**Learning from punishments**

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# Abstract

**Background:** Punishment helps us learn the dangers and values of objects in the environment. The way we perceive punishments and reward and how it affects learning is dynamic and changes over time. Hence, it was important to probe the learning process in a longitudinal experiment maintained over days. Our aim was to monitor punishment affects the performance, recall, and habituation of subjects over time.

For that purpose we used a mobile-phone platform to deliver tasks to subjects outside the laboratory. that can be and heartrate during a trial-and-error learning task performed regularly, day and night, for 12 consecutive days.

**Methods:** Subjects performed regularly, morning and evening, a trial-and-error choice task and their behavioral and physiological responses were collected for 12 days. They were assigned randomly to one of the two types of punishment (white-noise or monetary-loss) and played the tasks in a novel mobile-app platform that was installed on their devise and therefore was conducted in their own familiar environment outside the lab.

**Results:** Subjects in both groups maintained high performance throughout the experiment. Additionally, subjects maintained a good recall of stimuli value for a long time after they learned them. The heartrate data showed a difference between groups in the response to punished and not punished trials.

**Conclusions:**Subjects learned and remembered well …

**Keywords:** Operant instrumental learning, Loud white Noise, Monetary loss.

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# Introduction

Through operant instrumental learning the agent learns associations between behavior and its consequences (Franzoi, S. L. 2015). As a result, we can obtain more beneficial behaviors in the future. To learn these connections we use reinforcement learning. We act (or observe actions) in different states, observe the consequences (reward, punishment or neutral) obtained by those actions and correct our behavior accordingly.

Appetitive or aversive outcomes are used to encourage or inhibit, respectively, a state-action behavior. They are essential components in operant instrumental learning. The interaction between the agent's actions (approach or withdrawal) or inaction (inhibition, ignorance) in a specific state and the outcome obtained molds the value of that state-action over time.

In a way, punishment and reward are "two sides of the same coin" in the process of operant learning. **Nevertheless it is well known that they differ in some important characteristics** (*Jean-Richard-Dit-Bressel et al 2018*). The activation and nonactivation of dopaminergic neurons in the ventral striatum in the brain are classically attributed to reward mechanisms of positive reward prediction error and negative reward prediction error, respectively (*Schultz 2007*), whereas in aversive learning mechanisms the amygdala is more widely implicated (*Eldar et al. 2016a; Toshikazu et al. 2018; Jean-Richard-Dit-Bressel et al 2018*; *Costafreda et al 2008*). For example, Michely et al show that subregions in the basolateral amygdala encodes a punishment prediction error (Michely et al 2020). Furthermore, with respect to neurotransmitters, Dopamine is associated with reward prediction errors whereas Serotonin is implicated in punishment prediction errors (Cools et al 2008).   
Moreover, there is evidence that punishment has a different influence on learning and behavior than reward. Steel et al found that punishment had greater effect on learning in both sequencing skill task (SRTT) and motor skill task (FTT), although the effect on the SRTT task was positive whereas the effect on the FTT task was negative (Steel et al 2016). Galea et al. found that punishment produced faster learning for motor adaptation whereas reward caused greater retention (Galea et al 2015)**.** Moreover, according to the prospect theory (*Kahneman & Tversky 1979)* people are more inclined to choose the no-punishment option than the matching reward option, phenomenanamed as loss aversion bias. In animal research of punishment, Marchant et al found individual differences in the susceptibility to constant shock intensity in alcohol preferring Pack rats. The data showed a bimodal distribution in the response to punishment (*Marchant et al 2018*). Nevertheless, other studies did not find a significant difference in classical conditioning through reward and punishment (**Delgado et al**).

In the clinical psychiatric perspective, disfunctions in reward or punishment perception, result in different kinds of clinical disorders. For example, a dysfunctional reward system (e.g. unstable learning rate) has been linked to depression and bipolar disorder (*Eldar 2016*). In contrast, a dysfunctional punishment system, was linked to anxiety (more precisely, cognitive anxiety; see *Wise & Dolan 2020*). For example, Aylward et al found that anxious participants learned faster from negative outcomes, i.e.- had higher learning rate (*Duits et al 2015; Aylward et al 2019*; although see *Wise & Dolan 2020*). On the other hand, a lower sensitivity to punishment is implicated in addiction and psychopathy (*Jean-Richard-Dit-Bressel et al 2018*).

research in operant conditioning predominantly focused on the processes of appetitive reinforcement. Reward incentivization and its traits, mechanisms and implications are widely probed, and great progress has already been made. This is not the case for punishment. Although punishment has an important role in learning processes and its extensive potential implications for psychiatric disorders (*Jean-Richard-Dit-Bressel et al. 2018; Wise & Dolan 2020*), we are still in ignorance with respect to some of its traits, neuronal and computational mechanisms, and its precise influence on human behavior (*Jean-Richard-Dit-Bressel et al. 2018; Wise & Dolan 2020*). Thus, the investigation of punishment is crucial and has a promising, fruitful prospect.

Based on Azrin and Holtz we can define punishment as the delivery of a stimulus that is contingent\* to some behavior and causes a reduction in the likelihood of that behavior occurring again (*Azrin and Holtz 1966*). This famous *Azrin and Holtz* definition emphasizes two important points, the punisher is not necessarily an aversive stimulus and that an aversive stimulus is not always punishment. The main feature a punisher must have is the reduction in the probability of a behavior to occur. If, for example, aversive US is paired with another CS but there is no reduction in the occurrences of the CS, the aversive US is not a punisher. We must see a learning process (e.g. the rat is not eating the cheese anymore to avoid a repugnant taste). The other feature is the contingency of the punisher with a behavior. In other words, the punisher's temporal association with the stimulus drives a reduction in the stimulus attraction and hence reducing its probability to happen in the future.

Two theories offered to describe the **effect** of punishment on choices: The additive theory and the subtractive theory. The **additive** theory claims that punishment reinforce another stimulus that avoids the punishment, therefor reducing the occurrences of the punished stimulus, whereas the **subtractive** theory claims that punishment suppresses the appetitive attraction of a stimulus and thus causing a reduction in the probability of choosing that punished stimulus (Toshikazu et al, 2018). Furthermore, in the subtractive school there is a long dispute about the symmetrical nature of reward and punishment (*Rasmussen and Newland 2008*). *Rasmussen and Newland* concluded that punishment has a greater effect on choices than reward and therefor they are not symmetrical: a penny you lose perceived greater than a penny you earn. Interestingly, Palminteri et al show, that over time, in a punishing context, punishment shifts to a reward system of reinforcement. The agent starts associating the non-punishing response with reward and the punishing response with no-reward (Palminteri et al 2015).

## The psychological literature presents a few types of punishers. One distinction is between positive and negative punishment (*Franzoi, S. L. 2015*). A positive punisher is the appearance of an undesirable or aversive stimulus contingently after an operant response. Some examples in research of positive punishers will be the delivery of an air puff, electric shock, and loud noise. Conversely, a negative punisher is the removal of an appetitive stimulus (a reward). Examples in research for negative punishers will be the removal of food and monetary loss (*Jean-Richard-Dit-Bressel et al 2018*). [In this context, an interesting question is whether the loss of an existing reward (a negative punisher) is equal to the loss of a potential future reward (Negative RPE)].

## Another distinction in the punishment literature is of primary and secondary aversive stimulus (*Franzoi, S. L. 2015*). The primary punisher is one that the agent instantaneously perceives as aversive and unpleasant without the need for learning or conditioning. Examples of this type are the delivery of an air puff, electric shock, and loud noise that create an immediate repulsion when encountered. Conversely, a secondary punisher is one that needs to be conditioned and learned. For example, a parking ticket, monetary loss, and social punishments like an angry or disapproving face.

*Delgado et al* conducted experiments to probe the effects of monetary loss as a secondary reinforcer and to examine the differences between a primary and secondary punisher in a fear conditioning paradigm. They found that the striatum has an important role in monetary loss punisher (secondary) as in mild shock punisher (primary). Interestingly, the amygdala was activated only in the mild shock condition. They concluded that learning from monetary losses may depend on reinforcement learning mechanisms whereas primary punishers rely more on biological mechanisms. Importantly, they did not find a significant difference between primary and secondary punishment in the acquisition of conditioned responses (*Delgado et al 2011*; *Delgado et al* 2006). In a different study, *Delgado et al* show punishment prediction error signals in the striatum both in primary and secondary punishers. (*Delgado et al* 2008).  
In a different study, *Delgado et al* observed similaritiesbetween negative reward prediction error signal and monetary loss signal(*Delgado et al 2000*).

Like Electric Shock, Loud White Noise is a common unconditioned stimulus (US) used in punishment conditioning research (Sperl et al 2016). For experiments with many conditioning trials, Sperl et al asked which of the two US will cause a long and strong Conditioned Stimulus, that will satisfy an EEG and MRI test, and will be strong enough to avoid extinction. They designed a comparison study between them and concluded that Loud White Noise had greater valence of unpleasantness, less extinction of Conditioned Response (CR), and a better recall of the CR after 24h (Sperl 2016).

As mentioned above, punishment is considered a complementary side to appetitive reinforcement (*Jean-Richard-Dit-Bressel et al 2018*). ***Conceptually***, they differ in the direction of the probability of choices. While Reward ***increases*** the likelihood of a behavior to occur, punishment ***decrease*s** it (*Johnston, J. M. 1972*). This may explain the fact that research of punishment in humans mainly focused on the ways in which punishment suppress appetitive behavior in a monetary context (*Wise & Dolan 2020*). Money reinforcer is a context that punishment can easily and plainly be manipulated and quantitively measured and compared in the same dimension as monetary gain (*Rasmussen and Newland 2008*). On each stimulus the potential outcomes are gain or loss (and sometimes also a neutral outcome – no loss/gain). In many studies, punishment was not a single reinforcer but working simultaneously with reward (Steel et al 2016). Another reason for this common paradigm is that experiments want to simulate the frequent environment of learning, an environment that includes punishment/reward, withdrawal/approach, and repulsion/attraction. In this kind of design each stimulus has the prospect of delivering reward, punishment and sometimes a neutral feedback. Each stimulus also has different probabilities for each feedback (e.g. Palminteri et al 2015; O'Doherty et al 2001). Another within group paradigm is to designate one session to each reinforcer (Delgado et al). In a between group paradigm researchers designated a group for reward, punishment and added a control group (e.g. Galea et al 2015).

In this study we test responses exclusively in an aversive environment. The only possible outcomes are punishment and the absence of punishment. Hence, there is only punishment prediction error. Importantly, the subject's choice is to avoid the stimulus that has the worse potential outcome by withdrawing their finger from it and as a result, the other (supposedly better) stimulus, is chosen. This design is implementing a scenario in which the agent can only lose, there is nothing to gain by avoiding the bad stimulus except avoiding punishments. It simulates a situation of running away from a threat and choosing the least dangerous choice, therefor all the attention is going to the punisher. As a result of this excluding environment, we wanted to capture the clear effect of punishment and its unique features and see more clearly how punishment affect learning and decision-making. Furthermore, we can test the effects of different kinds of punishments and compare between them (*Delgado et al 2011*). Notably, Delgado et al 2011 design is different from the one we use in our experiment in two ways. (1) their design is of a fear conditioning task when the subjects simply observe the CS and the US attached to it. (2) their experiment is a within-subject design, meaning each subject had two sessions – one of each punisher.

**Importantly, this experiment has a novel methodology** to collect behavioral, physiological, and psychological data to probe learning mechanisms over long period of time. It is a longitudinal experiment conducted for 12 days. The experiment is running through a novel mobile platform design and conducted outside of laboratory setting. This is a new realistic approach for human studies that allow us to get highly dense and realistic data collection. There are challenges for this methodology, including the lack of experimental control, tracking subject's performance and technical variables that may interfere with the progress of the experiment. We used various measures to overcome these challenges.

The aim of this study is to validate that our design is working, and subjects do learn the values of the stimuli throughout the 12 days of the experiment, through punishments. Our target is to track the learning process through the performance in training and testing and eliminate the claim of habituation in both punishment types. These results will also give us a first glimpse about the differences between a positive-primary punisher and a negative-secondary punisher. Finally, we compare aversive instrumental learning results with the data of a parallel experiment on reward instrumental learning conducted in the lab. In addition to the behavioral data, we monitored the heartrate of subjects while doing the tasks. With this, we hope to see physiological differences between punished and non-punished trials and look for differences between groups. This experiment will hopefully give us good preliminary results that would help in developing similar studies in the future.

## 

# Materials and Methods

## Participants:

19 healthy volunteers (mean-age: 25.47±3.53; range 20 – 33 years old; 12 female subjects) were recruited through social media advertisements and participated in a 12-day experiment conducted through a trial-and-error game installed on their phones. Subjects who did not have phones that are compatible with the experiment application were delivered a phone owned by the lab. All subjects underwent a screening process to exclude any motoric, auditory or vision disability. The screening process also excluded any past psychiatric disorder or the use of psychiatric medications and drugs. The experiment was approved by the Helsinki committee and subjects signed a consent form accordingly. All subjects were paid by the hour (40 shekels) plus the amount left in the experiment bank or a finishing bonus (for elaboration on the paying method see the appendix section).

**Exclusion:** Seven participants were excluded from the study. Three participants excluded due to technical problems, another three because of insufficient compliance to the schedule of tasks, and one that had repeated bad performance from the beginning of the experiment.

After exclusion, 12 volunteers (mean-age: 25.58±2.96; range 20 – 31 years old; 8 female subjects) completed the experiment.

## Materials/Stimuli

**The mobile platform:** for the longitudinal learning game we used an Android app that was developed for experiment purposes by the lab P.I. Dr Eran Eldar. It was programed using the Android Studio programing environment (Google, Mountain View, CA). The game in the app was made for reward and we adjusted it for a punishing environment. All data collected by the app was stored locally on the phone as SQLite databases and regularly uploaded to a cloud storage space, designated for it.

For generating the white noise and cutting sound duration (0.5 seconds) we used the sound editor software *Audacity* (<http://audacityteam.org/>) version 2.4.2.

For the "Wheel of fortune" task, we used and edited the example code from <https://github.com/zarocknz/javascript-winwheel> (Copyright (c) 2016 Douglas McKechie).

The Learning game contained 64 images (round fractals with styled backgrounds). Each stimulus had a fixed probability of delivering punishment (0, .33, .66, 1).

The games in the preliminary lab meeting consisted of 13 games and overall 388 trials. The games outside the lab consisted of 44 games (within 11 days) of overall 3088 trials. Altogether, each subject had 3476 trials. 2211 of them were training trials (with feedback) and 1265 were testing trials (without feedback).

On each trial, two images were presented to the subject, and the subject had to remove her finger from the image she thought will most probably deliver punishment.

Punishments were either the loss of a coin (worth approximately 0.2 shekels) for the monetary-loss group or, the delivery of a loud white noise (92-95 dB, duration: 0.5 seconds) for the noise group.

## Procedure

Subjects were assigned randomly into two groups of two types of punishments. Each participant went through a screening interview to suffice the experiment criteria and if successful the subject was invited to the preliminary lab meeting.

**Preliminary lab meeting:** First, subjects signed a consent form. Then the experimenter explained them the schedule of the task throughout the days of the experiment.

For the **monetary-loss group**, we conducted a preliminary task beforehand to create an experimental bank from which the subject can lose money. This task is somewhat similar to other monetary loss studies (such as *Delgado et al 2011*; Steel et al 2016; Steel et al 2020) although our task was unique. The task included spinning a Wheel of fortune (in a computer program) with different amounts of gains (400-1000 shekels). Unknown to the participants, the win was fixed on 600 shekels (eq to ~182 dollars) in order to equalize the amount of money for all subjects. This was their bank of money from which they can lose and therefore should do their best to avoid punishments. The aim of this task was to magnify the effect of money loss on subjects by creating a sense of endowment to make the subject value more the initial sum of money. We also wanted to create a sense of agency, to increase the engagement and interest of subjects (Taub et al. 2020). The reason for doing that is our fear that since the amount being reduced on each loss of a coin is meager (0.2 shekels, ~ 0.06 dollars) we might lose the loss aversion effect and the motivation to avoid punishments might be sparse too. Although we have many trials along the experiment, and therefor the potential amount of loss is great, still, participant might not look on the "big picture" and therefor disregard the loss on a single trial. The sense of endowment and agency over the money increases the aversiveness of the monetary loss, therefore magnifying the effect on the subject (*Delgado et al 2011*; *Tricomi et al., 2004; Zink et al., 2004;* *De Martino et al., 2009*).

**The loud white noise group** was supplied with earphones from the lab (Miracase MBTO106). To make sure that subjects are wearing the earphones throughout the games and listening to the delivery of punishments, we added "attention colors task" that appeared between trials. Randomly, every few trials appeared a screen with six rectangles of different colors. Then, one of the color names randomly asserted, sometimes to the left ear and sometimes to the right ear, and the subject needed to press the matching colored-rectangle. Also, in games where no-feedback trials administered, when a set of punishments was delivered, the task appeared randomly between noises.

After that, for both groups, the experimenter downloaded and installed the application of the experiment on the subject's phone (or, if it was not compatible, the phone was delivered by the lab – "Redmi Note 9 Pro").

**Volume Calibration:**

For the delivery of aversive audio stimuli in a web-based experiments, Seow & Hauser (2021) showed that they are reliable for inducing affective states similar to in-lab studies, with the right technical measures.

For the White Noise group, a sound calibration was made beforehand to set the system's volume to the range predetermined by the experimenter (92-95 dB). To check the sound volume we used a sound meter monitor "UT353 Mini Sound Level Meter". As in Sperl et al study, the range was between 92-95 dB for every subject in the noise group (mean dB=92.68±0.69; range 92 – 93.6 dB). The variability in the dB volume is due to the different phone systems and from the amount of intensity of the noise perceived by each subject. If the noise was unbearably intense for the subject, we lower the volume but maintained a minimum of 92 dBs. In addition to the white noise volume calibration, we also needed to calibrate the volume of the "attention colors task". We wanted to keep volume to the minimum necessary for the subject to hear the names of the colors asserted but not higher so that they could not hear it without earphones. For each subject, while wearing the earphones, we played the names of colors in the lowest volume and increased it until the subject said she hear them clearly, but not more than that.

After that, we instructed the subject how to put the wearable heartrate sensor on her body, a "Polar H10 " device monitor that measures heartbeat rates.

A person and person in swimsuits on a beach

Description automatically generated with low confidence

Subjects had to wear the sensor whenever they played the experiment game, and it included a rest state measure of five minutes before starting the games.

Next, we explained the tasks to the subjects in details, including the structure of the game.

**APP SCHEDULE:**

The schedule of the app starts in the morning and when the subject wakes up, she needs to press a "woke up" button in the app and report the quality of her sleep and the content of her dreams if she can recall. Also the subject needed to play two games of the task in the morning and two games in the evening and to fill three mood questionnaires throughout the day. Before going to sleep, a video recording task was delivered in which the subject needed to talk about her day within 20 seconds and following that, pressing a "went to sleep" button when she is ready to go to sleep. This routine was kept for 10 Consecutive days, following by a rest day and finally another experiment day meant as a summery test for all stimuli.

**THE GAME:**

The game itself is a trial-and-error learning game in which subjects need to choose between 2 stimuli in every trial. Each stimulus has its own probability to deliver punishment. Unknown to the subjects, the probabilities were set to be in a hierarchical structure with the probabilities of [0, .33, .66, 1] where 0 represents no chance of getting punished and 1 means that punishment will be delivered 100% of the time.

Notably, subjects started each trial by pressing on both the right-side stimulus and left-side stimulus and the way of choosing is by lifting the finger pressing the unwanted stimulus. as a result, the counter stimulus is chosen.

After they choose, subjects can see the outcome of their choice and learn the value of that stimulus. A punishment outcome was seen as a red arrow pointing down inside a circle with black background (and in the noise group was paired with a loud white noise) and no punishment outcome was seen as a blank black circle. It was emphasized to subjects, that the game is probabilistic and therefore a bad stimulus can sometimes not deliver punishment (although it is still the worst choice) and a not bad stimulus can sometimes deliver punishment (although it is still the best choice).

A picture containing shape

Description automatically generated

After enough times that a set of stimuli was repeated, a curtain covered the outcomes to conceal them from the subject. This means that the training phase is over for these set of stimuli, and the **testing** phase starts. This way we can see how much is learned throughout the trials of those stimuli and test for their recall. Nevertheless, the outcomes of choices were stored, and punishments are presented as a message to the subject after every 10 trials saying that she lost X number of coins in the last 10 trials, in the money loss group, and in the white noise group saying that she was punished X times in last 10 trials. In addition to the message, in the white noise group, a loud white noise was delivered the number of times that the hidden outcomes conveyed punishments. This way we kept the incentives for high performance without revealing the outcomes and therefore ending the learning phase.

## Analysis

# We analyzed the behavioral data using R studio, and for the physiological data (HR) we used MATLAB for processing.

# Results

**Table 1: Accuracy & Rt**

| **Group** | **Accuracy** | **RT (milliseconds)** |
| --- | --- | --- |
| *White noise* | 82.6% ± 9% | 1628.6 ± 63 |
| *Money loss* | 81.7% ± 4% | 1867 ± 202 |
| *Reward* | 83.1% ± 6% | 1707.7 ± 130 |

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A picture containing text, sky, screenshot

Description automatically generated

# Discussion

**This study is using a novel design** in which 12 subjects played a trial-and-error learning game on a mobile platform for 12 days outside of the laboratory at their natural environment.

**The results show** that subjects of both groups learned stimuli values throughout the 12 days of the experiment…

habituation…

motivation…

**Moreover,** from the heartrate data that we collected when subjects played the games, we can see….

**This study has a small sample size** and therefore will not enable us to make conclusions about the differences between groups. However…

**The between-subjects design** is different from some other human studies probing punishments. This design gives a cleaner effect to the US punisher, as we avoid the confounds that a within design might obtain (Charness et al 2012). Importantly, we used a different primary punisher (Loud White Noise) than *Delgado et al 2011* (Mild shock) that showed more efficacy in the Sperl et al study (2016).

Our target was to make the task **similar to the environment of punishment** and therefore the method of choosing was by avoidance. To do that we made participants withdraw from the stimulus they did not wanted and only by that the paired stimulus was chosen. This method choosing by withdraw was also used in Huys et al (2011).

**Limitations and confounds** of the study.

**Similar future studies should** explore more conclusively the differences between a primary-positive and a secondary-negative punishers and compare them to the mechanisms of reward reinforcers.

**Conclusions:**

# Acknowledgments:

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# Footnotes

\**Azrin and Holtz* uses the phrase ***immediate***. we used the word ***contingent*** because, though weaker, a punisher may also be delayed and still reduce the likelihood of the preceding behavior. Additionally if we explain the delay to the subject there is an increase in probability reduction (*Trenholme & Baron, 1975*)