups compensating for greater or less than 50 percent of the kcal expended during exercise. Differences between groups tested via ANCOVA with corresponding baseline value used as covariate.

	6-day / week group N = 15	2-day / week group N = 17	Control N = 12
ΔExercise reinforcement[a]	30.81 ± 16.68	−2.06 ± 12.04	0.91 ± 6.17
ΔSedentary reinforcement[b]	0.00 ± 1.20	−1.18 ± 1.63	−16.82 ± 8.87
ΔMVPA bouts[c]	1.86 ± 1.54^	0.92 ± 1.44*	−6.36 ± 1.95*^#
ΔBody fat (%)[d]	−7.79 ± 2.23^#	−1.86 ± 1.2*	4.20 ± 2.82*^
ΔPreference[e]	−0.80 ± 0.69	0.35 ± 0.66	0.33 ± 0.76
ΔTolerance[e]	−0.40 ± 0.65	0.76 ± 0.63	−0.78 ± 0.74
	Over 2000 kcal/week N = 16	**Under 2000 kcal/week N = 16**	**Control 12**
ΔExercise reinforcement[a]	18.94 ± 14.51	13.67 ± 16.99	0.91 ± 6.17
ΔSedentary reinforcement[b]	0.00 ± 1.11	−1.25 ± 1.74	−16.82 ± 8.87
ΔMVPA bouts[c]	2.38 ± 1.56^	0.46 ± 1.40*	−6.36 ± 1.95*^#
ΔBody fat (%)[d]	−6.52 ± 1.29^#	−2.35 ± 2.17*	4.20 ± 2.82*^
ΔPreference[e]	−1.06 ± 0.62	0.69 ± 0.68	0.33 ± 0.76
ΔTolerance[e]	0.06 ± 0.61	0.38 ± 0.69	−0.78 ± 0.74

- Energy expenditure:
  2 day=745
  6 day=460

- Δ exercise reinforcement
p = 0.06

Table 3. Regression models predicting pre- to post-intervention changes in MVPA bouts (7-day total) using independent variables that were expected to be influenced by the exercise intervention or a characteristic of the intervention (energy expended per week).

Effect	β	SE	p
Full model of all predictors			
Intercept	19.82	6.49	0.01
ΔExercise reinforcement[a]	0.04	0.01	0.02
kcal expended/week[b]	<−0.01	<0.01	0.47
ΔBody fat[c]	−0.21	0.20	0.31
% kcal compensated[d]	−0.05	0.02	0.05
Liking of exercise[e]	−0.15	0.07	0.06
Like of sedentary[e]	−0.05	0.07	0.46
ΔSedentary reinforcement[f]	0.18	0.13	0.19
Reduced model of significant predictors			
Intercept	3.86	1.15	<0.01
ΔExercise reinforcement[a]	0.04	0.01	0.01
% kcal compensated[e]	−0.05	0.02	0.03

- Δ exercise reinforcement predicted greater MVPA

Can we increase the reinforcing value of exercise? III

- 36 people were randomized, 29 completed (81%)
- 5 days/week, 12 weeks at 300 or 600 kcal/session (1500 or 3000 kcal/week)
- Garmin Vivofit was used to record activity and HR and exercise intensity adjusted based on fitness test to accomplish expenditure goals
- Measures
  - RRV
  - Liking
  - PRETIE
  - Exercise energy expenditure

Flack, et al. Increasing the reinforcing value of exercise in overweight adults. Frontiers in Behavioral Neuroscience, 2019, 13: 265.

TABLE 2 | Outcome variables at baseline and 12-weeks for participants exercising to expend either 1,500 kcal/week or 3,000 kcal/week for 12 weeks.

	300 kcal/session (n = 14)			600 kcal/session (n = 15)		
	Baseline	12 week	adjusted group change (95% CI)[1]	Baseline	12 week	adjusted group change (95% CI)[1]
$RRV^{2}_{exercise}$	0.67 ± 0.10	0.88 ± 0.1	0.17 (0.02, 0.31)*	0.78 ± 0.1	0.91 ± 0.1	0.17 (0.03, 0.31)*
P_{max} exercise[3]	35.1 ± 11.0	42.0 ± 10.7	5.3 (−51.3, 61.9)*,^	41.1 ± 10.7	137.6 ± 35.4	98.0 (43.3, 152.7)*,^
P_{max} sedentary[4]	13.4 ± 5.0	5.4 ± 2.6	−6.4 (−9.5, −3.2)*	9.1 ± 4.5	1.9 ± 1.2	−8.7 (−11.8, −5.7)*
Preference for exercise intensity[5]	24.6 ± 1.3	26.0 ± 1.5	1.1 (−1.6, 3.8)	26.1 ± 1.2	29.3 ± 1.5	3.5 (0.9, 6.2)*
Tolerance for exercise intensity[5]	24.4 ± 1.8	28.4 ± 1.4	4.2 (2.4, 6.0)*	23.6 ± 1.5	27.5 ± 1.1	3.7 (2.0, 5.5)*
Preference + Tolerance[5]	48.9 ± 2.8	54.4 ± 2.3	5.3 (1.7, 9.0)*	49.7 ± 2.4	56.8 ± 2.1	7.3 (3.8, 10.8)*

- Reinforcing value of exercise increased for 600 kcal group
- Reinforcing value of sedentary decreased
- Neither baseline nor changes in liking predicted changes in exercise reinforcement

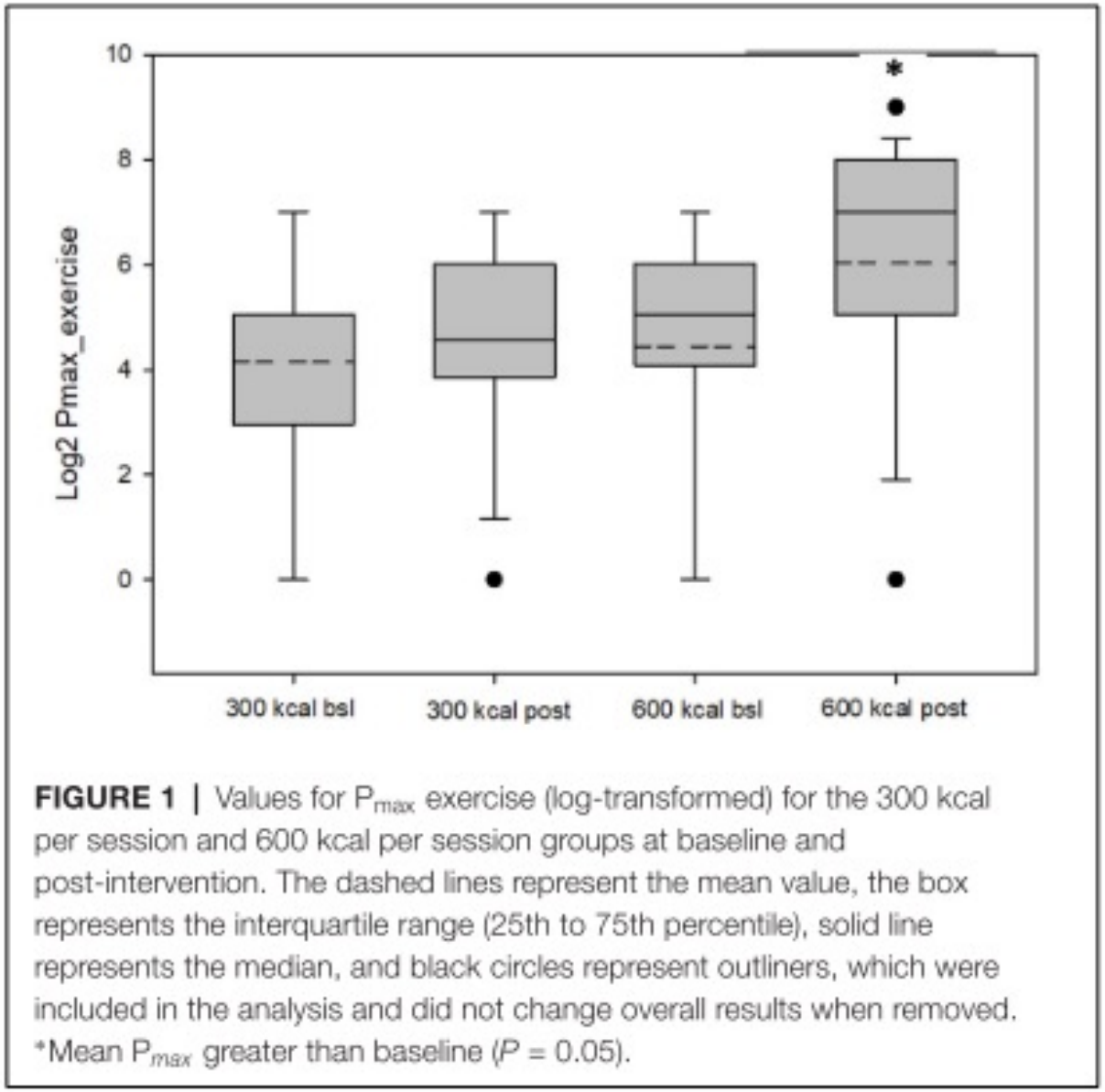


FIGURE 1 | Values for P_{max} exercise (log-transformed) for the 300 kcal per session and 600 kcal per session groups at baseline and post-intervention. The dashed lines represent the mean value, the box represents the interquartile range (25th to 75th percentile), solid line represents the median, and black circles represent outliners, which were included in the analysis and did not change overall results when removed. *Mean P_{max} greater than baseline ($P = 0.05$).

Exercise reinforcement related to SNP associated with fewer DRD2 receptors across these studies.

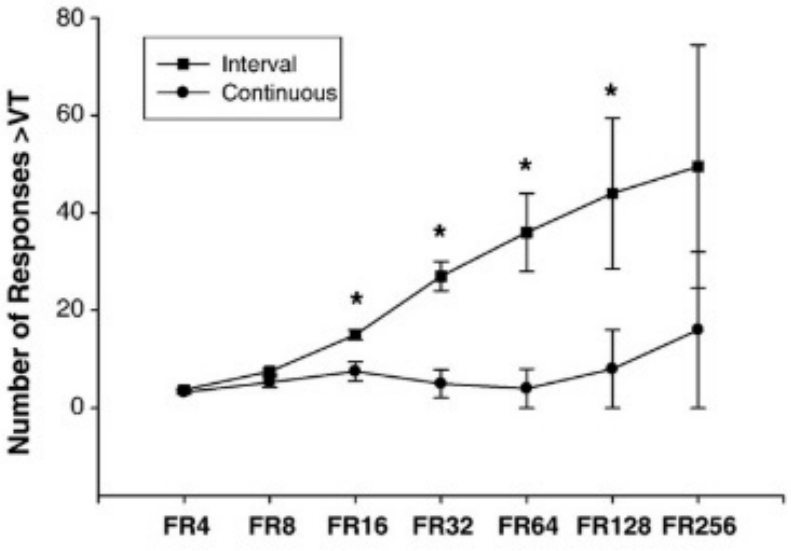
Flack et al., Genetic variations in the dopamine reward system influence exercise reinforcement and tolerance for exercise intensity. Behavioural Brain Research, 2019, 375, 112148.

Reinforcing value of HIIT versus traditional aerobic exercise

Reinforcing value of interval versus continuous exercise: Children

- 32 children, sedentary 8-11 year-old children were studied
- V02 peak/Ventilatory threshold was established using standard cycle ergometer exercise protocol and metabolic cart
- Using within subject design, children experienced:
  - Above VT
    - » Continuous for 5 min at resistance elicited VO2 > VT, 50 rpm
    - » Intervals for 20s > VT, 80 rpm, 20s .5 kpm, 50 rpm for 5 min
  - Below VT
    - » Continuous for 5 min at resistance HR = 140 bpm (20% below VT), 50 rpm
    - » Intervals of 20s HR = 140, 80 rpm, 20s .5 kpm, 50 rpm for 5 min
  - Free choice session of two 7 min bouts either doing interval or continuous exercise above or below VT

Barkley, et al. Reinforcing value of interval and continuous physical activity in children. Physiology & Behavior, 2009, 31-36.



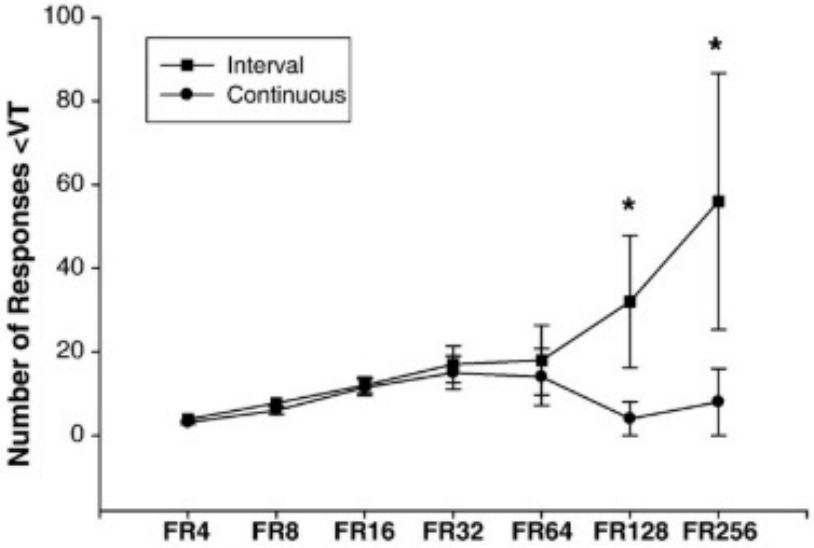


Fig. 1. Response patterns across the seven fixed ratio (FR) levels to gain access to interval and continuous physical activity performed above (top panel) and then below (bottom panel) the ventilatory threshold (VT). Data presented are non-transformed means ± SE. Data from boys and girls were combined because there were no significant sex differences. *Number of responses for interval physical activity was greater ($P<0.01$ for all) than continuous physical activity for the given FR level.

- Reinforcing value, RPE and liking measured
- Greater reinforcing value for interval versus continuous exercise above and below VT
- Greater RPE for continuous than interval exercise above VT
- Above VT, liking positively associated with continuous exercise and liking negatively associated with interval exercise
- Below VT, liking was positively associated with interval exercise and negatively associated with continuous exercise.

Reinforcing value of HIIT versus aerobic exercise: Adults

- EXP 1 20 sedentary females engaged in HIIT or MIAE for two sessions to establish reliability of effects and establish power for EXP 2
  - Randomized to either 1:1 or 1:2 minutes of HIIT to MIAE
  - Session 1
    - » Fitness test to set HIIT or MIAE workloads
    - » Sampled both HIIT and MIAE protocols, including 5 min warmup and cooldown, order counterbalanced, 30 min after fitness test and between sampling of protocols
  - Sessions 2-5
    - » Measured reinforcing value of HIIT and MIAE
- HIIT protocol 30 s 80-90% HRR, 30 s 30-40% HRR
- MIAE protocol 50% HRR

Epstein, et al. Comparing the reinforcing value of high intensity interval training versus moderate intensity aerobic exercise in sedentary adults. Physiology & Behavior, 2021, 238, 113468.

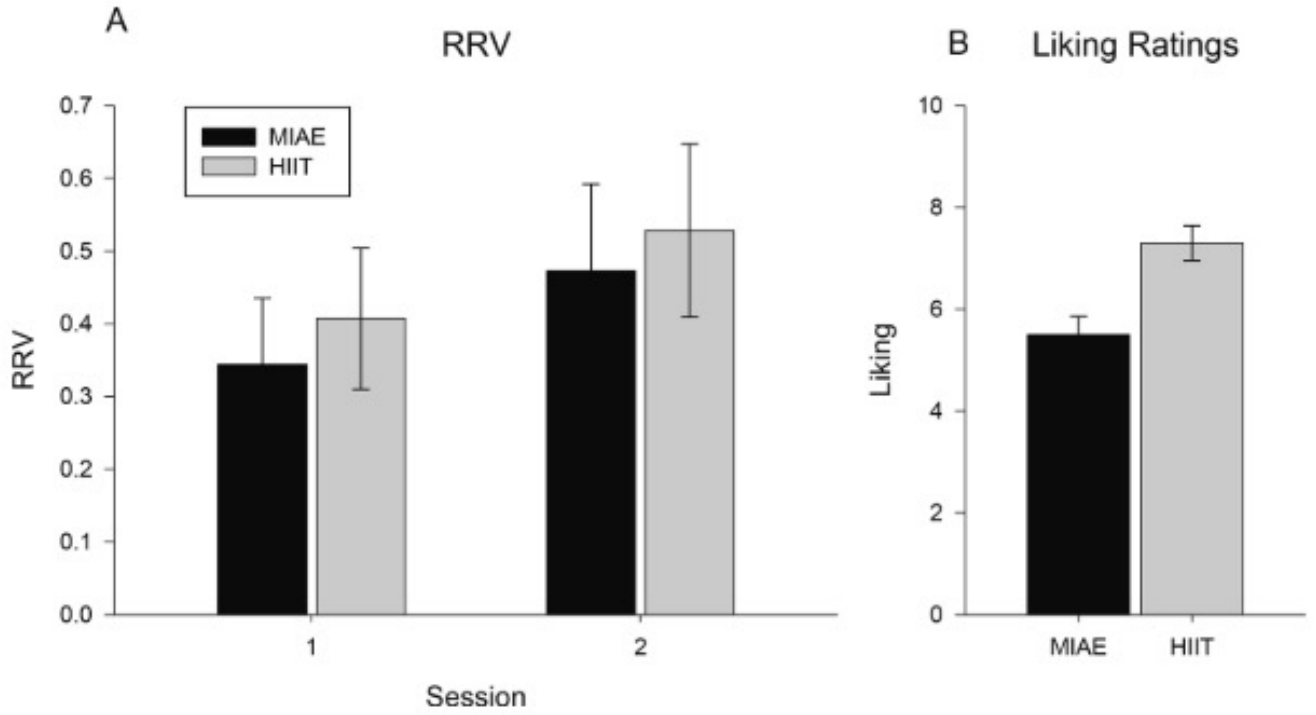


Fig. 1. Relative reinforcing value for HIIT or MIAE (mean ± SEM, **A**) and differences in liking (**B**). HIIT was more reinforcing ($p = 0.005$) and more liked ($p = 0.003$) than MIAE.

- Reinforcing value of HIIT was greater than MIAE
- Reliability of reinforcing value across sessions was .96 for HIIT and .72 for MIAE (p's < 0.01)
- Greater liking for HIIT than MIAE during sampling.

Reinforcing value of HIIT versus aerobic exercise: Adults

- EXP 2 44 sedentary adults
  - Session 1
    - » Fitness test to set HIIT or MIAE workloads
    - » Sampled both HIIT and MIAE protocols, including 5 min warmup and cooldown, order counterbalanced, 30 min after fitness test and between sampling of protocols
  - Sessions 2
    - » Measured reinforcing value of HIIT and MIAE during exercise, affect during and for 20 min after exercise
- Measures
  - Reinforcing value of exercise
  - Physical Activity Enjoyment Scale (PACES)
  - Affect Grid (pleasure/displeasure, arousal/sleepiness
  - RPE
  - PRETIE-Q

Epstein, et al. Comparing the reinforcing value of high intensity interval training versus moderate intensity aerobic exercise in sedentary adults. Physiology & Behavior, 2021, 238, 113468.

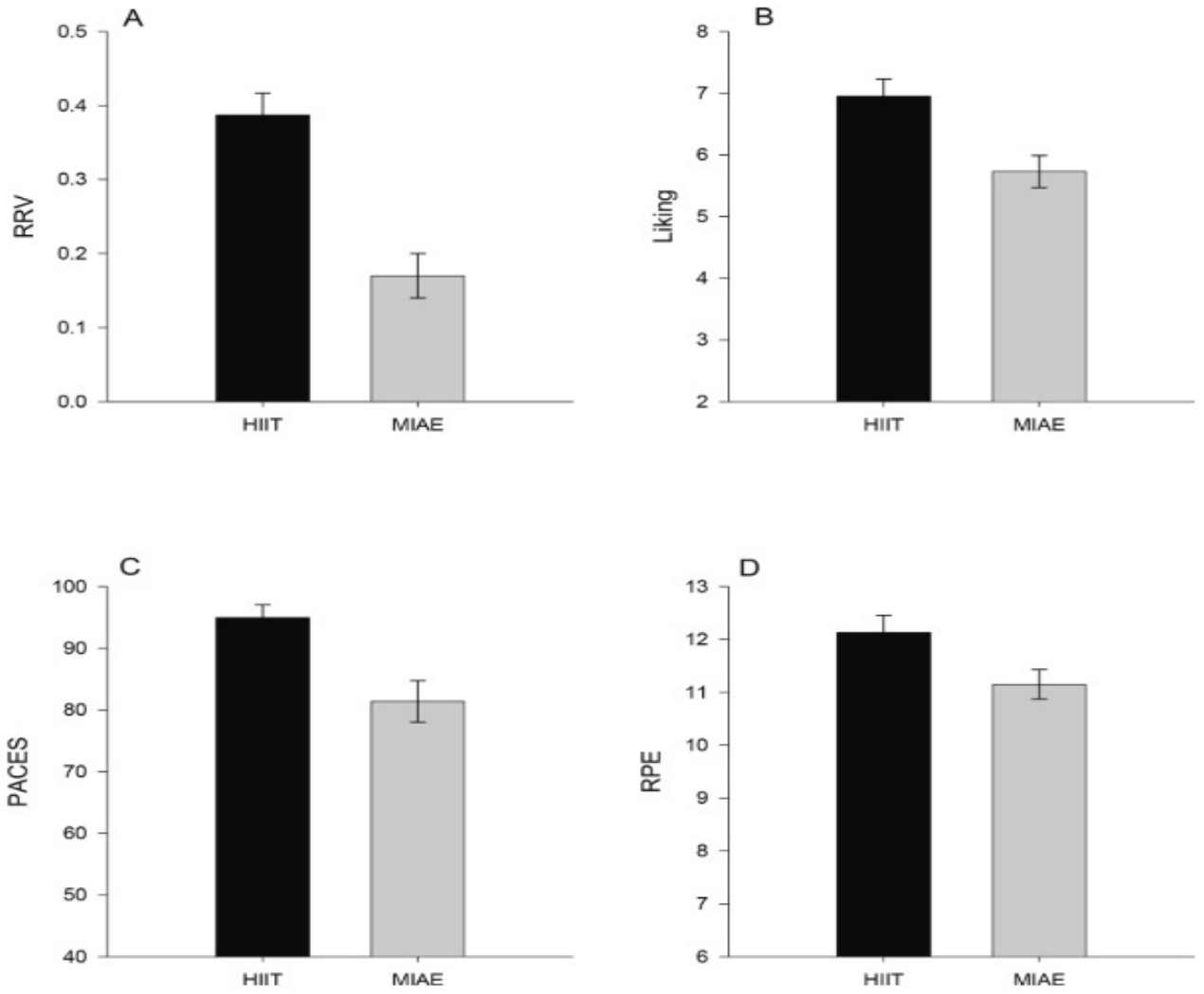


Fig. 2. Relative reinforcing value for HIIT or MIAE (mean ± SEM, **A**), liking (**B**), enjoyment (**C**) and ratings of perceived exertion (**D**) after sampling the two types of exercise programs. There was greater reinforcing value ($p < 0.001$), liking ($p < 0.001$), enjoyment ($p < 0.001$) and ratings of perceived exertion ($p = 0.002$) for HIIT in comparison to MIAE.

- HIIT more reinforcing, more liked, greater enjoyment and greater RPE than MIAES
- Reinforcing value of MIAE was predicted by liking of MIAE and affect post exercise

Questions?
Comments?