Behavioral Economics for Drug Abuse Potential Testing

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I have no competing financial interests or personal relationships that could have influenced this presentation. The content presented is solely based on objective research and analysis, without any external influences that could potentially bias the findings.

The views expressed herein are solely the responsibility of the author and do not necessarily represent the official views of the United States Food and Drug Administration.

The approaches discussed in this presentation are of an exploratory nature and intended for informational purposes only. It is important to note that behavioral economics is an evolving and active area of research, including within the FDA. However, the FDA does not yet endorse or recommend that industry sponsors adopt the methods that will be described here. Any decisions to implement these approaches should be made in consultation with CSS.

Overview

Background

Advantages
Evolution of Demand Models
Model Variants

Examples

Preclinical: (1) Hursh & Winger, 1995; (2) Ko et al., 2002; (3) Winger et al., 2002

Clinical: (1) MacKillop et al., 2019

Areas for Further Research

Recommended Readings & Resources

Background

Behavioral economics is the application of microeconomics principles to the study of behavior in animals and humans

Demand curve analysis is an economic approach to examining the relationship between the price of a commodity and the quantity demanded and can be used to quantify the intrinsic value of drugs

Demand elasticity is a measure of how demand responds to changes in price and can represent relative reinforcing efficacy across drugs in both animal and human studies

Advantages of Demand Curve Analysis for Abuse Potential Assessment

1. Provides a method that is both dose and potency independent

    Dose independent
    The demand elasticity for a demand curve created with one dose of a drug generally represents the demand elasticity for all self-administered doses of the drug within a specified dose range (in preclinical models)

    Potency independent
    Different drugs varying in potency are easily compared

2. Provides for a more sensitive and specific assessment of reinforcing effects

3. Provides a quantitative approach that returns a single parameter (α) that reflects the essential difference among drug reinforcers (relative reinforcing efficacy)

Models of Demand

Linear-Elasticity Model of Demand (Hursh et al., 1989)

$$\ln(Q) = \ln(L) + b * \ln(P) - a * P$$

Exponential Model of Demand (Hursh & Silberberg, 2008)

$$\log_{10}(Q) = \log_{10}(Q_0) + k * (e^{[-\alpha * Q0 * C]} - 1)$$

Exponentiated Demand Model (Koffarnus et al., 2015)

$$Q = Q_0 * 10^{k * (e^{[-\alpha * Q0 * C]} - 1)}$$

Model Variants

Left-Censored Mixed Effects Model (Liao et al., 2013)

Two-Part Mixed Effects Model (Zhao et al., 2016)

Bayesian Hierarchical Model (Ho et al., 2018)

Exponentiated Linear Elasticity Model (Yu et al., 2014)

Newman and Ferrario Model (Newman and Ferrario, 2020)

Zero-Bounded Exponential Model (Gilroy et al., 2021)

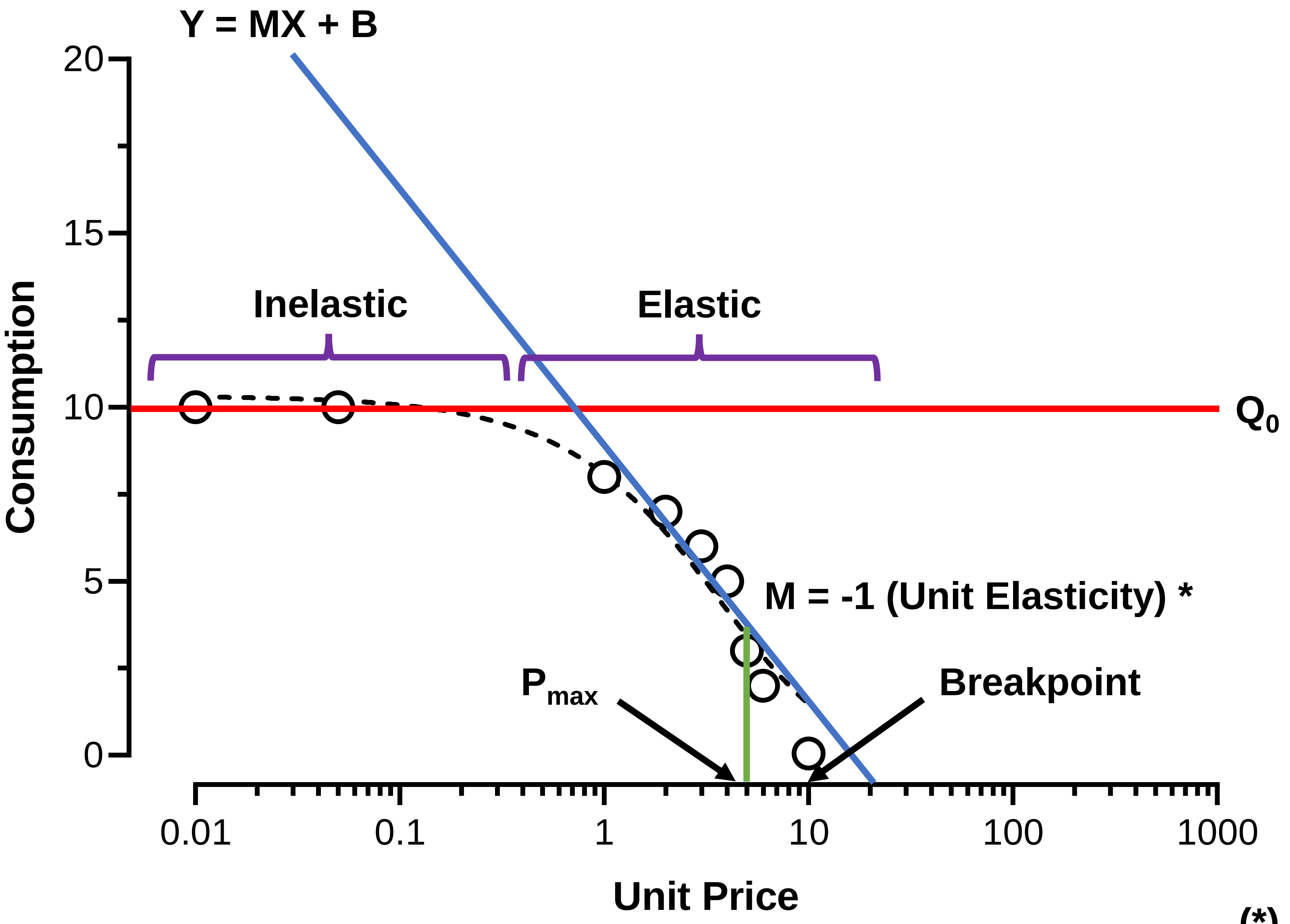
Exponentiated Demand Model

$$Q = Q_0 * 10^{k * (e^{[-\alpha * Q_0 * C]} - 1)}$$

Symbol	Parameter/Metric	Description
Q	Demand Intensity	Level of consumption or likelihood of purchase
Q_0	Demand Intensity @ C = 0	Level of consumption or likelihood of purchase at low or no costs
k	Constant	Range of consumption in logarithmic units
e	Constant	Euler’s number = 2.718
α	Demand Elasticity	Rate of change in elasticity across the demand curve
C	Cost	Cost of each reinforcer

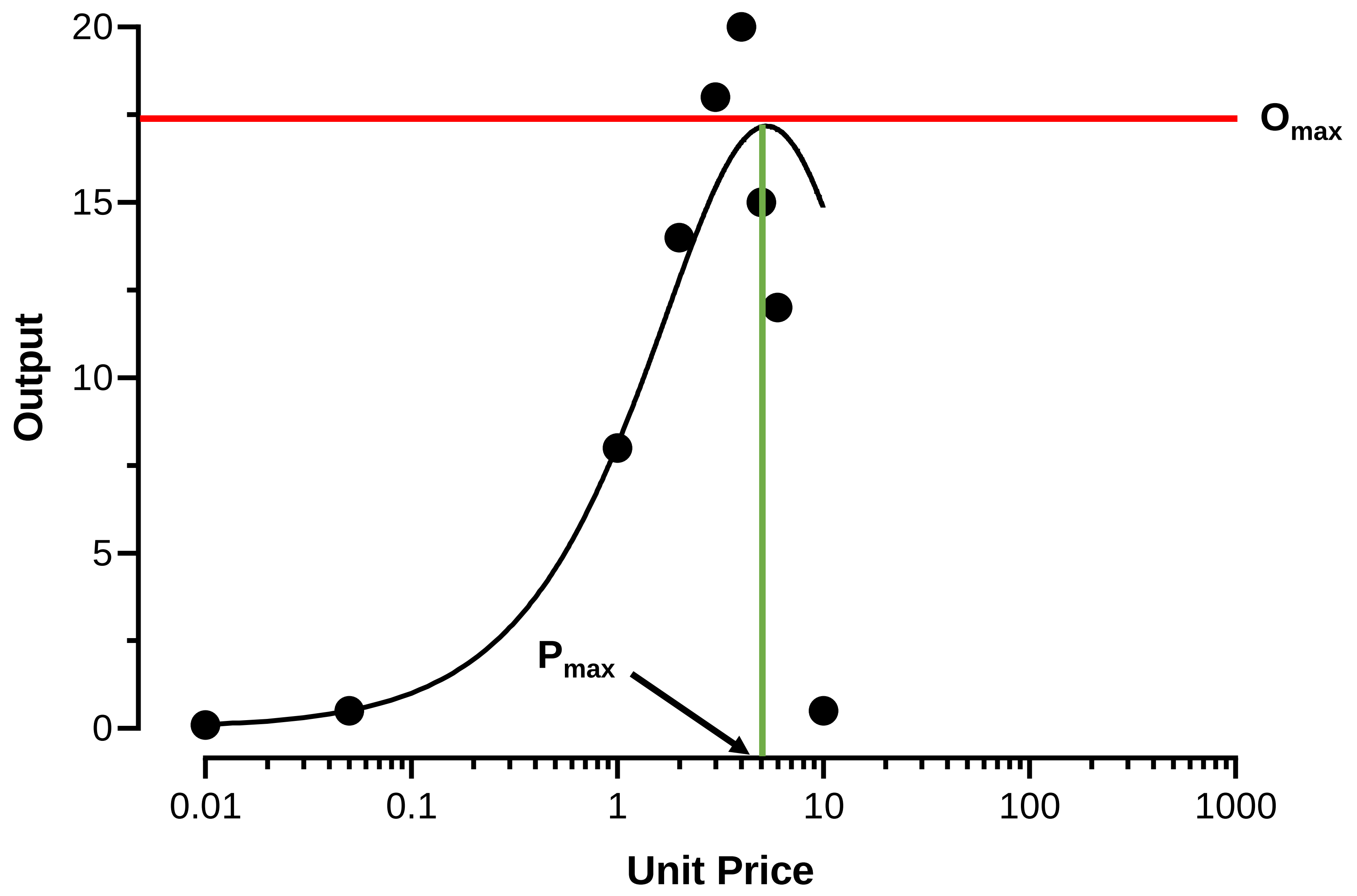
Koffarnus, M. N., Franck, C. T., Stein, J. S., & Bickel, W. K. (2015). A modified exponential behavioral economic demand model to better describe consumption data. *Exp Clin Psychopharmacol, 23(6), 504-512. https://doi.org/10.1037/pha0000045*

Demand Curves Relate Reinforcer Cost to Consumption

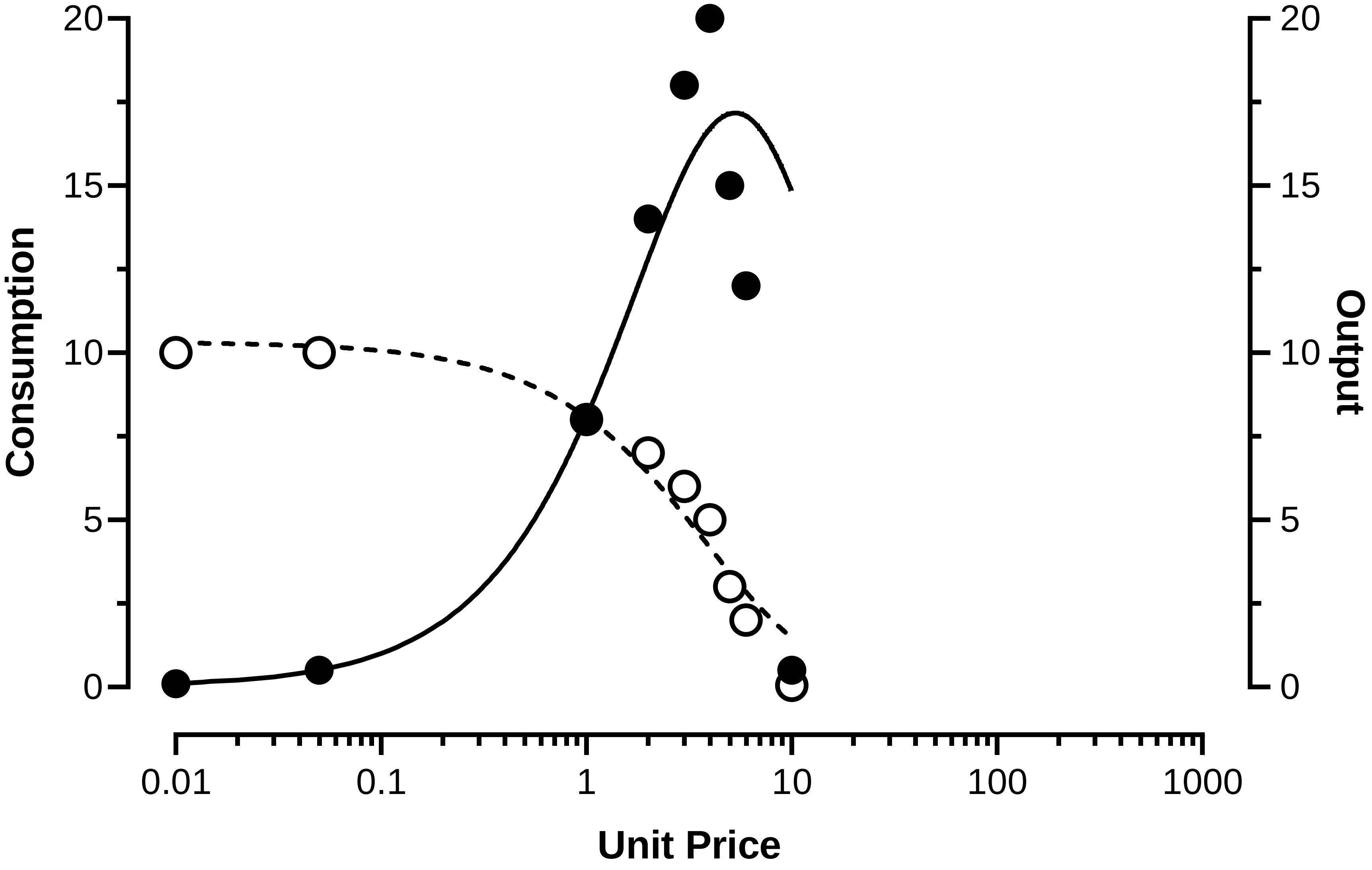


(*) on a double-log plot

Work Curves Relate Reinforcer Cost to Responses



Demand Curve vs Work Curve



Preclinical Example 1
(Hursh and Winger, 1995)

JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1995, **64**, 373–384 NUMBER 3 (NOVEMBER)

NORMALIZED DEMAND FOR DRUGS AND OTHER REINFORCERS

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The concepts of behavioral economics have proven to be useful for understanding the environmental control of overall levels of responding for a variety of commodities, including reinforcement by drug self-administration. These general concepts have implications for the assessment of abuse liability and drug abuse intervention and the formulation of public policy on drug abuse. An essential requirement is the ability to compare the demand for different drugs directly in order to assess relative abuse liability, and to compare demand for the same drug under different environmental and biological interventions to assess their ability to reduce demand. Until now, such comparisons were hampered by the confounding effect of varying drug doses and potencies that prevent quantitative comparisons of demand elasticity—sensitivity of consumption and responding to the constraint of price (effort). In this paper we describe a procedure to normalize demand-curve analysis that permits dose- and potency-independent comparisons of demand across drugs. The procedure is shown to be effective for comparing drug demand within and across the drug classes. The technique permits a quantitative ordering of demand that is consistent with the peak levels of responding maintained by the drugs. The same technique is generalized for the comparison of other types of reinforcers under different biological conditions.

Key words: behavioral economics, normalized demand, demand curve, elasticity, drug self-administration, cost, unit price, fixed-ratio schedule, overall response output, cocaine, alfentanil, nalbuphine, methohexital, phencyclidine, rhesus monkeys

Preclinical Example 1
(Hursh and Winger, 1995)

Aim: Test the validity of the normalized demand method by comparing different doses and drugs

Methods: Data from two previous studies (Winger et al., 1993a; Winger et al., 1996) were used to test the validity of the method

Subjects were adult rhesus monkeys (n = 7 in Winger et al., 1993a; n = 11 in Winger et al., 1996)

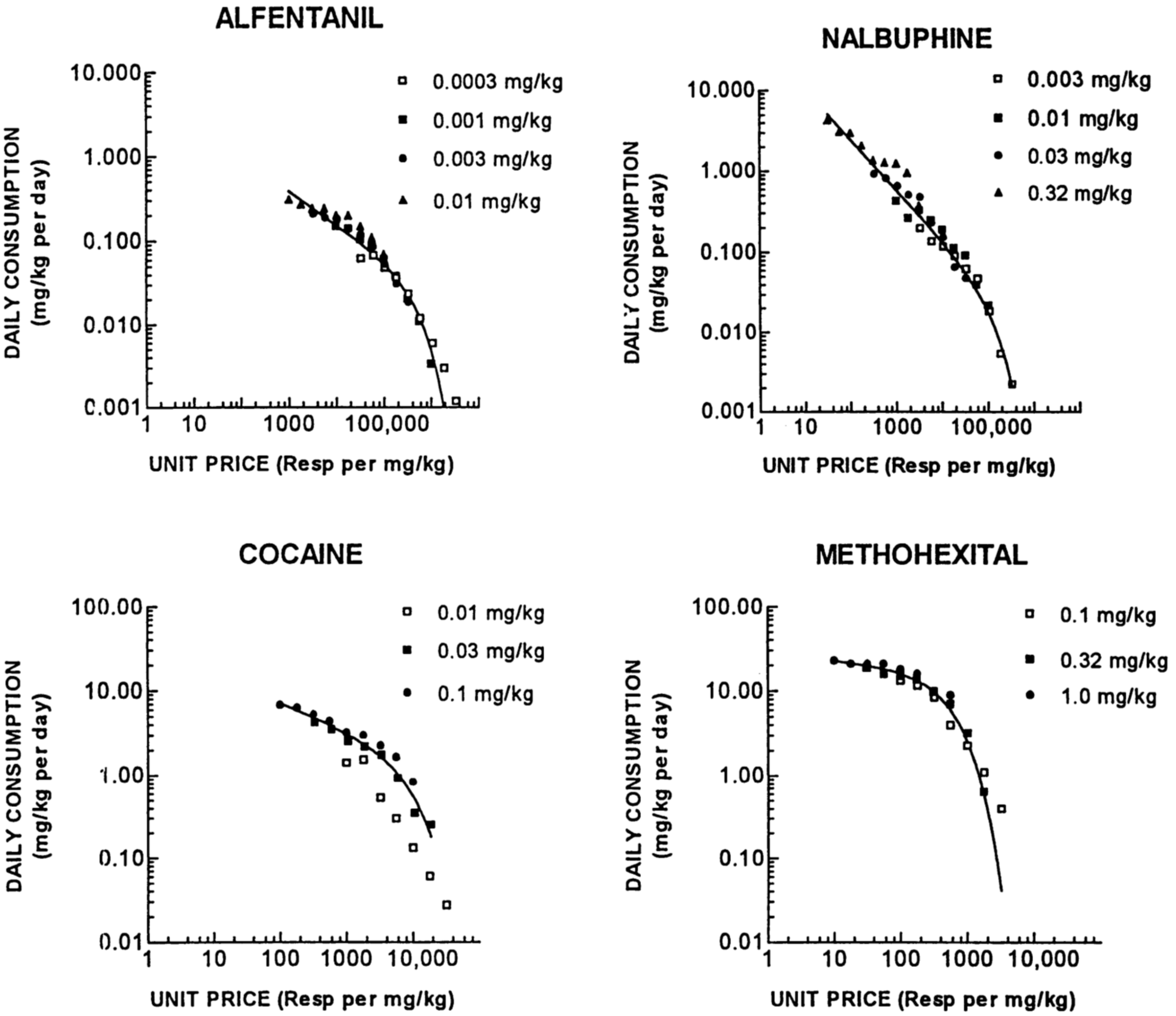
Drug was dispensed through indwelling intravenous catheters. Session length = 130 min

In the **first study** (Winger et al., 1993a), consumption of two drugs (cocaine and methohexital) was compared across a range of doses and FR schedules (10, 17, 32, 56, 100, 178, 320, 560, and 1,000)

In the **second study** (Winger et al., 1996), two opioid agonists (alfentanil and nalbuphine) were compared across doses and the same range of FR schedules

Primary endpoint was the average number of injections per day of each drug and dose across subjects

Preclinical Example 1 (Hursh and Winger, 1995)



Preclinical Example 1
(Hursh and Winger, 1995)

Table 1

Mean number of injections per day under each FR schedule and normalized dose (q) for each drug.

Fixed ratio	Alfentanil (mg/kg)				Nalbuphine (mg/kg)				Cocaine (mg/kg)			Methohexital (mg/kg)		
	0.01	0.003	0.001	0.0003	0.32	0.03	0.01	0.00	0.10	0.03	0.01	1.00	0.32	0.10
10	31.0	70.0	151.0	209.0	13.60	31.00	43.10	66.30	69.10	144.13	141.90	23.00	59.00	132.00
18	27.0	63.0	142.0	226.0	9.80	27.50	26.50	45.50	63.80	117.90	153.80	21.00	50.00	115.00
32	24.0	61.0	105.0	163.0	9.30	22.00	33.00	39.20	53.70	85.40	53.30	0.21	47.00	84.00
56	24.0	47.0	91.0	123.0	6.50	17.00	24.90	30.40	44.17	74.00	30.30	21.00	43.00	40.00
100	20.0	40.0	62.0	79.0	4.30	16.00	19.00	20.80	32.17	58.40	13.30	18.00	31.00	23.00
178	20.0	29.0	38.5	40.0	4.00	7.70	11.20	15.80	30.10	31.00	6.10	16.00	22.00	11.00
320	15.0	18.0	20.7	20.0	3.90	5.10	9.20	6.20	22.75	11.70	2.75	10.00	10.00	4.00
560	11.0	10.5	11.2	10.0	3.00	2.20	4.00	1.80	16.50	8.50		9.00	2.00	
1,000	7.0	6.3	3.4	4.0	1.16	1.60	2.20	0.75	8.35			0.00		
q	3.22	1.43	0.66	0.48	7.35	3.23	2.32	1.51	1.45	0.69	0.70	4.35	1.69	0.76

Normalization Procedure

Hursh and Winger developed a normalization procedure, according to which maximum daily consumption observed at the lowest price investigated is taken as a reference level

Each dose is expressed as a percent of the total daily drug consumed at the lowest price

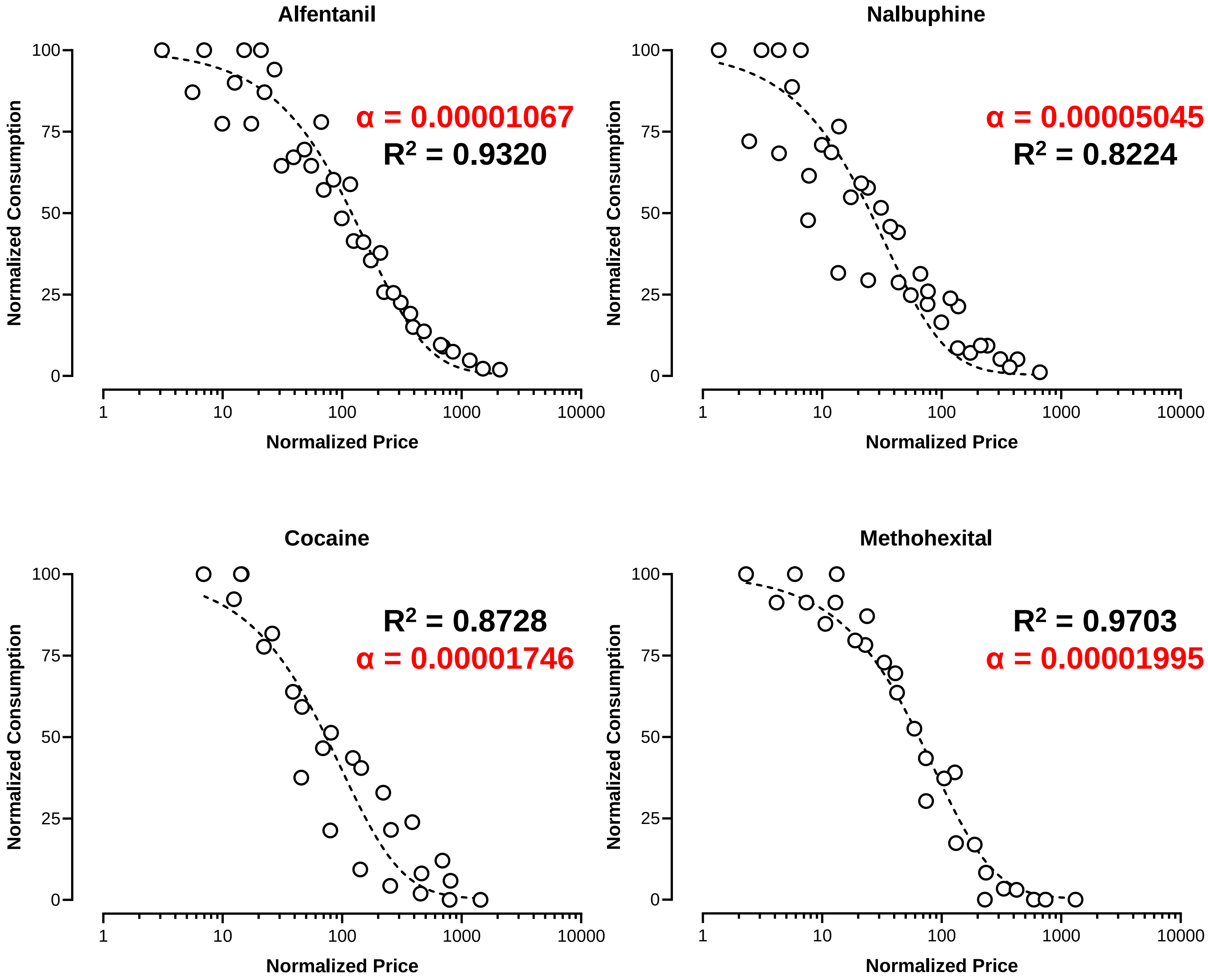
Normalized price and consumption are computed in terms of the **q value**: **q = 100/baseline consumption**

Normalized price (P) is the number of responses required to produce an infusion of drug (FR) divided by its q value: **P = FR / q**

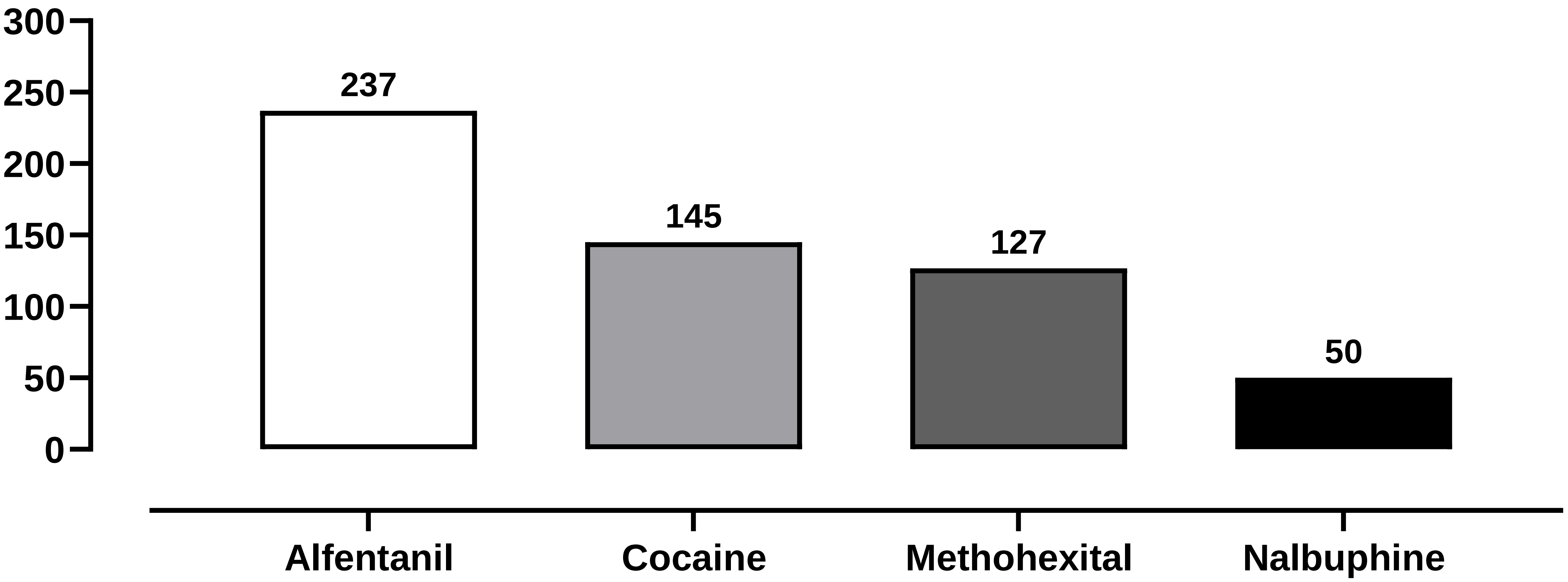
Normalized daily consumption (Q) is the product of total number of units administered per day (r) at a given FR and the q value for that dose of drug: **Q = r * q**

At the lowest price, normalized consumption (Q) will always equal 100, that is, all normalized demand curves have a starting level of 100 percent

Expressing price and consumption in relative terms allows demand for different drugs to be compared, independent of both dose and potency


Alfentanil
α = 0.00001067
R² = 0.9320
Nalbuphine
α = 0.00005045
R² = 0.8224
Cocaine
R² = 0.8728
α = 0.00001746
Methohexital
R² = 0.9703
α = 0.00001995
Normalized Consumption
Normalized Price
100
75
50
25
0
1
10
100
1000
10000

Essential Reinforcer Value [1/(α*(k^1.5)*100)]



Demand Curve Metrics

	Alfentanil	Cocaine	Methohexital	Nalbuphine
Q_0	100	100	100	100
k	2.5	2.5	2.5	2.5
α	0.00001067	0.00001746	0.00001995	0.00005045
Essential Value (EV)	237	145	126	50
P_{max}	203	124	109	43
O_{max}	6616	4043	3539	1399
$Breakpoint_0$ (FR)	N/A	N/A	1000	N/A
$BreakPoint_1$ (FR)	1000	1000	560	1000

Q_0: Hursh, S. R., & Winger, G. (1995). Normalized demand for drugs and other reinforcers. J Exp Anal Behav, 64(3), 373-384. https://doi.org/10.1901/jeab.1995.64-373
k = [$\log_{10}(Max_Q - Min_Q)+0.5$]: Kaplan, B. A., Gilroy, S. P., Reed, D. D., Koffarnus, M. N., & Hursh, S. R. (2019, Mar). The R package beezdemand: Behavioral Economic Easy Demand. Perspect Behav Sci, 42(1), 163-180. https://doi.org/10.1007/s40614-018-00187-7
α: Koffarnus, M. N., Franck, C. T., Stein, J. S., & Bickel, W. K. (2015). A modified exponential behavioral economic demand model to better describe consumption data. Exp Clin Psychopharmacol, 23(6), 504-512. https://doi.org/10.1037/pha0000045
EV = [1/(α*(k^1.5)*100)]: Hursh, S. R., & Roma, P. G. (2016). Behavioral Economics and the Analysis of Consumption and Choice. Managerial and Decision Economics, 37(4-5), 224-238. https://doi.org/10.1002/mde.2724
Approximate P_{max} = [$1/(Q_0$*α*(k^1.5))*(0.083*k+0.65)]: Hursh, S. R., & Roma, P. G. (2016). Behavioral Economics and the Analysis of Consumption and Choice. Managerial and Decision Economics, 37(4-5), 224-238. https://doi.org/10.1002/mde.2724
For **Analytical P_{max}** see: Gilroy, S. P., Kaplan, B. A., Reed, D. D., Hantula, D. A., & Hursh, S. R. (2019). An Exact Solution for Unit Elasticity in the Exponential Model of Demand. Journal of Experimental and Clinical Psychopharmacology. https://doi.org/10.1037/pha0000268
O_{max}: Kaplan, B. A., & Reed, D. D. (2014). Essential Value, Pmax, and Omax Automated Calculator [spreadsheet application]. In University of Kansas Applied Behavioral Economics Laboratory. http://hdl.handle.net/1808/14934
$Breakpoint_0$, $Breakpoint_1$: Foster, R., Fincham, T., Becirevic, A., & Reed, D. (2020). Observed Demand Calculator [spreadsheet application]. In University of Kansas Applied Behavioral Economics Laboratory. https://doi.org/10.17605/osf.io/gpvw6

Preclinical Examples 2 & 3
(Ko et al., 2002) & (Winger et al., 2002)

Relative Reinforcing Effects of Three Opioids with Different Durations of Action

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Relative Reinforcing Strength of Three *N*-Methyl-D-Aspartate Antagonists with Different Onsets of Action

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Received October 9, 2001; accepted February 6, 2002   This article is available online at http://jpet.aspetjournals.org

Preclinical Examples 2 & 3
(Ko et al., 2002) & (Winger et al., 2002)

Ko et al., 2002	**Winger et al., 2002**
Aim: Evaluate the relative reinforcing effects of three opioid agonists **Drugs:** fentanyl, alfentanil, and remifentanil	**Aim:** Evaluate the relative reinforcing effects of three NMDA antagonists **Drugs:** ketamine, phencyclidine, dizocilpine

Methods:

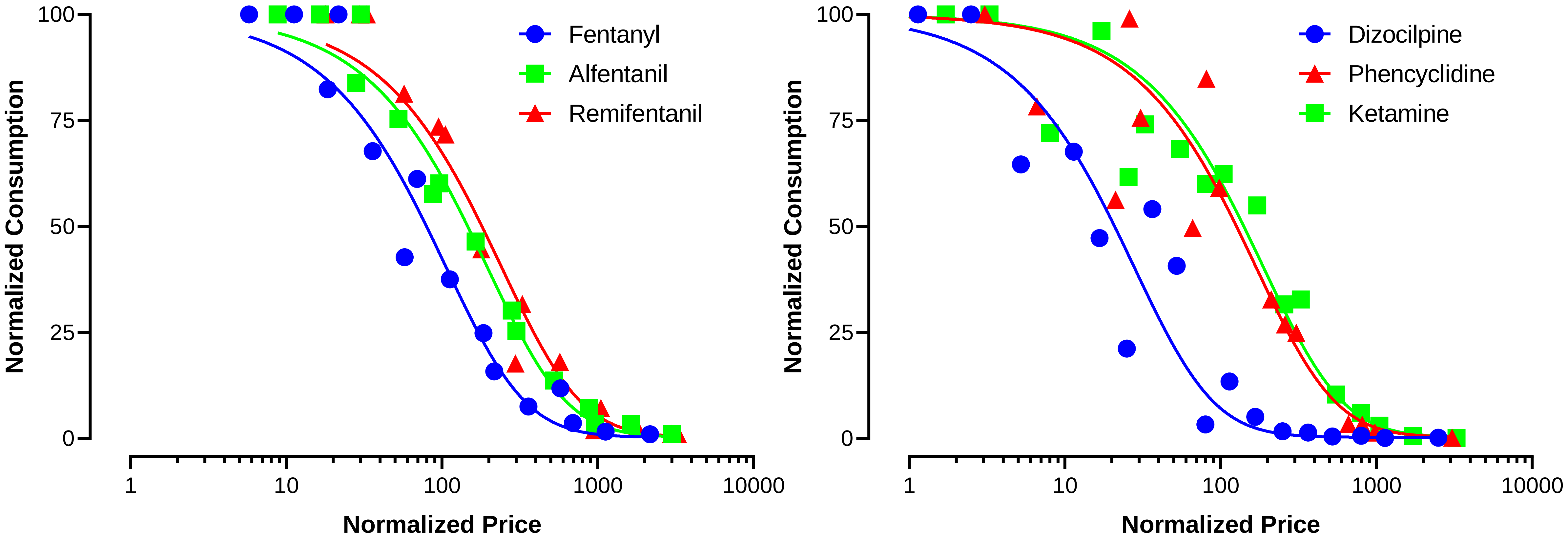
Subjects were adult rhesus monkeys (n = 3)

Drug was dispensed through indwelling intravenous catheters. Session length = 130 min

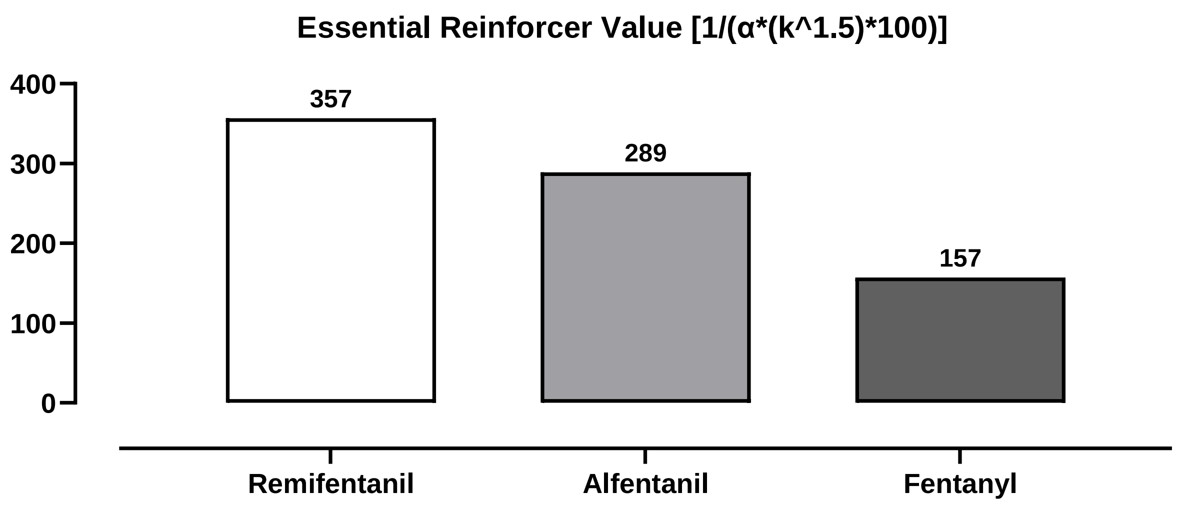
FR schedules (1, 10, 32, 100, 320, 1000)

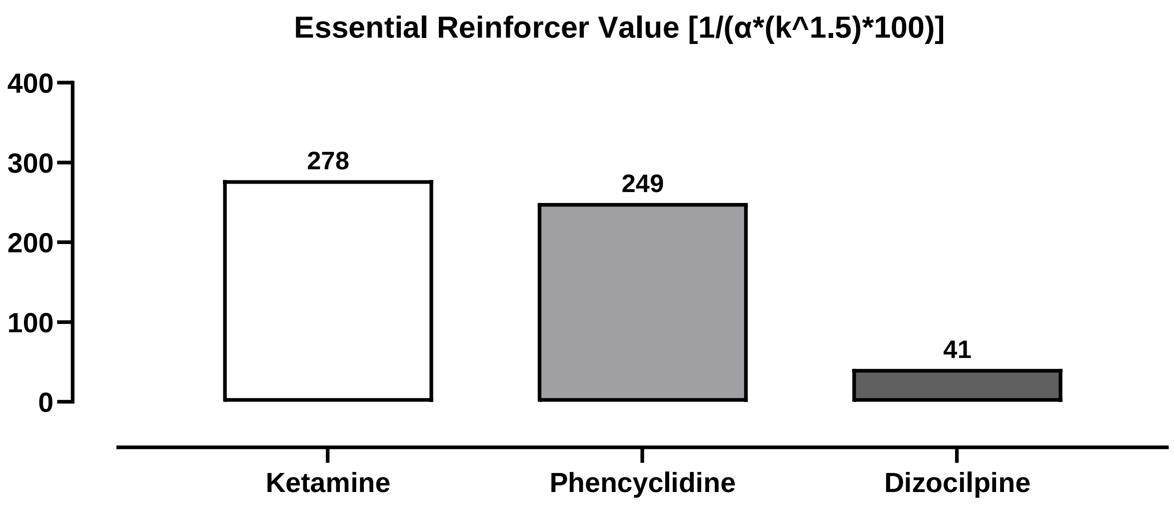
Primary endpoint was the average number of injections per day of each drug and dose across subjects

Preclinical Examples 2 & 3
(Ko et al., 2002) & (Winger et al., 2002)



Preclinical Examples 2 & 3
(Ko et al., 2002) & (Winger et al., 2002)





Clinical Example (MacKillop et al., 2019)

ORIGINAL ARTICLE

doi:10.1111/adb.12592

Validation of a behavioral economic purchase task for assessing drug abuse liability

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ABSTRACT

Behavioral economic purchase tasks quantify drug demand (i.e. reinforcing value of a drug) and have been used extensively to assess the value of various drugs among current users. However, purchase tasks have been rarely used with unfamiliar drugs to address a compound's abuse liability, and the current study sought to validate the paradigm in this capacity. Using a double-blind placebo-controlled within-subjects drug challenge design, the study evaluated differential drug demand on an experimental drug purchase task for a 20 mg dose of oral D-amphetamine (versus placebo), a prototypic psychostimulant, in 98 stimulant-naïve participants. Compared with placebo, amphetamine significantly increased intensity, breakpoint and O_{max}, and significantly decreased elasticity. Mechanistic analyses revealed that O_{max} and breakpoint mediated the relationship between subjective drug effects and '*willingness to take again*', a putative indicator of liability via motivation for future drug-seeking behavior. These findings validate the purchase task paradigm for quantifying the reinforcing value and, in turn, abuse liability of unfamiliar compounds, providing a foundation for a variety of future applications.

Purchase Task Study Overview

Aim: Evaluate differential drug demand using an experimental drug purchase task for a 20 mg dose of oral D-amphetamine (versus placebo) in 98 stimulant-naïve participants using a double-blind, placebo-controlled, within-subjects, drug challenge design.

Methods: Healthy young adult volunteers (N = 98) were recruited from the Los Angeles metropolitan area via Internet announcements, newspaper advertisements, community bulletin boards and local human subject participation pools announcing the opportunity to participate in a study on drug effects.

Inclusion criteria:

1. Age between 18 and 35 years (which is the typical age of first psychostimulant exposure);
2. High school education or higher;
3. Fluency in English;
4. Body mass index of 19–30 (to restrict variability drug metabolism).

Exclusion criteria:

1. Night shift work (to restrict variability in arousal);
2. Any medical or psychiatric condition requiring prescription medication or contraindicated for amphetamine (e.g. abnormal electrocardiogram);
3. Lifetime history of psychostimulant use (ever-use of methamphetamine/ amphetamine, crack/cocaine or a prescription stimulant medication);
4. use of drugs of abuse (other than alcohol) in the prior 30 days, by self-report and with biochemical verification of the last few days by a urine toxicology screen;
5. Current use of medication contraindicated for D-amphetamine;
6. Any current DSM-IV Axis I disorder;
7. Current or former substance use disorder;
8. Use of ≥10 cigarettes per week (to control for any nicotine withdrawal experience during testing)
9. Pregnant or breastfeeding.

Purchase Task Session Timeline

Time	Activity
10:00	Start
10:15	Pre-Drug Administration (Breathalyzer Test, CO Monitor Test, Urine Toxicology Test, Urine Pregnancy Test, Physiological/Subjective Measures Tests)
10:30	Drug Administration
11:00	Post-Drug Administration 1 (Physiological/Subjective Measures)
11:30	Post-Drug Administration 2 (Physiological/Subjective Measures)
12:00	Post-Drug Administration 3 (Physiological/Subjective Measures)
12:30	Post-Drug Administration 4 (Physiological/Subjective Measures)
1:00	Post-Drug Administration 5 (Physiological/Subjective Measures)
1:15	Purchase Task / (VAS) Drug-Liking / (VAS) Take-Drug Again
1:30	End

Purchase Task Instructions

Please respond to these questions as if you were actually in this situation.

1. Imagine that you return to this laboratory at a future time and were given a 12 hour period of time to consume the same drug you were given today. This session would last a full day, three times as long as today's session.

2. During that session, you would have the opportunity to take the drug whenever you wanted over the 12 hours. For example, you could take multiple pills all at once, you could take one pill several times throughout the day, or you could take multiple pills several times throughout the day.

3. The session would be scheduled to avoid any responsibilities afterwards or the following day, so there would be no direct negative consequences.

4. During this session, you could take as many pills as you wanted. However, you would have to purchase all of the pills at the beginning of the 12-hour session, and this would be your only opportunity to buy the drug. You would have to use your own money to purchase the drug in the form of cash. (Assume that your personal finances on the day of this session are the same as they currently are).

5. Importantly, at the end of the session, you would not be able to take any leftover pills home with you. If you don't consume them, the pills will be reclaimed and you would not get any of your money back. In other words, you wouldn't be able to save the pills for a later date or get a refund for unused pills.

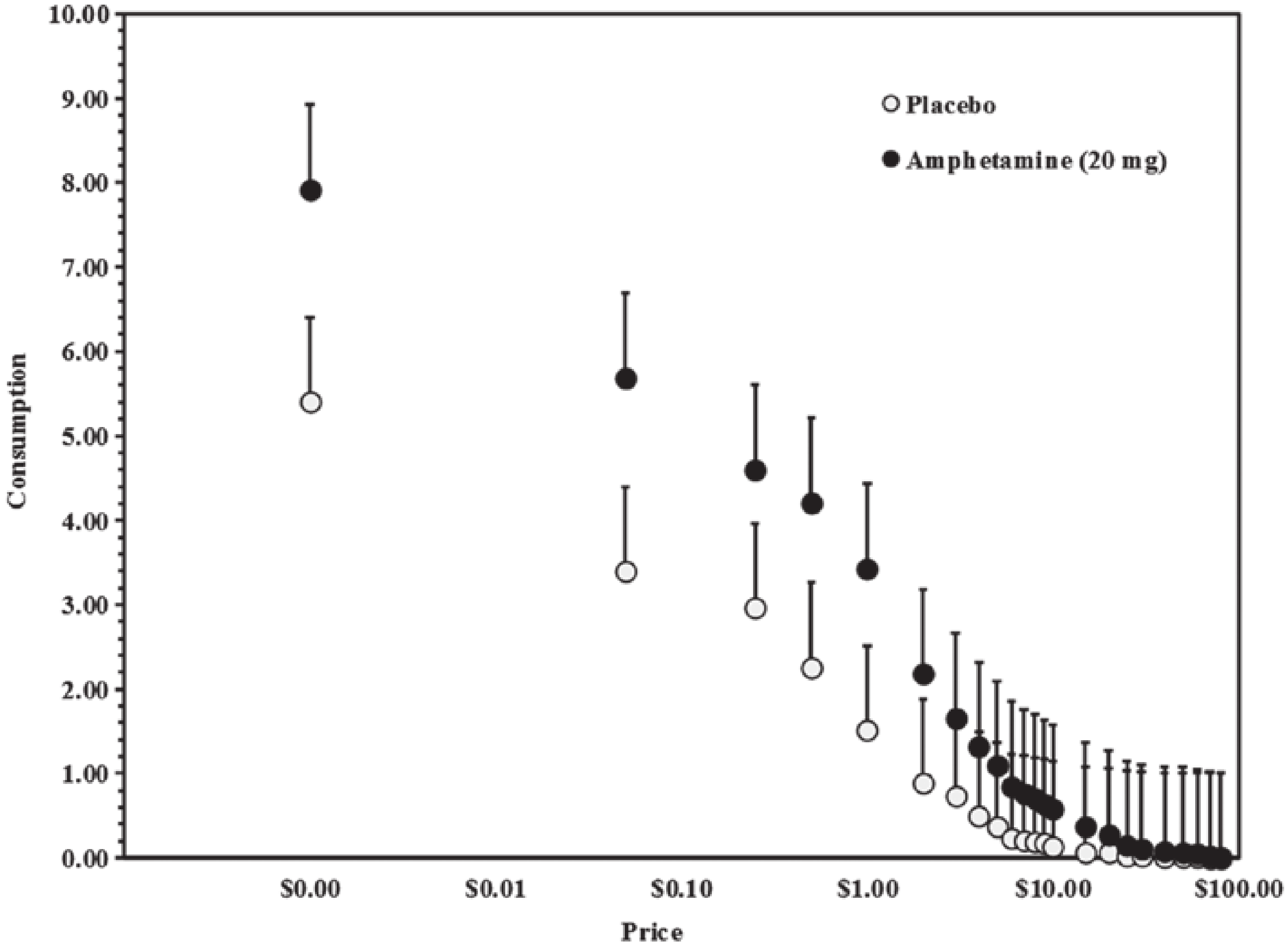
6. Finally, assume that you did not use any other drugs or alcohol before you attend the session. You would be completely sober at the beginning of the session.

Purchase Task Questionnaire

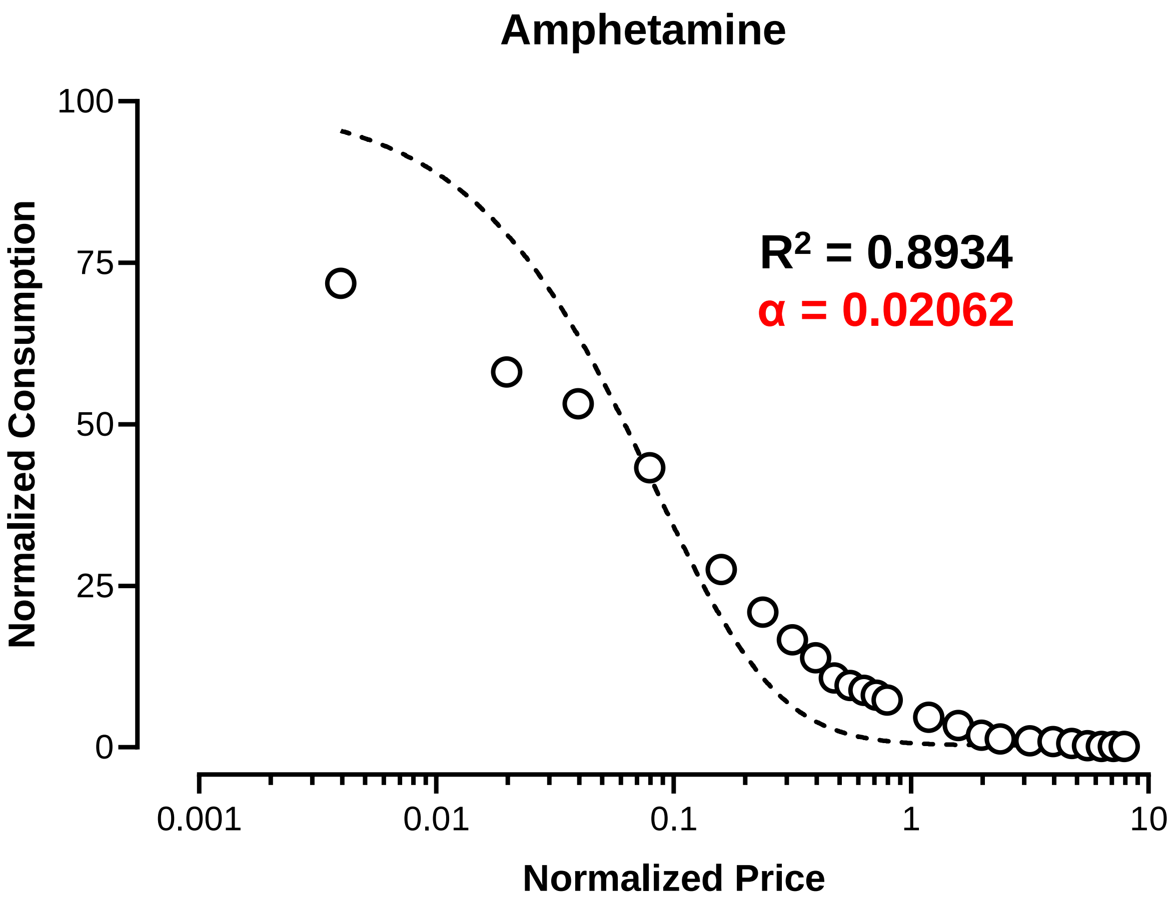
<u>Given the previous conditions, in a future 12-hour session with no direct negative consequences, how many pills of the drug you took today would you buy at the following prices?</u>

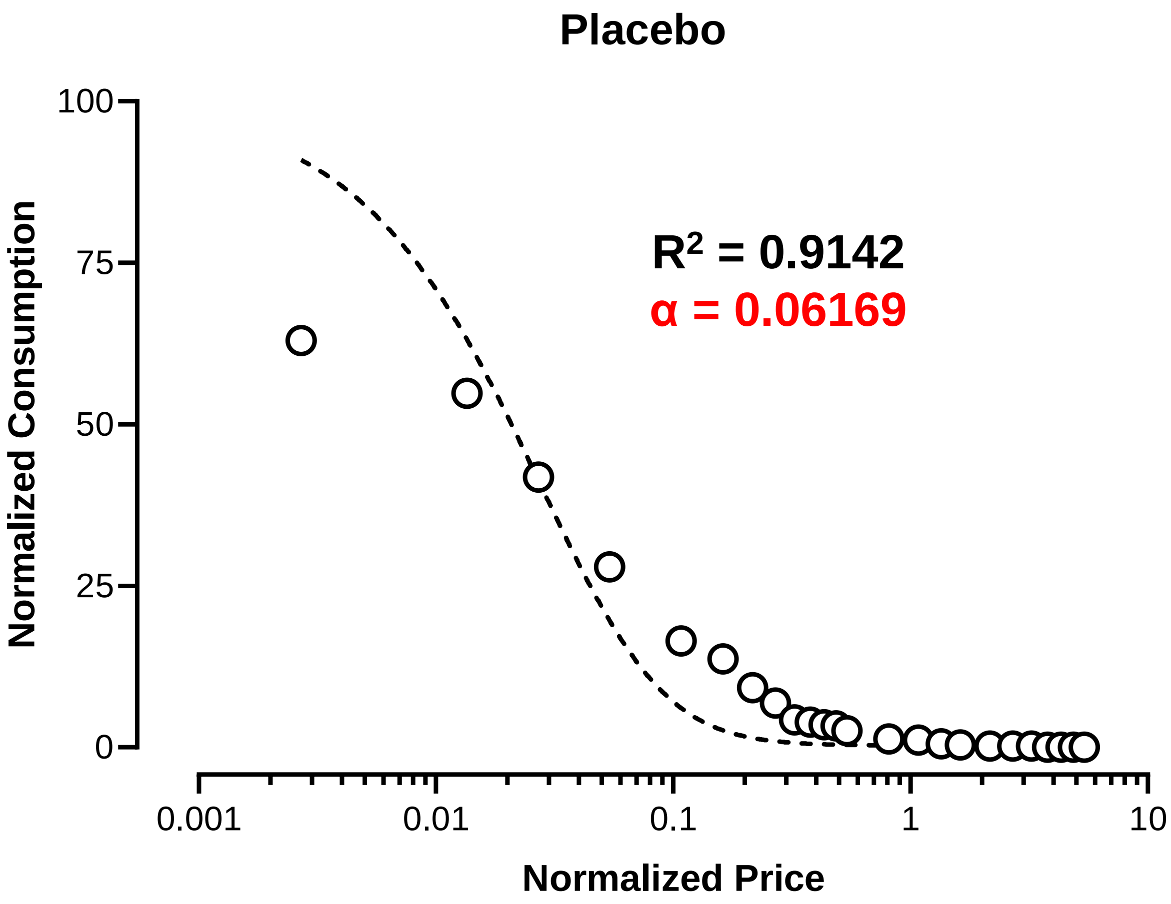
1. How many pills would you purchase if they were FREE? ________
2. How many pills would you purchase if they were 5¢ each? ________
3. How many pills would you purchase if they were 25¢ each? ________
4. How many pills would you purchase if they were 50¢ each? ________
5. How many pills would you purchase if they were $1 each? ________
6. How many pills would you purchase if they were $2 each? ________
7. How many pills would you purchase if they were $3 each? ________
8. How many pills would you purchase if they were $4 each? ________
9. How many pills would you purchase if they were $5 each? ________
10. How many pills would you purchase if they were $6 each? ________
11. How many pills would you purchase if they were $7 each? ________
12. How many pills would you purchase if they were $8 each? ________
13. How many pills would you purchase if they were $9 each? ________
14. How many pills would you purchase if they were $10 each? ________
15. How many pills would you purchase if they were $15 each? ________
16. How many pills would you purchase if they were $20 each? ________
17. How many pills would you purchase if they were $25 each? ________
18. How many pills would you purchase if they were $30 each? ________
19. How many pills would you purchase if they were $40 each? ________
20. How many pills would you purchase if they were $50 each? ________
21. How many pills would you purchase if they were $60 each? ________
22. How many pills would you purchase if they were $70 each? ________
23. How many pills would you purchase if they were $80 each? ________
24. How many pills would you purchase if they were $90 each? ________
25. How many pills would you purchase if they were $100 each? ________

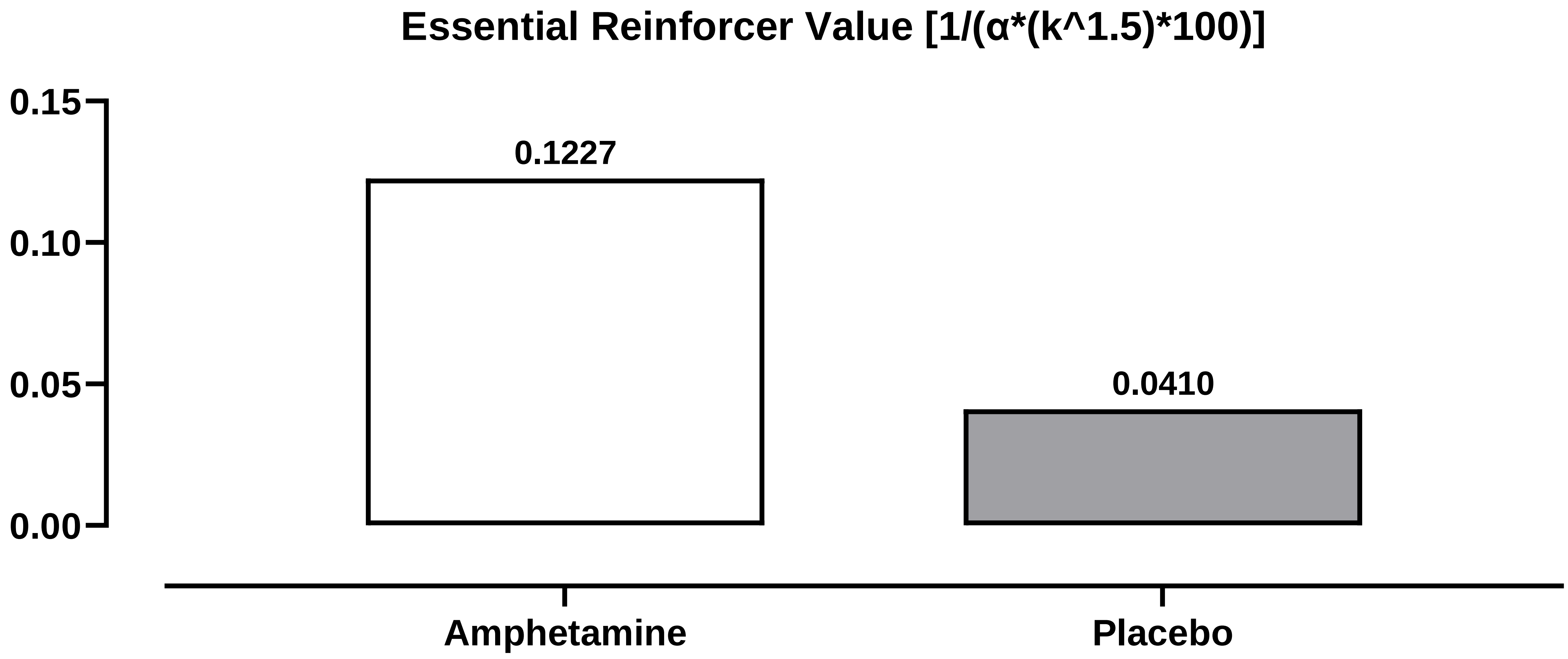
Amphetamine vs. Placebo



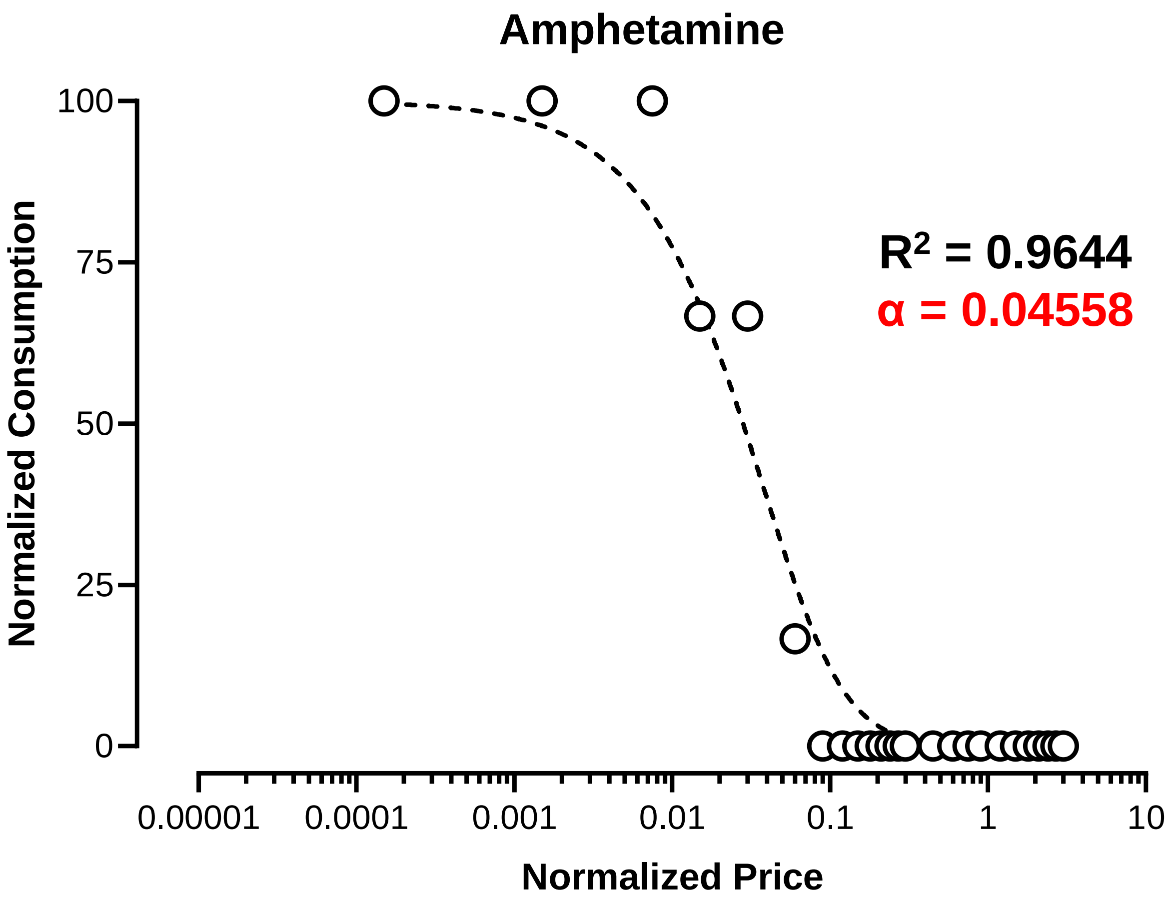
Amphetamine vs. Placebo (Mean Consumption)

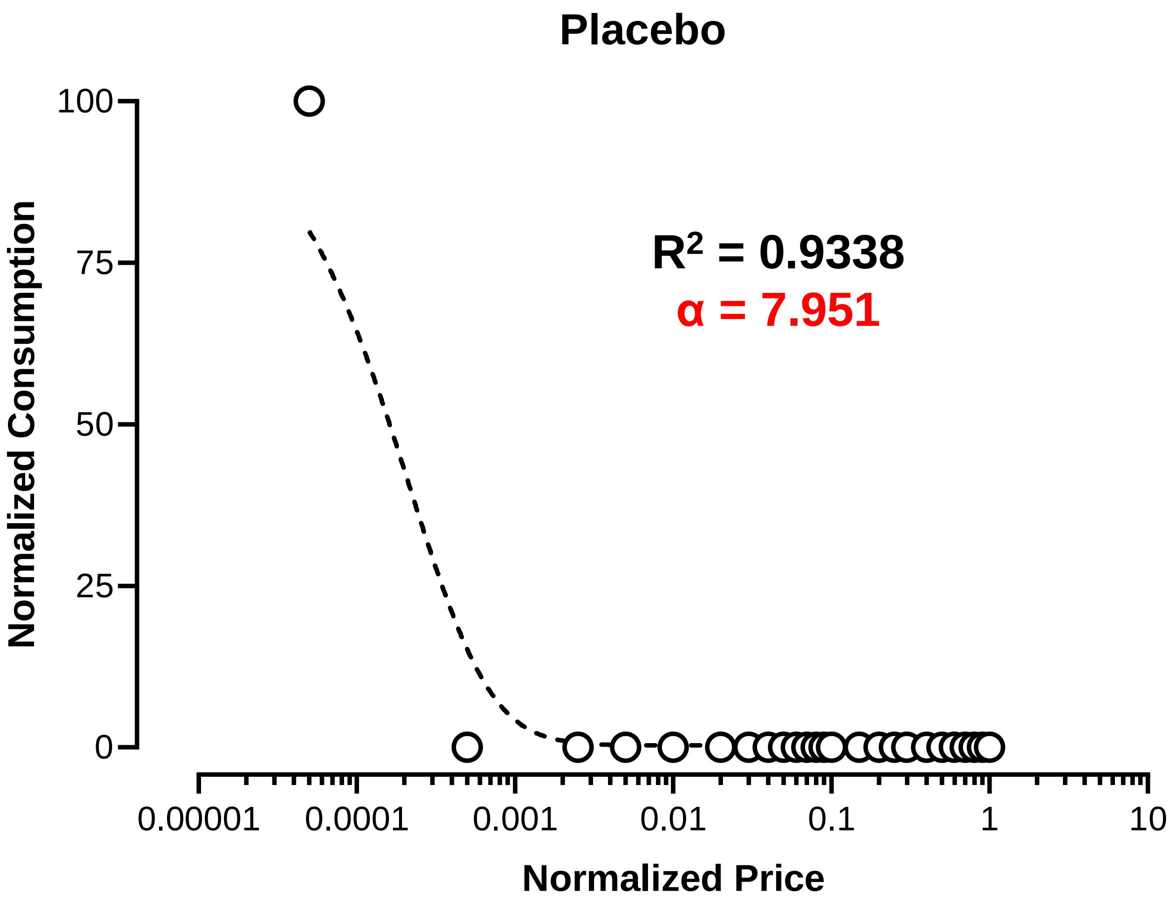




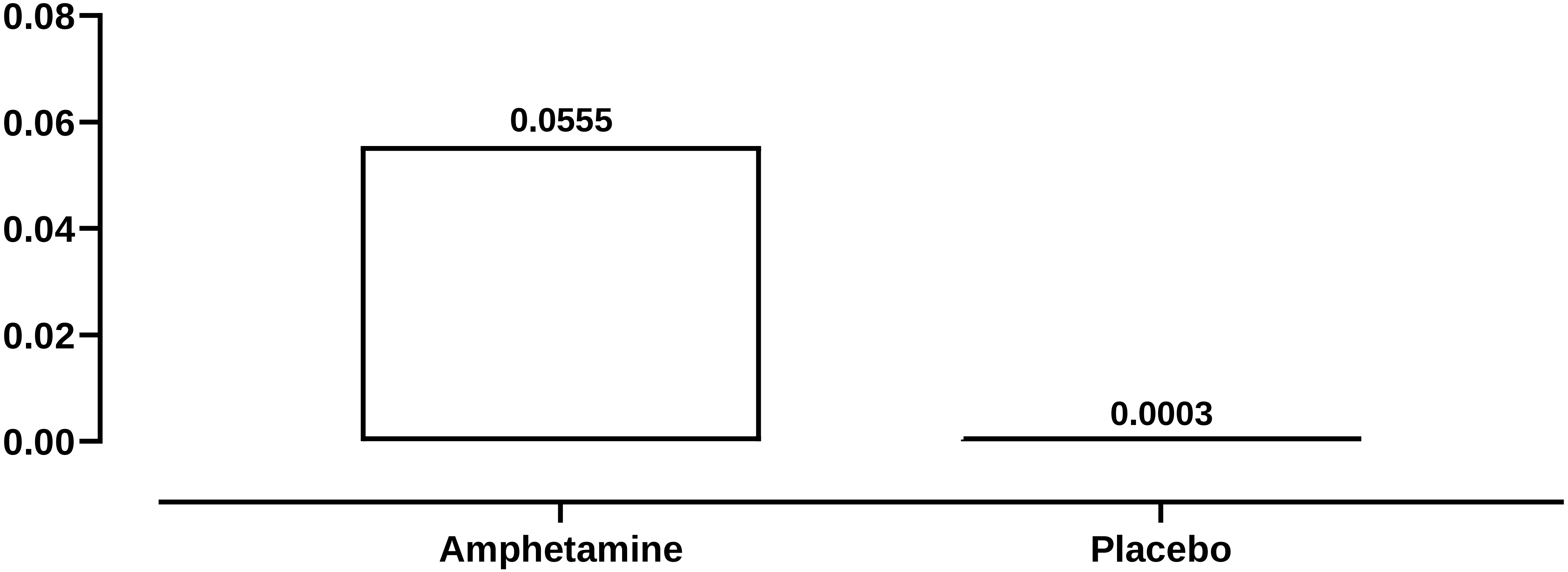

Essential Reinforcer Value [1/(α*(k^1.5)*100)]
0.15
0.10
0.05
0.00
0.1227
0.0410
Amphetamine
Placebo

Amphetamine vs. Placebo (Median Consumption)





Essential Reinforcer Value [1/(α*(k^1.5)*100)]



Demand Curve Metrics

	Amphetamine (M)	Placebo (M)	Amphetamine (MED)	Placebo (MED)
Q_0	100	100	100	100
k	2.5	2.5	2.5	2.5
α	0.02062	0.06169	0.04558	7.95100
Essential Value (EV)	0.12269	0.04101	0.05550	0.00032
P_{max}	0.10520	0.03516	0.04759	0.00027
O_{max}	3.42371	1.14438	1.54886	0.00888
$Breakpoint_0$ ($)	N/A	70	3	0.05
$BreakPoint_1$ ($)	100	60	2	0

Q_0: Hursh, S. R., & Winger, G. (1995). Normalized demand for drugs and other reinforcers. J Exp Anal Behav, 64(3), 373-384. https://doi.org/10.1901/jeab.1995.64-373

k = [$\log_{10}$(Max_Q-Min_Q)+0.5]: Kaplan, B. A., Gilroy, S. P., Reed, D. D., Koffarnus, M. N., & Hursh, S. R. (2019, Mar). The R package beezdemand: Behavioral Economic Easy Demand. Perspect Behav Sci, 42(1), 163-180. https://doi.org/10.1007/s40614-018-00187-7

α: Koffarnus, M. N., Franck, C. T., Stein, J. S., & Bickel, W. K. (2015). A modified exponential behavioral economic demand model to better describe consumption data. Exp Clin Psychopharmacol, 23(6), 504-512. https://doi.org/10.1037/pha0000045

EV = [1/(α*(k^1.5)*100)]: Hursh, S. R., & Roma, P. G. (2016). Behavioral Economics and the Analysis of Consumption and Choice. Managerial and Decision Economics, 37(4-5), 224-238. https://doi.org/10.1002/mde.2724

Approximate P_{max} = [1/(Q_0*α*(k^1.5))*(0.083*k+0.65)]: Hursh, S. R., & Roma, P. G. (2016). Behavioral Economics and the Analysis of Consumption and Choice. Managerial and Decision Economics, 37(4-5), 224-238. https://doi.org/10.1002/mde.2724

For **Analytical P_{max}** see: Gilroy, S. P., Kaplan, B. A., Reed, D. D., Hantula, D. A., & Hursh, S. R. (2019). An Exact Solution for Unit Elasticity in the Exponential Model of Demand. Journal of Experimental and Clinical Psychopharmacology. https://doi.org/10.1037/pha0000268

O_{max}: Kaplan, B. A., & Reed, D. D. (2014). Essential Value, Pmax, and Omax Automated Calculator [spreadsheet application]. In University of Kansas Applied Behavioral Economics Laboratory. http://hdl.handle.net/1808/14934

$Breakpoint_0$, $Breakpoint_1$: Foster, R., Fincham, T., Becirevic, A., & Reed, D. (2020). Observed Demand Calculator [spreadsheet application]. In University of Kansas Applied Behavioral Economics Laboratory. https://doi.org/10.17605/osf.io/gpvw6

Areas for Further Research

Range of Costs Assessed

Doses of Drug Evaluated

Other Experimental Parameters:

- Total session duration and interval between opportunities to self-administer a drug
- Force required to register each behavioral response
- Physiological state of the subject (e.g., food deprivation, recent drug history)
- Stimuli used in the test chamber
- Task instruction language and questionnaire design

Analysis Pipeline:

- Identification and management of outliers
- Handling of missing data
- Treatment of nonsystematic data patterns
- Nonlinear demand model chosen
- Starting values and constraints for fitted parameters
- Convergence criteria for accepting model results

Readings

Reed, D. D., Niileksela, C. R., & Kaplan, B. A. (2013). Behavioral economics: A tutorial for behavior analysts in practice. Behavior Analysis in Practice, 6 (1), 34–54.

Reed, D. D., Kaplan, B. A., & Becirevic, A. (2015). Basic research on the behavioral economics of reinforcer value. In Autism Service Delivery (pp. 279-306). Springer New York.

Hursh, S. R., & Silberberg, A. (2008). Economic demand and essential value. Psychological Review, 115 (1), 186-198.

Koffarnus, M. N., Franck, C. T., Stein, J. S., & Bickel, W. K. (2015). A modified exponential behavioral economic demand model to better describe consumption data. Experimental and Clinical Psychopharmacology, 23 (6), 504-512.

Stein, J. S., Koffarnus, M. N., Snider, S. E., Quisenberry, A. J., & Bickel, W. K. (2015). Identification and management of nonsystematic purchase task data: Toward best practice. Exp Clin Psychopharmacol, 23(5), 377-386.

Kaplan, B. A., Gilroy, S. P., Reed, D. D., Koffarnus, M. N., & Hursh, S. R. (2019). The R package beezdemand: Behavioral Economic Easy Demand. Perspect Behav Sci, 42(1), 163-180.

Gilroy, S. P., Kaplan, B. A., Schwartz, L. P., Reed, D. D., & Hursh, S. R. (2021, May). A zero-bounded model of operant demand. J Exp Anal Behav, 115(3), 729-746.

Resources

The R package beezdemand: Behavioral Economic Easy Demand
https://cran.r-project.org/web/packages/beezdemand/index.html

Institute for Behavior Resources (IBR), Inc.
https://ibrinc.org/behavioral-economics-tools/

Electronic Resources from the University of Kansas Applied Behavioral Economics Laboratory
http://www.behavioraleconlab.com/resources---tools.html

Nonsystematic Purchase Task Data Identification Tool: Supplement to Stein, Koffarnus, Snider, Quisenberry, & Bickel (2015)
https://www.researchgate.net/publication/283513311_Nonsystematic_Purchase_Task_Data_Identification_Tool_Supplement_to_Stein_Koffarnus_Snider_Quisenberry_Bickel_2015

Foster, R., Fincham, T., Becirevic, A., & Reed, D. (2020). Observed Demand Calculator [spreadsheet application]. In University of Kansas Applied Behavioral Economics Laboratory.
https://doi.org/10.17605/osf.io/gpvw6

Kaplan, B. A., & Reed, D. D. (2014). Essential Value, Pmax, and Omax Automated Calculator [spreadsheet application]. In University of Kansas Applied Behavioral Economics Laboratory.
http://hdl.handle.net/1808/14934

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