Are Two Bads Better Than One? A Model of Sensory Limitations*

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Abstract

We present a theoretical framework which explains the optimizing behavior of individuals who are exposed to many latent stimuli but prone to experience only the most salient one. We show that individuals with such preferences may find it optimal to engage in seemingly dysfunctional behavior such as self-harm. Our model also explains the behavior of individuals experiencing depression or trapped by multiple competing problems. We present experimental evidence suggesting such preferences explain the behavior of more than two thirds of subjects exposed to single and multiple painful stimuli.

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1 Introduction

At any given time, an individual is exposed to countless latent stimuli. Some of these are in the foreground of the individual's attention such as an engaging task at work, an interesting movie, or the back and forth of a conversation with a colleague. Unnoticed in the background are many other stimuli such as background noise, minor aches, or the drone of a boring conference presenter. While this observation is perhaps obvious, the consequences of human limits to processing stimuli has a number of interesting implications that, to our knowledge, have not been explored in economics. Furthermore, these insights may explain why some optimizing individuals engage in a number of seemingly counterproductive behaviors such as self-harm and fail to undertake low cost actions to improve their situation.

To most simply illustrate our key idea, consider the following example. Suppose an individual is watching a movie, with a utility measure of 10, while experiencing a headache, with a utility measure of -2. Suppose further that the movie and headache each have a measure of salience, and that the individual only experiences the utility of the most salient stimulus. If the salience of the movie exceeds that of the headache, the individual does not notice the headache in the background and enjoys a utility of 10 from watching the movie. On the other hand, if the salience of the headache exceeds that of the movie, then the individual cannot pay attention to the movie and instead experiences the utility level of the headache, -2. What are the behavioral implications of such a decision maker?

In this paper, we present a theoretical framework which explains the optimizing behavior of individuals who are exposed to many latent stimuli but prone to experience only the most salient one. This framework has the power to explain a variety of interesting economic behaviors and phenomena. Naturally, this model predicts that individuals and firms will often bundle unpleasant stimuli with a more pleasant distraction (Filcheck et al., 2005; Milkman et al., 2014; Al-Khotani et al., 2016).

Hence, individuals may listen to music while exercising or watch TV while prone in the dentist's chair. More significantly, however, the model rationalizes a number of seemingly dysfunctional behaviors as well.

First, consider the case of self-harm behaviors such as cutting, risky sexual behaviors, or substance abuse. In the setting we consider, individuals may engage in such activities even if they are not intrinsically pleasurable in isolation. Suppose an individual is exposed to an emotionally painful event, perhaps due to poor mental health or a difficult interpersonal conflict. In this case, an individual may engage in cutting, not because the stimulus is pleasurable but rather because it has higher utility than the emotional suffering and is more salient. In this sense, it acts as an effective, if unpleasant, distraction from an even more painful stimulus. While the individual would prefer a pleasant distraction, there may not exist any pleasant experiences that are sufficiently salient to distract from the emotional suffering. In this sense, the self-harming behavior serves as a feasible optimal distraction.

Second, our model explains the behavior of individuals experiencing depression. We model depression as a very salient negative stimulus. Because depression is so salient, it crowds out the utility associated with activities that would normally be considered pleasant. Consequently, depressed individuals have little motivation to engage in a variety of activities associated with a functional life. Indeed, to the extent that the only stimuli sufficiently salient to break through depression are either risky or harmful, our model also explains why depressed individuals are at risk of illicit drug use, overeating, and self-harm.

Third, our model predicts that individuals experiencing multiple problems have a diminished incentive to fix any single problem. This is because the benefit of removing one negative stimulus is negligible if the individual is also experiencing another more salient negative stimulus. Even the benefit of solving the problem associated with the most salient negative stimulus is limited by the fact that removing the stimulus will

simply bring another problem to the fore of the individual's attention. In this manner, individuals may appear apathetic about improving their situation in the presence of multiple problems. This can explain why stressed individuals act in a manner that seems irrational or self-defeating.

We derive empirical predictions of our model that are testable in a laboratory setting. The key prediction is that an individual's minimum willingness to be paid to endure two negative stimuli is less than or equal to the willingness to be paid for the most painful of the two negative stimuli. We examine this in the case of subjects who are asked their willingness to endure listening to a painfully loud fire alarm, put a hand in ice cold water, or do both at the same time. Strikingly, we find that fully 68 percent of individuals are willing to be paid as much or less to endure both stimuli compared to enduring the most painful one. 13 percent are willing to be paid strictly less to endure both than the most painful of the two. This is strong evidence suggesting our model is empirically relevant in explaining human behavior.

We continue our discussion by exploring in more detail the examples listed above. We then formally present the general behavioral implications of our model and discuss related theoretical literature. We follow by describing our experimental protocol and presenting our empirical results. We then conclude.

2 Examples

Before proceeding to a formal development of our model, it is helpful to illustrate the intuition underlying our model with several simple examples. Furthermore, these examples illustrate the relevance of our idea for explaining a number of behaviors of interest to economists, clinical psychologists, and policy makers.

For these examples, we assume that each stimulus is indexed by a measure of utility and a measure of salience. Exposed to a set of stimuli, an individual experiences

the utility of the stimulus within this set that has the highest salience. That is, for stimulus x, let $u(x)$ denote the individual's utility of x and let $s(x)$ denote the individual's salience of x. If $X = \{x, y, z, \ldots\}$ is the individual's set of stimuli, then the utility experienced by the individual under X is

$$U(X) = \max_{x \in X} u(x) \text{ subject to } s(x) \geq s(y) \text{ for all } y \in X. \tag{1}$$

So returning to the headache and movie example of the introduction, we have $u(\text{movie}) = 10$ and $u(\text{headache}) = -2$. If we had $s(\text{movie}) = 5$ and $s(\text{headache}) = 10$, then the individual would experience the utility $U(\text{movie}, \text{headache}) = -2$ since the headache is more salient. While the above utility function takes the same form as one attributed to Strotz (1955) in the temptation literature, we reinterpret the framework to generate important insights in very different domains. We discuss the relationship between our work and Strotz (1955) further in section 3 following the presentation of our examples.

2.1 Self-injury

> *I used self-injury as a coping mechanism to help me overcome the emotional stress that I was incapable of dealing with in any other way. Self-injury was a means of escape, a way to relieve the numbness, and an expression of the pain within me.*
>
> –Giblin (2006), *Hailey's Story*.

There is a large psychology literature on non-suicidal self injury (NSSI).[1] An important commonality across many of the leading explanations for self-injury is the notion that NSSI distracts individuals from painful emotional stimuli. Consistent

[1] See for instance Suyemoto (1998), Brown et al. (2002), Chapman et al. (2006), Selby et al. (2010), and Fox et al. (2017).

with this framework, the fifth edition of the *Diagnostic and statistical manual of mental disorders*, or DSM-5, states that "most commonly, the purpose is to reduce negative emotions, such as tension, anxiety, and self-reproach, and/or to resolve an interpersonal difficulty." Consequently, those who engage in NSSI will often report an immediate sensation of relief that occurs during the process. "When the behavior occurs frequently, it might be associated with a sense of urgency and craving, the resultant behavioral pattern resembling an addiction."

Nock (2010) provides a comprehensive review of research on NSSI. While there is no consensus on its exact prevalence, researchers estimate that between 10 and 30 percent of adolescents in the general population engage in self-harming behaviors. Most common among these behaviors are found to be cutting, burning, and overdosing on medications (Doyle et al., 2015). Sociodemographic and psychological factors, including exposure to self-harming friends or family members, dysfunctional family relationships, and sexual orientation are found to be the strongest correlates (Doyle et al., 2015; Swannell et al., 2014; Somer et al., 2015; Kharsati and Bhola, 2016).

To explain self-injury in the context of our framework, suppose there are three possible stimuli with the following utilities and salience.

Stimulus	u	s
g	1	0
b	-2	3
h	-1	4

We think of g as a good stimulus, b as a bad stimulus (e.g. being in an abusive relationship), and h as self-harm (i.e. a negative but salient stimulus). The utility an individual receives from a set of stimuli is given by U in Equation 1. Recall that the individual experiences the utility of the most salient stimulus.

Suppose that life can either be going well or poorly for the decision maker. If life is going well, then he experiences the set $\{g\}$. If life is going poorly, then he

experiences the set $\{g, b\}$. Suppose further that the decision maker has the ability to add h to any set of experiences. If life is going well, then he would rather not have h present. I.e.

$$U(\{g\}) > U(\{g, h\}).$$

However, when life is going poorly, then this preference switches and the individual does want stimulus h present. I.e.

$$U(\{g, b, h\}) > U(\{g, b\}).$$

Thus when things are going well, the decision maker will not engage in self-harm. However, if life takes a turn for the worse, then the decision maker will engage in self-harm in order to distract himself from the bad stimulus.

Fox et al. (2017) attempt to shed empirical light on why NSSI engagement may make individuals feel better. Examining a population of individuals with a history of self-harm, the researchers induced a negative mood by asking the subjects to spend five minutes writing about the most significant time "in which they failed or let themselves down in their life." Control subjects were exposed to no additional stimulus while other subjects were also exposed to a physically painful stimulus. Compared to control subjects, individuals in the pain condition expressed no significant improvement of mood on average. However, subjects prone to self-criticism did experience an improvement in mood under the pain condition relative to the control condition. The authors interpret this as evidence that individuals engage in self-harm because their mood improves when they engage in self-punishment for perceived shortcomings.

Our model, however, supports an alternative interpretation of the findings. The intervention to induce a negative mood, namely having individuals recall events in which they failed, caused more disutility for individuals prone to self-criticism than for other subjects. Consequently, the pain intervention was more likely to provide a

relative utility boost for such individuals because it displaced a more painful stimulus from the subjects' attention.

2.2 Depression

> *To have depression is to have no motivation; No motivation to wake up, no motivation to socialize, no motivation to live. It is a crushing weight that you just need some support to lift.*
>
> –Anonymous (2014).

The DSM-5 characterizes depressive disorders by "sad, empty, or irritable mood, accompanied by somatic and cognitive changes that significantly affect the individual's capacity to function." Risk factors for depressive disorders include both genetic and environmental factors. Additionally, bereavement and other severe life challenges can induce symptoms of a depressive disorder without meeting the criteria for such a diagnosis. Regardless of the causes of depressive disorders and symptoms, our framework provides insight into the resulting behaviors.

Regarding major depressive episodes, the DSM-5 reports, "The mood in a major depressive episode is often described by the person as depressed, sad, hopeless, discouraged, or 'down in the dumps'." However, on occasion individuals "complain of feeling 'blah,' having no feelings, or feeling anxious." From these descriptions, it seems reasonable to model the phenomenon of depression as an extremely salient, and generally negative, stimulus that crowds out other feelings. In the context of our theoretical framework, the existence of such a powerful stimulus provides a compelling explanation for a variety of observed behaviors of individuals suffering from depression.

First, the DSM-5 states, "Loss of interest or pleasure is nearly always present, at least to some degree. Individuals may report feeling less interested in hobbies, 'not

caring anymore,' or not feeling any enjoyment in activities that were previously considered pleasurable. In some individuals, there is a significant reduction from previous levels of sexual interest or desire." To see how this relates to our model, consider the following example. Assume three possible stimuli: the absence of depression, g; depression, d; and a pleasurable activity, a. The utility and salience of these measures are given in the table below.

Stimulus	u	s
g	1	0
d	-10	10
a	5	5

An individual will enjoy the pleasurable activity in the absence of depression, since $U(\{g, a\}) > U(\{g\})$. However, when depression is within the set of stimuli, an individual will not find that the pleasurable activity increases utility since it is not sufficiently salient to be enjoyable, yielding $U(\{d, a\}) = U(\{d\})$. Thus for sufficiently salient depression, individuals would become indifferent to many activities they would otherwise find enjoyable.

A similar example can explain the difficulty that, according to the DSM-5, depressed individuals exhibit in thinking, concentration, and decision making. Note that depression need not be associated with very low utility or extreme sadness in order to bring about these changes in behavior. Indeed, what is most significant is not the utility associated with the stimulus of depression but rather its overwhelming salience which numbs an individual to other stimuli, both pleasant and unpleasant.

Second, the DSM-5 indicates that depression is often comorbid with substance-related disorders and that while some depressed individuals display a lack of interest in food, others report increased appetite and weight gain. Similarly, Strine et al. (2008) find a significant relationship between depression and unhealthy behaviors such as smoking, obesity, physical inactivity, and heavy drinking in a cross-section of adults

in the US. Zetterqvist (2015) reports that among individuals engaging in NSSI, 70 to 80 percent are depressed as well. These behaviors associated with depression are consistent with our explanation of self-harm in the prior section. Indeed, depressed individuals are likely to engage in any behavior which is more pleasant than depression and sufficiently salient to increase their utility.

2.3 The Trap of Competing Problems

> *Shawn, an office manager in Cleveland, was struggling to make ends meet. He was late on a bunch of bills. His credit cards were maxed out. His paycheck ran out quickly. As he said, "There is always more month than money." Every phone call made him tense: another creditor calling to "remind" him? Being out of money was also affecting his personal life. And there was no end in sight. He had bought a Blu-ray player on credit, with no payments for the first six months. That was five months ago. How would he pay this extra bill next month?*
>
> –Mullainathan and Shafir (2013)

Researchers have long puzzled over why individuals in difficult situations fail to undertake action to improve their situation or indeed engage in behavior that would seem to exacerbate the difficulties they already face. Going back to Strotz (1955), economists have also considered the possibility that individuals have limited self-control and hence are subject to temptation that they may wish to avoid. Furthermore, Mani et al. (2013) show that individuals in poverty demonstrate reduced cognitive function that prevents them from making optimal financial decisions. The evidence for these theories is compelling. Our framework, however, presents an additional explanation for such behaviors.

In particular, when individuals face a large number of problems or negative stimuli, the effect on their realized utility of eliminating one negative stimulus may be quite

small. An individual who receives utility only from the most salient stimulus has no incentive to remove a negative stimulus that is insufficiently salient to be felt. Even when the experienced negative stimulus is undesirable, the benefit of eliminating it may be limited by the fact that another negative, if slightly less salient, stimulus will simply be brought to the fore of the individual's attention. This intuition is similar to that of a competing risks model in epidemiology. The life-saving benefit of curing one illness is limited by the health risks posed by a second. For example, reducing the health risks of heart disease by dieting are negligible for an individual diagnosed with terminal cancer.

Consider the following example that illustrates this intuition. Suppose there are three possible stimuli with the following utilities and salience.

Stimulus	u	s
g	1	0
b	-2	3
w	-3	4

We think of g as a good stimulus, b as a bad stimulus (e.g. being unemployed), and w as a worse stimulus (e.g. marital problems).

Suppose the decision maker is experiencing the set $\{g, b, w\}$. He has the ability to remove b from this set, but doing so takes effort and thus will reduce his utility by some small amount $\epsilon > 0$. This means if he removes b from $\{g, b, w\}$, he will experience utility $U(\{g, w\}) - \epsilon = -3 - \epsilon$. However $U(\{g, b, w\}) = -3$. Thus no matter how small ϵ, the decision maker will not want to remove b.

Even the willingness to ameliorate the worse stimulus, w, is limited by the existence of the bad stimulus, b. An individual experiencing the set $\{g, w\}$ would be willing to exert effort to eliminate w from the set up to a utility cost of 4. However, if the decision maker is experiencing the set $\{g, b, w\}$ he would only be willing to exert effort at a utility cost of 1 or less to eliminate w.

This example also highlights the indifference of individuals experiencing negative stimuli to the addition of other negative stimuli. To an individual with the preferences we describe, $U(\{g, b, w\}) = U(\{g, w\})$. Hence the addition of the bad stimulus, b, to the set that already includes the worse stimulus, w, has no effect on realized utility.

This example demonstrates that the existence of multiple problems limits the willingness to eliminate any one problem. Consequently, individuals with a variety of problems will often not find it optimal to fix any of them. They may also find it suboptimal to prevent the occurrence of new problems. Hence, behavior that may seem irrational, impulsive, or demonstrating poor cognitive function may instead reflect the complementarity of negative stimuli arising from the fact that once a person has problems, adding more problems may not change experienced utility.

3 Theory

These accompanying examples are helpful for illustrating the economic relevance of our model. In this section we formalize our treatment of the Strotz (1955) utility representation and consider alternative preferences over sets of stimuli. This formalization provides empirical predictions that can be tested in the laboratory. We then discuss related theoretical literature.

3.1 Model

Let A denote the (finite) set of possible stimuli, and let $\mathcal{P}(A)$ denote the set of all subsets of A. A decision maker will experience a set of stimuli $X \in \mathcal{P}(A)$, and has a preference relation $\succeq$ over $\mathcal{P}(A)$. We define $\succ$ and $\sim$ in the usual way. We say *U represents* $\succeq$ if $U(X) \geq U(Y)$ if and only if $X \succeq Y$. Note that we include the empty set in our domain. For all of the following representations and without loss of generality, we set the utility of the empty set equal to zero.

Definition. We say $\succeq$ has a *Strotz representation* if there exist real-valued functions u and s such that

$$U^S(X) = \max_{x \in X} u(x) \text{ subject to } s(x) \geq s(y) \text{ for all } y \in X,$$

represents $\succeq$. If $\succeq$ has a Strotz representation, then we say that $\succeq$ is a *Strotz preference.*

As previously discussed, the interpretation is that s is the decision maker's subjective measure of salience of stimuli while u is the decision maker's true utility. The decision maker experiences the utility of only the most salient stimulus.

Strotz's original model was one of changing tastes, and he considered how a self-aware individual might behave in such a situation. He proposed that the decision maker would prefer commitment. However in the absence of commitment opportunities, Strotz proposed the "strategy of consistent planning": Today's self chooses a plan of consumption that tomorrow's self will actually implement. In this interpretation of U^S, s represents tomorrow's preferences while u represents today's.

Gul and Pesendorfer (2001) (henceforth GP) extended Strotz's analysis to a setting of temptation and self-control in a paper that kicked off a large decision theoretic literature on temptation.[2] They introduced the following representation.

Definition. We say $\succeq$ has a *GP representation* if there exist real-valued functions u and s such that

$$U^{GP}(X) = \max_{x \in X} [u(x) + s(x)] - \max_{x \in X} s(x),$$

represents $\succeq$. If $\succeq$ has a GP representation, then we say that $\succeq$ is a *GP preference.*

One way to think about the Strotz representation is as a limiting case of the GP

[2]See Lipman and Pesendorfer (2013) for a survey of this literature. Also, note that Gul and Pesendorfer's (2001) set up is different than our finite one. Specifically, their primitive is a preference relation over non-empty compact subsets of lotteries over a compact metric space. See Gul and Pesendorfer (2005) for an in depth analysis of these preferences in a finite setting.

representation. To see this, consider the GP representation

$$U_{\alpha}^{GP}(X) = \max_{x \in X} [u(x) + \alpha s(x)] - \max_{x \in X} \alpha s(x), \;\; \alpha > 0,$$

and note that $U_{\alpha}^{GP} \to U^S$ as $\alpha \to \infty$.

The GP representation can be applied in our setting of sensory limitations. The functions u and s are the true utility and salience respectfully, as before. However as opposed to the Strotz representation, a decision maker can experience the utility of a stimulus other than the most salient one, but doing so requires exerting some mental effort. To see this, rewrite U^{GP} is

$$U^{GP}(X) = \max_{x \in X} [u(x) - c_s(x, X)],$$

where $c_s(x, X) = \max_{y \in X} s(y) - s(x)$. The function $c_s(x, X)$ represents the cost of concentrating on $x \in X$. Thus a decision maker with GP preferences evaluates sets of stimuli according to the utility function u net concentration costs.

It is straightforward to show that both the Strotz and GP preferences satisfy:

Set Betweenness. If $X \succeq Y$, then $X \succeq X \cup Y \succeq Y$.

However only the Strotz representation satisfies:

No Compromise. For all X and Y, either $X \sim X \cup Y$ or $Y \sim X \cup Y$.

Recognizing these differences will allow us to test in an experimental setting whether a decision maker is consistent with the Strotz and GP preferences. It will also allow us to potentially differentiate between the two models.[3]

[3]Given the limited data we can observe in an experimental setting, we can only potentially differentiate GP preferences from Strotz preferences; we cannot differentiate Strotz preferences from GP preferences. This is because any preference consistent with No Compromise is also consistent with Set Betweenness, while there are preferences consistent with Set Betweenness that are inconsistent with No Compromise (e.g. $X \succ X \cup Y \succ Y$).

One obvious alternative model to compare ours to is an additive model. After all, if X represents the set of stimuli experienced by the individual, perhaps the utility from X is simply the sum of utilities from each stimulus:

$$U^A(X) = \sum_{x \in X} u(x).$$

The key behavioral property of the additive model is that any single stimulus is either always positive, always negative, or always neutral.

Definition. We say stimulus x is *universally positive* if for every $X \not\ni x$ we have $X \cup \{x\} \succ X$. We say x is *universally negative* if for every $X \not\ni x$ we have $X \succ X \cup \{x\}$. We say x is *universally neutral* if for every $X \not\ni x$ we have $X \cup \{x\} \sim X$.

Additivity. For every $x \in A$, x is exactly one of the following: universally positive, universally negative, universally neutral.

More generally, we will refer to the additive model to be not just those preferences that can be represented by the functional form above, but to be all preferences satisfying the axiom Additivity. Note that Set Betweenness and Additivity are generally opposed, as the following lemma shows.

Lemma 1. *Suppose $\succeq$ satisfies $\{w\} \succ \{x\} \succ \{y\} \succ \{z\}$. Then $\succeq$ cannot satisfy Additivity and Set Betweenness.*

Proof. Suppose $\succeq$ satisfies Set Betweenness. Then we have $\{x\} \succeq \{x, y\} \succeq \{y\}$, with one of these strict.

Case 1 – $\{x\} \succ \{x, y\}$. Then y is not universally positive or universally neutral. However since $\{y\} \succ \{z\}$, Set Betweenness implies $\{y, z\} \succeq \{z\}$. But this implies that y cannot be universally negative.

Case 2 – $\{x, y\} \succ \{y\}$. Then x is not universally negative or universally neutral. However since $\{w\} \succ \{x\}$, Set Betweenness implies $\{w\} \succeq \{w, x\}$. But this implies that x cannot be universally positive. □

Thus under Strotz and GP preferences, a stimulus cannot be universally positive or negative — it depends on the set of stimuli to which it is added.

3.2 Related Theoretical Literature

Our model shares a passing resemblance to recent choice theoretic work on inattention and rationalization (Manzini and Mariotti, 2007; Masatlioglu et al., 2012; Cherepanov et al., 2013; Lleras et al., 2017). These papers all model a decision maker who, for a given choice set, forms a consideration set and chooses a preference-maximal alternative from the consideration set. A special case of this would be a decision maker with sensory limitations who forms his consideration set from the most salient alternatives as given by some function s. However, these papers all study a decision maker who chooses *one* alternative from a set, whereas our model considers a decision maker who will consume (or experience) *all* alternatives in a set. Thus our primitive is not a choice function from sets, but a preference over sets. This allows us to study behavior and settings that are materially different from these papers.

Even among the growing literature on preferences over sets, our interpretation that the decision maker will experience the whole set is not widely adopted. Gul and Pesendorfer (2001) (and the temptation literature in general) view a set as representing a choice set from which the decision maker will ultimately choose a single alternative to consume in an unmodeled future period.[4] Related is the literature on decision making under complete uncertainty wherein the decision maker chooses a set with the understanding that 'nature' will ultimately choose one alternative from the set for the decision maker to consume, usually with no knowledge about how nature will choose. (See e.g. Bossert et al. (2000) and Olszewski (2007) as examples.) There has been some work that considers preferences over sets in which the alternatives are not mutually exclusive. But this has usually been in the context of group choice, such

[4] Kreps (1979) and Dekel et al. (2001) also adopt this interpretation in non-temptation settings.

as purely hedonic games (Bogomolnaia and Jackson, 2002), voting (Barberà et al., 1991), and matching (Roth, 1985). See Barberà et al. (2004) for a comprehensive review of the literature on ranking sets.

Salience plays an important role in the work of Bordalo et al. (2013b, 2012, 2013a, 2015) and Ellis and Masatlioglu (2017). However, in these papers, an alternative has multiple attributes and salience is defined relative to these attributes. E.g. a good's attribute is salient if, among all its attributes, it deviates most relative to the choice set's average level for that attribute. In contrast, an alternative's salience is purely a subjective judgment in our model; we put no structure on the composition of alternatives.

4 Laboratory Experiment

4.1 Experimental Protocol

We conducted a laboratory experiment to test the key prediction of our model. In particular, our experiment was designed to test whether an individual's minimum willingness to be paid to endure two negative stimuli is less than or equal to the willingness to be paid for the most painful of the two negative stimuli.

The experiment was administered to each subject individually in a private room. Upon signing the consent form, the subject was asked to practice each of the four unpleasant tasks for 30 seconds. The tasks were: 1) listening to a loud (85 decibel) fire alarm sound through headphones, 2) holding a hand in ice cold (32 degrees Fahrenheit) water, 3) doing 1 and 2 simultaneously, and 4) holding two hands in ice cold water.[5] To avoid potential order effects, subjects practiced each task twice in

[5]While unpleasant, these tasks were in compliance with Occupational Safety and Health Administration regulations and not deemed dangerous by a physician. The Institutional Review Board of Brigham Young University approved the protocol. Kahneman et al. (1997) and others have tested individuals' responses to painful stimuli by having subjects place their hand in cold water.

random order. For the purposes of the current study, we focus on the first three tasks, though in the results section we briefly discuss results from the fourth task.

Participants were then asked to write down the minimum amount (from \$0 to \$15, in fifty-cent increments) that they would be willing to be paid to complete one of the four tasks for two minutes. They were told that after they write down the amount for each task, the experimenter would randomly select one of the four tasks as well as one of the ten threshold amounts, ranging from \$0 to \$15, from an envelope. If the chosen threshold amount exceeds the minimum amount listed by the subject for a particular task, the subject would receive that amount after she completes the task for two minutes. If the threshold amount is less than the minimum amount listed by the subject for a particular task, the subject would not have an opportunity to complete the task, but would need to sit in the room for the remaining two minutes until they can be paid a show-up fee of \$2. This protocol ensured that the amounts listed by the subjects were incentive compatible and strategy-proof.

To ensure the subjects understanding of the instructions, before writing down the amounts, they were asked to answer multiple comprehension questions correctly to proceed. At the end of the experiment, subjects completed a post-experimental questionnaire intended to collect their demographic information, including gender, age, university status, GPA, and study major. An average experimental session lasted approximately 15 minutes and subjects earned \$6 on average, in addition to the show up fee.

Subjects in our experiment were students at Brigham Young University recruited through email advertisements. The exact content of the recruitment email can be found in appendix A and detailed experimental instructions are included in appendix B.

Relating this experiment to our proposed model, let ℓ and h denote listening to the loud siren for two minutes and submerging one hand in ice water for two minutes

respectively. How a subject ranks $\emptyset$, $\{\ell\}$, $\{h\}$, and $\{\ell, h\}$ (as revealed by his/her reservation payments) will determine whether he or she is consistent with a given model. For example, the ordering

$$\emptyset \succ \{\ell\} \succ \{\ell, h\} \succ \{h\}$$

is consistent with Set Betweenness, but not No Compromise or Additivity. Hence this ordering is consistent with GP preferences, but not Strotz or additive preferences. As another example, the ordering

$$\emptyset \sim \{\ell\} \succ \{\ell, h\} \sim \{h\}$$

is consistent with No Compromise, Set Betweenness, and Additivity. Hence it is consistent with Strotz, GP, and additive preferences.

4.2 Results

We collected data from 65 subjects. From this sample, we drop 5 subjects who stopped the protocol prior to completion. This leaves us with an analysis sample of 60 subjects who completed the protocol. Table 1 shows summary statistics for these subjects. Consistent with the fact that we recruited subjects in a university setting, the average age is approximately 22 years old. Only about a third of our subjects are female and a majority are white. After practicing with all of the tasks, students reported the minimum amount they would be willing to accept to perform each of the tasks, which we refer to as a reservation payment. We see that the average reservation payments in our sample for the various tasks range from \$2.50 to \$5.28.

We now turn our attention to the theoretical predictions of our model. Both the Strotz and GP utility representations predict that the reservation payment for two stimuli, which are each negative in isolation, should be less than or equal to

the maximum reservation payment of the two individual stimuli. In contrast, if we thought that the stimuli were additive in the amount of disutility imposed upon the subjects, we would expect to see the reservation payment for two stimuli exceed the maximum reservation payment of the two stimuli in isolation. Figure 1 sheds light on how well our models explain the data. The figure shows the empirical CDF of subjects' reservation payment for one hand in cold water and listening to a siren divided by the maximum reservation payment of the two stimuli in isolation. In our sample, all subjects for whom this ratio is equal to or below one exhibit preferences consistent with the GP and possibly Strotz representations.[6] We see that fully two thirds of individuals reveal a reservation payment for the two stimuli less than or equal to the greater of the two reservation payments corresponding to the individual stimuli. There is a discontinuous increase in the density at a value of 1 demonstrating that for many subjects the disutility of two stimuli is exactly equal to the disutility of the most uncomfortable individual stimulus. The behavior of a majority of subjects stands in stark contrast to the prediction of any additive model in which each additional stimulus should increase the subject's reported reservation payment.

Table 2 shows the fraction of subjects exhibiting each preference ordering across sets of stimuli. Note that only the preference orderings actually exhibited by subjects are shown in the table. Table 3 shows more concisely the fraction of subjects exhibiting preferences consistent with each utility representation. Note that the sum of these fractions exceeds one since some of these preferences are consistent with multiple models. Examining the table, we see that 63 percent of subjects exhibit preferences consistent with the Strotz representation in that the reservation payment is exactly equal to the reservation payment of one of the stimuli in isolation. 68 percent exhibit preferences consistent with a GP representation in that the reservation

[6]It is possible for preferences to be inconsistent with the Strotz or GP preferences and still have this ratio be less than one: $\{\ell, h\} \succ \{\ell\} \succ \{h\}$ is one such example. However none of our subjects exhibited such preferences.

payment for both stimuli lies in the closed interval between the reservation payments of the two individual stimuli. Only 40 percent of subjects exhibit additive preferences in which an additional stimulus increases the reservation payment. One individual (2 percent of subjects) demonstrates inconsistent preferences in the sense that the subject reports no disutility from hearing the siren yet the reservation payment for the siren and hand exceeds that of the hand alone. Collectively, the experimental evidence strongly suggests that most individuals only have a limited ability to experience multiple latent stimuli at the same time. Strikingly, the simple Strotz model in which an individual is able to experience the utility of only a single stimulus is sufficient to explain a majority of subjects' decisions in this setting.

One might be concerned that our results are driven in part by individuals who do not find the stimuli unpleasant. The results are virtually identical if we exclude the 6 observations who report a reservation payment of 0 for one or more stimuli.

As mentioned in our description of the protocol, we also elicited from subjects their reservation payment for placing two hands in cold water. In this setting 35 percent of subjects indicate the same reservation payment for placing two hands in water as for placing one hand in water. 2 percent (one subject) indicate a lower reservation payment for two hands than for one. 63 percent require a reservation payment for two hands that exceeds the reservation payment for putting a single hand into cold water. If we view each hand as a separate stimulus, 35 percent of subjects in this setting demonstrate preferences consistent with the GP and Strotz representations. To the extent that placing two hands in cold water represents an increased intensity of the same stimulus relative to placing one hand in cold water, this part of the protocol provides a less informative test of the theory.

5 Conclusion

We reinterpret the Strotz and GP utility representations to provide insight into how people behave when they have only a limited ability to experience competing latent stimuli. This framework demonstrates that one cannot characterize a stimulus as positive or negative absent the set of all latent stimuli. One key insight from our model regards the complementarity of negative stimuli. In particular, once one is experiencing a salient and negative stimulus the utility cost of additional negative stimuli might be quite small. This can lead to a variety of seemingly dysfunctional behaviors that are nevertheless consistent with utility maximization.

In particular, our theoretical framework provides explanations for phenomena including destructive distractions, an unwillingness to ameliorate negative situations in one's life, and the apathy of severe depression. In each of these examples, actions that would seem to objectively improve an individual's life fail to be optimal if the benefits are insufficiently salient to rise above the pain of other life circumstances. Furthermore, individuals may engage in behavior that seems destructive if doing so provides a salient distraction from a greater pain. Understanding how these behaviors are optimal from a utility maximization perspective may provide researchers, policy makers, and clinicians with insights regarding how to better help individuals in these conditions. In particular, policies to improve the circumstances of such individuals should take into account the full set of latent circumstances and stimuli to which an individual is exposed.

While our theory has a strong intuitive appeal, we also present convincing empirical evidence that our theoretical framework predicts behavior in a setting with both real payoffs and consequences. We find that over two thirds of individuals exhibit preferences consistent with our framework in an experiment in which subjects are exposed to single and multiple painful stimuli. In particular, after experiencing the stimuli together and in isolation, 68 percent of individuals experience the same or *less*

disutility from two painful stimuli than one of the stimuli in isolation. This suggests that, at least in this experimental context, our framework explains the majority of peoples' choices in a way that runs counter to what an additive model would predict.

Future researchers may wish to consider building upon the current project in at least two ways. First, our model assumes that both the utility and salience of stimuli are exogenous and fixed. It may be that actors such as therapists and advertisers seek to alter individuals' well-being and decision making by changing either the salience or utility of particular stimuli. Extending the model to include such possibilities may be clinically and empirically relevant. Second, we encourage researchers to also design and execute observational tests of the theory with data from individuals who experience self-harm, despair, and depression. Such studies are likely to shed insight into the applicability of the theory in important settings that cannot be ethically studied experimentally.

Tables and Figures

Table 1: Summary Statistics

Variable	Mean
Age	22.18
	(2.21)
Female	0.35
	(0.48)
GPA	3.68
	(0.34)
White	0.83
	(0.38)
Asian	0.13
	(0.34)
Reservation Payment to Perform Task	
Siren	\$2.50
	(2.21)
One Hand in Water	\$4.12
	(2.90)
Siren and One Hand	\$4.57
in Water	(3.17)
Two Hands in Water	\$5.28
	(3.56)
Observations	60

Notes: Standard deviations are in parentheses.

Table 2: Preference Ordering of Various Stimuli

Preference Ranking	Fraction	Consistent Representations
$\emptyset \succ \{\ell\} \succ \{\ell, h\} \sim \{h\}$	0.27	Strotz, GP
	(0.06)	
$\emptyset \succ \{h\} \succ \{\ell, h\} \sim \{\ell\}$	0.02	Strotz, GP
	(0.02)	
$\emptyset \succ \{\ell\} \sim \{\ell, h\} \succ \{h\}$	0.05	Strotz, GP
	(0.03)	
$\emptyset \succ \{\ell\} \sim \{\ell, h\} \sim \{h\}$	0.20	Strotz, GP
	(0.06)	
$\emptyset \sim \{\ell\} \succ \{\ell, h\} \sim \{h\}$	0.07	Strotz, GP, Additive
	(0.03)	
$\emptyset \sim \{\ell\} \sim \{\ell, h\} \sim \{h\}$	0.03	Strotz, GP, Additive
	(0.02)	
$\emptyset \sim \{\ell\} \succ \{\ell, h\} \succ \{h\}$	0.03	GP
	(0.02)	
$\emptyset \succ \{\ell\} \succ \{\ell, h\} \succ \{h\}$	0.02	GP
	(0.02)	
$\emptyset \succ \{\ell\} \succ \{h\} \succ \{\ell, h\}$	0.23	Additive
	(0.06)	
$\emptyset \succ \{h\} \sim \{\ell\} \succ \{\ell, h\}$	0.05	Additive
	(0.03)	
$\emptyset \succ \{h\} \succ \{\ell\} \succ \{\ell, h\}$	0.02	Additive
	(0.02)	
$\emptyset \sim \{\ell\} \succ \{h\} \succ \{\ell, h\}$	0.02	Inconsistent
	(0.02)	
Observations	60	

Notes: Robust standard errors are in parentheses.

Table 3: Fraction of Subject Preferences Consistent with Each Utility Representation

Utility Representation	Fraction
Strotz	0.63
	(0.06)
GP	0.68
	(0.06)
Additive	0.40
	(0.06)
Inconsistent	0.02
	(0.02)
Observations	60

Notes: Robust standard errors are in parentheses.

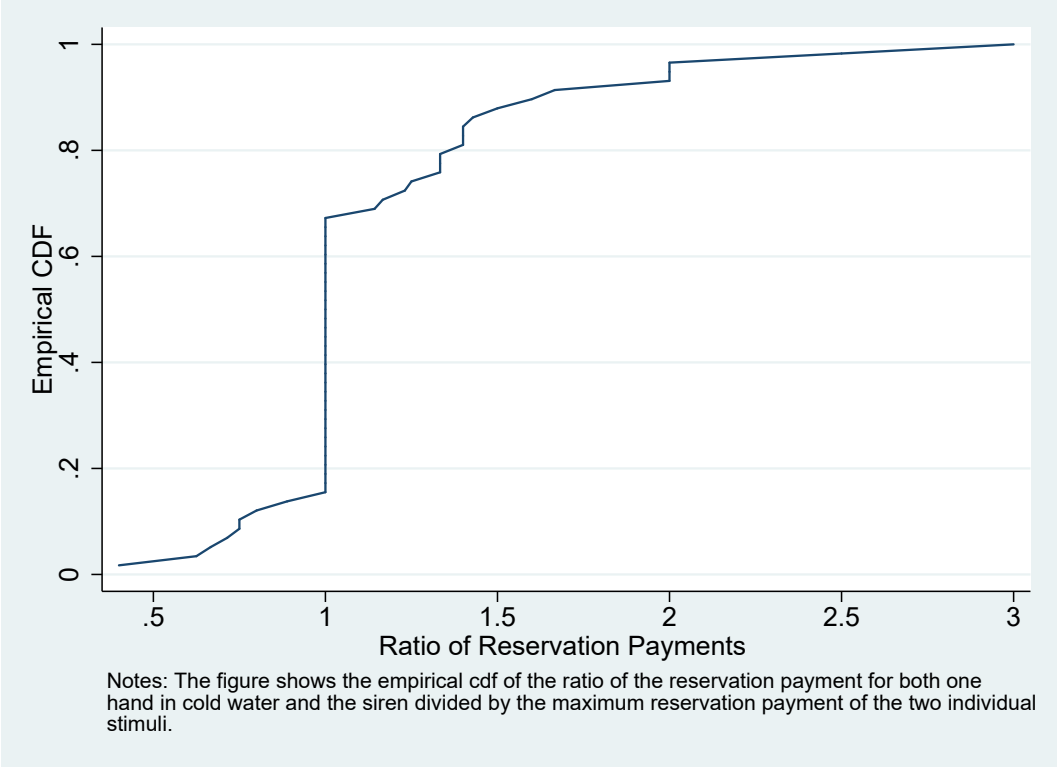

Figure 1: Are Reservation Payments Higher for Two Negative Stimuli than for One?

Appendix

A Email announcement

New time-slots are available for the research study "Economics of decision making" next week. If you are interested in participating, please sign up for an available session of "Economics study on decision making." Please show up on time to your scheduled session in room 340 TNRB (Behavioral Lab).

*The link that will be provided (http://byu-marriott.sona-systems.com/Default.aspx?ReturnUrl=%2f) which will direct the students to the SONA recruitment site where they can sign up for a session. They will see the following details about the project before they sign up.

Study name: Economics experiment on decision making.
Brief abstract: In this study you will participate in a task that will involve listening to a loud (85 dB) sound as well as holding your hands submerged in cold water. You will also complete a short demographic questionnaire. Please read the eligibility requirements carefully before you sign up to participate.
Eligibility requirements and risks: To participate in the study, you need to have good hearing and be willing to have your hands submerged in uncomfortably cold water for up to 5 minutes. If you have poor hearing and/or use a hearing device, you cannot participate in the experiment.

Also, be aware that there are certain medical pre-existing conditions, such as circulatory, rheumatological, and autoimmune disorders, which could cause longer-term symptoms. If you have any of these conditions, you will not be able to participate in this experiment.
Duration: 15 minutes
Pay: $6 on average, depending on your decisions. The exact compensation amounts

range from $2 and $15, depending on your decisions.

If you have any questions, please contact the primary researcher, Olga Stoddard, Ph.D. at olga.stoddard@byu.edu

B Participant Instructions

Welcome and thank you for your participation in this study. Please follow along as we read through the instructions. If you have any questions, please feel free to ask these questions as we move forward.

If you complete the study, you will receive at least $2 for your participation. The exact amount that you will be paid at the end of the study depends on your decisions, as I will explain shortly.

There are four tasks that you will need to perform during this experiment. To begin, we would like you to experience and practice each task for 30 seconds, two times (for a total of eight practice runs). We would like you to:

Treatment 1:	The subject listens to a loud siren-like sound (at 85 decibels) through headphones.
Treatment 2:	The subject submerges one hand in ice-cold water (41° F) up to the wrist.
Treatment 3:	The subject submerges both hands in ice-cold water up to. the wrists.
Treatment 4:	The subject submerges one hand in ice-cold water up to the wrist while listening to a loud siren-like sound through headphones.

Next, you are asked to write down the minimum amount (in 50 cent increments, up to $15) that you would be willing to accept to do one of these tasks for 2 minutes.

You will need to write down the minimum amount for each task, but only one of them will actually be selected for you to do. These four envelopes contain all four tasks. After you complete this sheet, you will select an envelope containing one of the four tasks.

Also, prior to the study, we have randomly chosen 10 different threshold amounts between \$0 and \$15 and have placed each one in an envelope. After you indicate the minimum amount you are willing to accept to do the task, you will be asked to choose one of the envelopes at random reveal the threshold amount. If the minimum amount you are willing to accept for the chosen task is less than the threshold amount, then you will be paid the threshold amount once you complete the task for 2 minutes. If the amount you are willing to accept is more than the threshold amount, then you will not have an opportunity to complete the task, and will be paid a \$2 show up fee to sit in the room for the remaining 2 minutes.

Note that it is in your best interest to state the true minimum amount that you are willing to accept since you can never receive less than that amount, but you can end up with a lot more.

To make sure that you understand the instructions, consider two hypothetical examples:

Example 1: Suppose that the minimum amount that you listed to do the chosen task is \$5. We draw the threshold amount of \$7.

Question: Will you have to do the task? How much will you earn?

Example 2: Suppose that the minimum amount that you listed to do the chosen task is \$5. We draw the threshold amount of \$3.

Question: Will you have to do the task? How much will you earn?

C In-Experiment Questionnaire

Participant ID #:

What is the minimum amount (in 50 cent increments, up to $15) that we would have to pay you to do one of these tasks for 2 minutes?

Task	Amount ($0 - $15)
Listen to the loud siren sound through the headphones	
Hold one hand submerged in ice cold water	
Hold two hands submerged in ice cold water	
Hold one hand submerged in ice cold water while also listening to loud siren through the headphones	

D Post-Experimental Exit Questionnaire

Participant ID #:

1. What is your age? ___
2. What is your gender? ___ M(=1) F(=2)
3. What is your ethnicity? ___

   (0=Caucasian, 1=Asian, 2=Hispanic, 3=African American, 4=Other)
4. What is your major at BYU? ___

   (1=Business, 2=Economics, 3=English, 4=Science, 5= Sociology,

   6=Mathematics, 7=Other)
5. What is your GPA? ___ (0=2.0, 100=4.0)
6. What is your marital status? ___ (1=single, 2=married)
7. How easy were these instructions? ___ (0=easy, 100=Hard)
8. Did you like the experiment? ___ Yes(=1) No(=2)
9. Do you have any comments regarding this experiment?

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