An experimental approach to train mood for resilience

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Abstract

According to influential theories about mood, exposure to an environment could shape mood response to future stimuli, raising the intriguing possibility that mood could be trained by exposure to controlled environments. The aim of the present study is to investigate experimental settings under which mood could be trained to become resilient to negative stimuli. To achieve this, we developed a new task where participants register their mood when rewards are added or subtracted from their score. Several experimental environments that are characterized by different mood and reward relationships were examined. In an exploratory set of experiments, we identified environments that have a greater effect on mood training. In a next step, we replicated our results and tested our training effect over time in a novel sample. We found that training effects are detectable and remain significant after multiple task rounds. These findings are a first step in our effort to better understand the mechanisms behind mood training and its potential clinical utility.

Keywords

mood; depression; mood training; computational psychiatry

Introduction

Mood is a defining component of subjective well-being (Yardley & Rice, 1991) with the presence of positive emotions and moods and the absence of negative emotions, as some of its core components (Centers for Disease Control and Prevention, 2021). Moreover, mood disorders such as depression are common (Kessler et al., 2005), debilitating and potentially lethal (Angst et al., 2002). Therefore, unsurprisingly, a great amount of scientific effort is invested in trying to regulate and change mood, including psychological and pharmacological therapies. In this paper, we utilise evolutionary theories about mood and create an experimental set-up to investigate whether mood could be trained in a way that promotes resilience to negative stimuli.

Mood is often considered a biological system that interacts with the environment for adaptive purposes. Under this perspective, mood is viewed as relatively enduring affective states which arise when positive or negative experiences in one context or time period alter the individuals' threshold for responding to potential negative and positive stimuli (Nettle&Bateson, 2012). The former suggests that the interaction between environmental events and mood can alter the way mood will respond to future events. This opens up the possibility that by exposing individuals to specific environments we may be able to train their mood in such a way as to make it resilient to future environmental events.

In order to explore whether mood could be trained to become resilient to negative stimuli, we utilised a well-established research framework of experiments which employ virtual environments and stimuli as a means to provoke mood changes (Keren et al. 2021; Rutledge et al, 2017; Eldar et al., 2015). The majority of these experiments study mood dynamics by utilising gambling tasks and study the effect of gains and loses on mood. These experiments have shown that momentary mood is affected by reward prediction errors which signify the difference between the expected and actual outcome of reward trials (Rutledge et al., 2014). When examining the influence of recent and past experiences on mood, Keren et al have shown that mood is modelled as a weighted average of environmental events with most recent experiences having a greater impact on momentary mood. Momentary mood has also been shown to be sensitive to the passage of time, as mood ratings during rest periods or even during a gambling task have been show spontaneous, distinct downward drifts in mood. This passage of time dysphoria appears to be distinct from boredom or mind-wondering (Jangraw et al., 2021).

For our experiments, we developed a new computerised task where participants are asked to rate their mood after points are added or subtracted from their score. From the experimenter's perspective, points are used as positive and negative stimuli with the purpose to train mood. Different relationships between mood ratings and immediate rewards define different experimental environments. We conducted a total of three sets of experiments in order to validate our task and identify possible environments that would be efficient in training mood for promoting mood resilience to negative task stimuli.

The first set of experiments comprised of three steps to ensure that the task is efficient in influencing mood and that the participants were following instructions by registering their real mood values and were not exploiting the task for profit. In accordance to previous computational approaches that were recording mood in response to virtual stimuli (Keren et al. 2021; Rutledge et al, 2017; Eldar et al., 2015), we hypothesised that the majority of participants would follow task instructions and register their true momentary mood.

The second set of experiments was exploratory and focused on the identification of task environments that would promote mood resilience to negative stimuli. For this purpose, sixteen different environments were introduced for mood training, each one characterised by a distinct relationship between registered mood and the subsequent stimuli. Mood's resilience to negative stimuli was tested before and after each training environment. We hypothesised that environments where negative mood is punished or positive mood is rewarded, would have a positive impact on mood's resilience.

Finally, in the third set of experiments, we aimed to examine whether the training effect, if achieved in the previous set of experiments, would replicate and endure over time. To achieve this, we added varying numbers of random stimuli following training and tested mood's resilience afterwards in a novel sample. We hypothesised that mood resilience would still be detectable over time.

Methods

General task design for all experiments

For this study, a task was developed with JavaScript using the PixiJS library. The task was executed using an internet browser and task responses were made using either the mouse or the keyboard. In an effort to engage participants, the task was animated and in colour. In this task, points were represented as coins, which were added to the participant's piggy bank when a reward was delivered. A magnet subtracted coins from the piggy bank every time a punishment was administered.

At each task round, participants were asked to register their mood when points were added or removed from their piggy bank. The task consisted of different experimental environments. Each environment was characterized by a specific relationship (for example proportional) between each mood rating registered by the participants and the proceeding reward. Alternatively, environments consisted of specific sequences of rewards including a pseudorandom or a monotonic sequence. Different environments could be administered depending on the purpose of the experiment and all environments started by asking participants to register their mood. The task rounds then followed, where participants were asked to rate their mood when rewards were subtracted or added to their total score. Each experimental environment was independent and the participants' score was zeroed before the start of each environment.

In order to register their mood, participants answered the question "How happy are you at the moment?". Mood was registered using a mood-o-meter which was similar to that used in previous experiments where momentary mood was studied (Keren et al., 2021, Rutledge et al., 2016). The mood-o-meter consisted of a vertical bar that did not have any mood values but contained signs and colours that helped participants better assess their mood. Smiling and sad faces were presented at each quarter of the meter to indicate the side where positive and negative mood should be registered, respectively. A color gradient from green to red was used to indicate the mood range, with red used at the edges of the meter to signal extreme negative and positive mood values. Participants could submit their mood by marking the height on the mood-o-meter that they believed better represented their momentary mood and the previously submitted mood was marked on the meter with the word "last". This was done to help participants on their judgement of momentary mood in relation to their previously registered mood (for screenshots of the task, including the mood-o-meter see Supplementary Material).

Participants

Participants for these studies were recruited online from the Amazon Mechanical Turk (MTurk) platform and the task was completed online. The MTurk Worker ID was used to distribute a fixed compensation for each participant who completed the task. Participants were clearly instructed that the amount of points they would win during the task would not be related to their final compensation which was fixed. This was done to prohibit participants from exploiting the task in order to gain bigger compensation. With a fixed amount given to all participants, there was no motivation for using the task in order to gather more points which would interfere with the design of our task and the data quality. The study population was adults of 18 years of age and older. Participants were not screened for eligibility, but only workers with an approval rate of 97% or greater and a number of approved hits greater than 1000 were allowed to participate in order to ensure data quality. Participants were excluded from performing the same experiment more than once and since multiple studies were conducted using the same task, participants were also excluded from future studies. Ethical approval for these studies was obtained from the NIH Office of Human Subjects Research Protection.

First set of experiments: Validation of the task

Study Design of first set of experiments

The purpose of this set of experiments was to validate the task before using it as a tool to examine whether mood could become more resilient to negative stimuli. As the task is newly developed and had not been used before in another study, we wanted to test its efficiency in influencing mood. For this purpose, in a first step, we created an environment with a pseudorandom sequence of rewards. In this environment, we placed three consecutive rounds (6th-8th) with large reward differences between the stimuli that would allow us to more clearly observe mood's responsiveness to rewards and identify any unexpected patterns of responses. These rounds were among the final ones to make sure that participants were already familiar with the task.

In an effort to further validate that task and ensure that participants will not exploit it in order to gain maximum points, in a second step, we conducted an experiment with a paradoxical environment. In this environment good mood is proportionally punished and bad mood proportionally rewarded. As a result, good mood would yield a punishment which would promote lower mood ratings, and negative mood would yield a reward and promote higher mood values. We expect that this would lead to an oscillatory mood course. However, if participants were exploiting the task for profit, they would be continuously submitting low mood ratings as these are maximally rewarded. For analysis purposes, we arbitrarily define as task exploiter anyone who registers minimum mood ratings for at least three consecutive rounds.

Finally, in order to examine whether participants are able to exploit the task, a modified version of the previous experiment with the same environment was administered. In this third step, we removed from our task instructions any reference around mood. The mood-o-meter was replaced with a simple meter and participants were advised to play the task as they see fit. We expected that in this task version, participants would submit extreme negative meter values as these are rewarded with maximum points.

Analysis of first set of experiments

For all the experiments we plotted and observed the mood courses for each participant.

For the first step, we calculated the percentage of participants for whom mood was responsive to task stimuli. For this, we examined mood ratings for the three specific, consecutive rounds with large differences between the administered stimuli, as mentioned in our study design. A responsive mood has a course that follows stimuli fluctuations.

For the second step, we identified task exploiters and measured mood oscillations. As stated in our study design, we define as task exploiter anyone who registers minimum mood ratings for more than three consecutive rounds. Oscillations are defined as changes in mood direction, and as our experiment consists of 40 rounds of the paradoxical environment, a maximum of 38 oscillations per participant is expected. We excluded task exploiters and calculated the number of oscillations for each participant and the mean and median oscillations for the group.

For the third step, where we expected participants to pursue maximum profit (see study design), the mean and median values that were registered from all participants were extracted to assess participants’ ability to gain maximum rewards by submitting minimum meter values.

All the data and code used for these analyses are included in the supplementary material.

Results

The demographics for this set of experiments are presented in Table 1. For the first experiment, for the majority (80%) of our sample, the mood course was consistent between participants and followed the stimuli fluctuations (Figure 1). In the second experiment, 10% of the participants were identified as task exploiters as per our criteria. For the remaining, the expected oscillatory pattern of mood ratings was observed (Figure 1) and the mean and median number of oscillations were 24.6 and 26.5 (SD=9.95, IQR=13.25), respectively. These findings are in line with our initial hypothesis and taken together with the previous finding, they indicate that the task is efficient in influencing mood. Participants avoid random ratings and in the majority of the task rounds they register their momentary mood and do not exploit the task for maximum gain. In the third experiment, where participants were not specifically instructed to register their momentary mood, the majority (93%) submitted extreme, low meter values (mean=-0.8, median=-0.98) that yield maximum points for this task (Figure 1). This finding further highlights the fact that participants comprehend the task and follow task instructions, although they can adjust their behaviour to win the maximum rewards.

Second set of experiments: Mood training and identification of efficient experimental environments for training

These experiments were conducted to test whether experimental environments could train mood and promote mood resilience

Study Design of second set of experiments

Our task design included an environment of a pseudorandom sequence (10 rounds) followed by the test sequence and 40 rounds of the training environment followed by the retest sequence (Figure 2). The test and retest sequences are identical and consist of three consecutive punishments of very big value (-40,-45,-50). We consider the value of these punishments big compared to the stimuli (-50 to +50) that participants experience throughout the task.

For this experimental design, two possible scenarios need to be accounted for and controlled: A) Before completion of the test or retest sequence, mood values are already so low that for the proceeding big, negative stimuli, mood’s expected fall would be restricted by the mood-o-meter range. This would lead to floor effects. To avoid this scenario, if the registered mood values fall below the lower quarter of the mood-o-meter, after the first or second stimulus of the test or retest sequence, the sequence is stopped. B) Before delivering the test or retest sequence mood is already in the negative half of the mood-o-meter. This would reduce the available range for mood to fall. To avoid this, if prior to the administration of the test or retest sequence mood is negative, a maximum of two rewards proportionate to its value are administered. The purpose of this is to push mood to the positive half of the meter.

The design of the control experiment is identical to that described above, but for the training environment randomly generated rewards are used.

Training environments of second set of experiments

For a better understanding of the relationship between mood and reward that characterise each environment we employed to train mood and then test its resilience, we represent mood and reward on a two-dimensional space. In this space mood is placed on the x axis and reward is placed on the y axis (Figure 4). Two quarters of this space belong to positive and two quarters to negative mood. For each quarter of this space we distinguish four possible training environments characterized by different mood and reward linear relationships. These relationships include A.a proportional one where mood and rewards have an analogous relationship B.an antiproportional one where mood and rewards have a reversed analogous relationship C.a monotonic one where a medium reward is always administered and D.a monotonic one where a maximum reward is always administered. A total of 16 training environments were examined.

Each training environment consists of 40 rounds. For the purpose of the training, for each environment, we have to ensure that mood ratings will always be kept to the desired side of the mood-o-meter. To achieve this, random rewards are administered that would guide mood towards the right direction. This is more common when the task stimuli push mood to the opposite direction of the mood valence we wish to train. An indicative example for this, is the study of the effects of positive rewards on bad mood (Figure 4). In this environment, rewarding bad mood would lead to mood bouncing towards the positive side, which is not the one we wish to train, thus, when necessary, we administer random punishments to push mood back to negative values.

Filters for participant selection for the second set of experiments

Two filters were applied to ensure that participants were performing the task according to our instructions and were registering their true momentary mood as well as to ensure data quality which is often compromised when data are collected online (for example see: Moss et al., 2021,Dennis et al., 2020, Rouse et al., 2020, Keith et al., 2017): A) Participants were allowed to proceed with the experiment only if during the starting pseudorandom sequence they were responsive to mood fluctuations at three specific, consecutive rounds; B) Participants were not allowed to proceed with the task if during the test sequence the last registered mood was higher than the mood before the beginning of test sequence. The same rule applied to the retest sequence. Participants that did not pass these filters, had a greater possibility of either not playing the task right or their mood being unresponsive to change or responding paradoxically and thus deviated from common forms that we cannot at this point test with our experiment. Based on these filters, the rejection rates were approximately 30%-40%. We acknowledge that this may indicate that our filters are very strict, but due to the exploratory nature of our experiments, we did not want to risk the quality of our data.

Analysis of second set of experiments

In order to determine whether our experimental environments had a training effect on mood so as to make it more resilient to negative stimuli, for each participant and for each of the 16 training environments we computed mood's decline (downward slope) for the test and the retest sequences.The slope was computed based on all mood ratings of the test and retest sequence. We then conduced a simple linear regression with the slope of the retest sequence as the dependent variable. The independent variables in our analysis were the slope of the test sequence and the registered mood value before the start of the retest sequence. We also included a dummy independent variable to indicate whether the experiment included an actual training environment or was a control experiment.

retest_slope ~ test_slope + mood_before_retest + is_training

Statistical significance was assessed by examining the beta coefficient of this dummy variable as this represents the added contribution of the specific training environment, in contrast to the control environment.

Results

Six environments were identified where there was a significant effect of training on mood, compared to the control experiment. In five of these environments (represented with green lines in Figure 5) there was a positive effect of training on mood resilience while in one environment there was a negative effect of training on mood resilience. Specifically, a statistically significant reduction of the mood slope was observed in A) the monotonic environment where any good mood value receives the maximum reward ($\beta=0.465$, SE=0.125, $p<.001$); B) the monotonic environment where any good mood values receive the medium reward ($\beta=0.263$, SE=0.129, $p<.05$); C) the anti-proportional environment where good mood and reward have a reverse analogous relationship ($\beta=0.411$, SE=0.105, $p<.001$); D) the monotonic environment where bad mood always receives that maximum reward ($\beta=0.201$, SE=0.079, $p<.05$) and E) the anti-proportional environment where bad mood and rewards have a reverse analogous relationship ($\beta=0.235$, SE=0.068, $p<.01$). A statistically significant increase of the mood slope ($\beta=0.17$, SE=0.074, $p<.05$) was observed in the environment where bad mood and rewards have an analogous relationship (represented with a red line in Figure 5). All the training environments that were examined for this study, the demographic data for each environment and the results of mood training are presented in Table 1 and Table 2.

Third set of experiments: Testing the resilience of the training effect after multiple number of rounds

In order to assess whether the training effect would last over time and replicate our previous findings, we isolated the two most effective training environments from the previous set of experiments and examined the resilience of the effect after 10 and 20 rounds. For a real time estimate, 10 and 20 rounds correspond to approximately 1 and 2 minutes, respectively.

Study Design

The experimental design we followed was identical to the one described in the second set of experiments including the same filters for participation. The only difference was that the training environment was followed by a of pseudorandom sequence (Figure 3). The number of rounds of this pseudorandom sequence depends on the duration of the training effect that we wish to test. This pseudorandom sequence is then followed by the retest sequence. The training environments used for these experiments were A) the monotonic environment where good mood is associated with the maximum positive reward and B) the antiproportional environment where good mood and positive rewards have an inverse relationship. These two environments were identified in the previous study as the ones with the greatest training efficiency. We checked the resilience of our training effect after 10 and 20 rounds, compared to the corresponding control experiments.

Analysis

The same analysis was followed as in the previous study.

Results

A statistically significant reduction of the mood slope, compared to the control environment was detectable 10 rounds after the training environment when the monotonic ($\beta=0.228$, $SE=0.080$, $p<.01$) and the antiproportional environment ($\beta=0.175$, $SE=0.083$, $p<.05$) that were selected from the previous set of experiments were examined (Table 3). The monotonic environment, however, was far superior to provoking longer lived effects of mood resilience compared to the antiproportional environment and mood resilience for this environment remained significant (β=0.307, SE=0.068, $p<.001$) 20 rounds after the training environment (Table 4), compared to the control experiment. The demographic data for these experiments are presented in Table 1.

Discussion

In this study we aimed to train mood in order to build mood resilience to negative stimuli. For that purpose, we developed a new experimental design which allowed us to examine various environments for mood training.

Given the exploratory nature of our task, in our initial set of experiments we tested and confirmed the task's efficiency in influencing mood. Previous experiments have successfully employed similar methods in order to study mood and identify the mechanisms that influence mood dynamics (Keren et al., 2021, Rutledge et al., 2017). Our aim however, was to develop a tool to examine the potential of mood to be trained. Additionally, and in contrast to previous tasks that examine mood in relation to rewards and punishments (Keren et al., 2021, Rutledge et al., 2017, Treadway et al., 2009, Pizzagalli et al., 2008), in our paradigm participants are not required to perform any action in order to receive or lose points. This allows for a more naturalistic study of mood, as each mood rating is an immediate outcome of the stimulus administered. Despite our deviations from previous task designs, we showed that in our task, mood follows the stimuli fluctuations while the majority of participants follow the task instructions and do not exploit the task for maximum gains. This is important as we aimed for the task to be able to capture the participants' momentary mood and thus allows to explore mood training and avoid participants registering random mood values.

In our second set of experiments, we tested sixteen different experimental environments to examine whether they would promote mood training. In five of these environments, mood training resulted to developing resilience to negative stimuli, while one environment promoted mood susceptibility to negative stimuli. Deviating from our initial hypothesis, which included a role for punishment in mood training, we found that only environments where mood is rewarded are efficient in training mood.

Several research studies have shown that in learning tasks, especially those involving procedural learning, and under specific experimental settings, rewards and punishments equally improve task performance but punishments, unlike rewards, fail to enhance learning (for example studies see Ballard et al., 2019; Hasson et al., 2015; Galea et al., 2015; Wächter et al., 2009). This could be attributed to rewards activating neuronal mechanisms that are more beneficial to learning and subsequent memory consolidation. Alternatively, punishment has been shown to reduce the quality and quantity of information that is retained, at least in decision making tasks (Ballard et al., 2019, Skinner et al., 1953). Although the relationship between reward and punishment-based learning could be rather complex (Steel et al., 2016), it is possible that in our task, punishment interfered with the acquisition of task dynamics that are necessary for mood training.

Another observation from our second set of experiments was that all environments that were successful in training mood were these where mood values close to zero are rewarded compared to more extreme values. In biology and neuroscience, mood has long been viewed as a mechanism to promote survival and help individuals better adapt to their environment (Riley et al., 2015; LeDoux, 2012; Nettle& Bateson 2012; Nesse et al., 2009). As such, mood states should be cost and energy effective but also amenable to change. It is thus possible that when mood is rewarded, good and bad values that are not extreme but closely above and below zero, are preferred as these would offer the optimal balance between rewards and cost but would also allow for a bidirectional change and adaptability to the environment. This observation is in line with recent findings from large studies showing that mood could be subject to homeostatic mechanisms probing individuals to behaviors that would help them retain their normal mood state (Taquet et al., 2020).

In order to test the replicability of our findings on mood training and examine whether mood resilience would be detectable after 10 and 20 rounds (1 and 2 minutes) of a pseudorandom environment, we conducted a third and final set of experiments. For these experiments we used the two environments where training had the greater effect on mood resilience and showed that mood resilience is present at least up to 2 minutes (20 rounds) after training. A recent experiment on the influence of past and previous events on mood, had showed that past events still carry a lot of weight when momentary mood is assessed (Keren et al., 2021). In accordance with these findings, we expected that mood training which occurred in an initial training environments could influence momentary mood even after several rounds.

In order to strengthen our findings and expand our knowledge on mood, several future experiments and analyses should be conducted. The task and our data on mood training would profit from a more detailed analysis of the task parameters including for example, the optimal number of rounds for training and different reward scales between the testing and training environments. Additionally, a computational modelling approach would allow us to characterise the parameters that are important for mood training. These parameters could then be used to construct a novel environment with maximum effects on mood. The generalisability of our task should also be tested by using other types of stimuli, such as pictures with positive and negative valence. Since different types of stimuli can activate different neuronal pathways during reward based learning, it is important to know whether the observed effects on mood are specific to monetary rewards or can also be applied to other types of rewards. Finally, the task could be used to examine the effect of positive stimuli on mood (anhedonia) as well as clinical populations and more specifically patients with mood disorders.

Our study has several limitations. Data collection for the studies involving our task was conducted online using MTurk. The use of online platforms allows for fast data collection and large experimental samples. However, several checks need to be performed to ensure data integrity as highlighted by other studies (for example see: Moss et al., 2021; Dennis et al., 2020; Rouse et al., 2020; Keith et al., 2017). We applied two filters in order to guarantee data integrity and make sure that our participants were performing the task based on our instructions and no random choices were made. However, we cannot be certain that we managed to avoid all the risks that are linked to online data collection. Since our study was exploratory, we investigated mood training using the simplest experimental environments. Environments that are characterized by more complex relationships between mood and rewards may have even greater efficacy in training mood. For some of the mood-reward relationships we targeted for mood training, we needed to guide the participant’s mood to the desired mood valence. As a result, in these environments some rounds were spent to adjust mood, which reduced the number of rounds that were attributed to mood training. Moreover, we cannot offer any insight on the specific mechanisms that underlie mood training and consequently the duration of its effect on mood over time. For example, we cannot exclude the influence that the total score *per se* could have on mood training.

Despite the several limitations, our study results show that our task could be used as an effective tool to study momentary mood and propose a way to investigate mood resilience. Future studies are needed to further fortify our findings and the usefulness of our methods.

References

Angst F, Stassen HH, Clayton PJ, Angst J. Mortality of patients with mood disorders: follow-up over 34-38 years. J Affect Disord. 2002 Apr;68(2-3):167-81. doi: 10.1016/s0165-0327(01)00377-9. PMID: 12063145.

Arab, A., Mehrabani, S., Moradi, S., & Amani, R. (2019). The association between diet and mood: A systematic review of current literature. Psychiatry Research, 271, 428–437. https://doi.org/10.1016/j.psychres.2018.12.014

D’cruz, M. M., & Chaturvedi, S. K. (2022). Sociodemographic and cultural determinants of mood disorders. *Current Opinion in Psychiatry*, *35*(1), 38–44. https://doi.org/10.1097/YCO.0000000000000766

Dennis, S. A., Goodson, B. M., & Pearson, C. A. (2020). Online Worker Fraud and Evolving Threats to the Integrity of MTurk Data: A Discussion of Virtual Private Servers and the Limitations of IP-Based Screening Procedures. *Behavioral Research in Accounting*, *32*(1), 119–134. https://doi.org/10.2308/bria-18-044

Dev, A., Roy, N., Islam, Md. K., Biswas, C., Ahmed, H. U., Amin, Md. A., Sarker, F., Vaidyanathan, R., & Mamun, K. A. (2022). Exploration of EEG-Based Depression Biomarkers Identification Techniques and Their Applications: A Systematic Review. *IEEE Access*, *10*, 16756–16781. https://doi.org/10.1109/ACCESS.2022.3146711

Eldar, E., Rutledge, R. B., Dolan, R. J., & Niv, Y. (2016). Mood as Representation of Momentum. *Trends in Cognitive Sciences*, *20*(1), 15–24. https://doi.org/10.1016/j.tics.2015.07.010

Franke, A. G., Bagusat, C., Dietz, P., Hoffmann, I., Simon, P., Ulrich, R., & Lieb, K. (2013). Use of illicit and prescription drugs for cognitive or mood enhancement among surgeons. *BMC Medicine*, *11*(1), 102. https://doi.org/10.1186/1741-7015-11-102

Galea, J. M., Mallia, E., Rothwell, J., & Diedrichsen, J. (2015). The dissociable effects of punishment and reward on motor learning. *Nature Neuroscience*, *18*(4), 597–602. https://doi.org/10.1038/nn.3956

Hagen, E. H. (2011). Evolutionary Theories of Depression: A Critical Review. *The Canadian Journal of Psychiatry*, *56*(12), 716–726. https://doi.org/10.1177/070674371105601203

Hasler, G. (2020). Understanding mood in mental disorders. *World Psychiatry*, *19*(1), 56–57. https://doi.org/10.1002/wps.20719

Hasson, C. J., Manczurowsky, J., & Yen, S.-C. (2015). A reinforcement learning approach to gait training improves retention. *Frontiers in Human Neuroscience*, *9*. https://doi.org/10.3389/fnhum.2015.00459

Jangraw, D., Keren, H., Sun, H., Bedder, R., Rutledge, R., Pereira, F., Thomas, A. G., Pine, D., Zheng, C., Nielson, D. M., & Stringaris, A. (2021). Passage-of-Time Dysphoria: A Highly Replicable Decline in Mood During Rest and Simple Tasks that is Moderated by Depression [Preprint]. PsyArXiv. https://doi.org/10.31234/osf.io/bwv58

Jones, C. M., Scholes, L., Johnson, D., Katsikitis, M., & Carras, M. C. (2014). Gaming well: Links between videogames and flourishing mental health. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.00260

Keith, M. G., Tay, L., & Harms, P. D. (2017). Systems Perspective of Amazon Mechanical Turk for Organizational Research: Review and Recommendations. *Frontiers in Psychology*, *8*, 1359. https://doi.org/10.3389/fpsyg.2017.01359

Keren, H., Zheng, C., Jangraw, D. C., Chang, K., Vitale, A., Rutledge, R. B., Pereira, F., Nielson, D. M., & Stringaris, A. (2021). The temporal representation of experience in subjective mood. *ELife*, *10*, e62051. https://doi.org/10.7554/eLife.62051

Kessler RC, Chiu WT, Demler O, Merikangas KR, Walters EE. Prevalence, severity, and comorbidity of 12-month DSM-IV disorders in the National Comorbidity Survey Replication. Arch Gen Psychiatry. 2005 Jun;62(6):617-27. doi: 10.1001/archpsyc.62.6.617.

LeDoux, J. (2012). Rethinking the Emotional Brain. *Neuron*, *73*(4), 653–676. https://doi.org/10.1016/j.neuron.2012.02.004

Lee, W. E., Wadsworth, M. E. J., & Hotopf, M. (2006). The protective role of trait anxiety: A longitudinal cohort study. *Psychological Medicine*, *36*(3), 345–351. https://doi.org/10.1017/S0033291705006847

Macht, M., & Mueller, J. (2007). Immediate effects of chocolate on experimentally induced mood states. *Appetite*, *49*(3), 667–674. https://doi.org/10.1016/j.appet.2007.05.004

Moss, A. J., Rosenzweig, C., Jaffe, S. N., Gautam, R., Robinson, J., & Litman, L. (2021). *Bots or inattentive humans? Identifying sources of low-quality data in online platforms* [Preprint]. PsyArXiv. https://doi.org/10.31234/osf.io/wr8ds

Nesse, R. M., & Ellsworth, P. C. (2009). Evolution, emotions, and emotional disorders. *American Psychologist*, *64*(2), 129–139. https://doi.org/10.1037/a0013503

Nettle, D. (2009). An evolutionary model of low mood states. *Journal of Theoretical Biology*, *257*(1), 100–103. https://doi.org/10.1016/j.jtbi.2008.10.033

Nettle, D., & Bateson, M. (2012). The Evolutionary Origins of Mood and Its Disorders. *Current Biology*, *22*(17), R712–R721. https://doi.org/10.1016/j.cub.2012.06.020

Öhman, A., & Mineka, S. (2001). Fears, phobias, and preparedness: Toward an evolved module of fear and fear learning. *Psychological Review*, *108*(3), 483–522.

https://doi.org/10.1037/0033-295X.108.3.483

Pinto, A., & van Praag, H. (2022). An exercise infusion benefits brain function. *Cell Research*, *32*(3), 223–224. https://doi.org/10.1038/s41422-022-00621-1

Pizzagalli, D. A., Iosifescu, D., Hallett, L. A., Ratner, K. G., & Fava, M. (2008). Reduced hedonic capacity in major depressive disorder: Evidence from a probabilistic reward task. *Journal of Psychiatric Research*, *43*(1), 76–87. https://doi.org/10.1016/j.jpsychires.2008.03.001

Rutledge, R. B., Moutoussis, M., Smittenaar, P., Zeidman, P., Taylor, T., Hrynkiewicz, L., Lam, J., Skandali, N., Siegel, J. Z., Ousdal, O. T., Prabhu, G., Dayan, P., Fonagy, P., & Dolan, R. J. (2017). Association of Neural and Emotional Impacts of Reward Prediction Errors With Major Depression. *JAMA Psychiatry*, *74*(8), 790. https://doi.org/10.1001/jamapsychiatry.2017.1713

Saarikallio, S., & Erkkilä, J. (2007). The role of music in adolescents' mood regulation. *Psychology of Music*, *35*(1), 88–109. https://doi.org/10.1177/0305735607068889

Schreurs, B., Guenter, H., Hülsheger, U., & van Emmerik, H. (2014). The role of punishment and reward sensitivity in the emotional labor process: A within-person perspective. Journal of Occupational Health Psychology, 19(1), 108–121. https://doi.org/10.1037/a0035067

Taquet, M., Quoidbach, J., Gross, J. J., Saunders, K. E. A., & Goodwin, G. M. (2020). Mood Homeostasis, Low Mood, and History of Depression in 2 Large Population Samples. *JAMA Psychiatry*, 77(9), 944. https://doi.org/10.1001/jamapsychiatry.2020.0588

Treadway, M. T., Buckholtz, J. W., Schwartzman, A. N., Lambert, W. E., & Zald, D. H. (2009). Worth the 'EEfRT'? The Effort Expenditure for Rewards Task as an Objective Measure of Motivation and Anhedonia. *PLoS ONE*, *4*(8), e6598.

https://doi.org/10.1371/journal.pone.0006598

Wachter, T., Lungu, O. V., Liu, T., Willingham, D. T., & Ashe, J. (2009). Differential Effect of Reward and Punishment on Procedural Learning. *Journal of Neuroscience*, *29*(2), 436–443. https://doi.org/10.1523/JNEUROSCI.4132-08.2009

Yardley, J. K., & Rice, R. W. (1991). The relationship between mood and subjective well-being. *Social Indicators Research*, *24*(1), 101–111. https://doi.org/10.1007/BF00292653

Figures

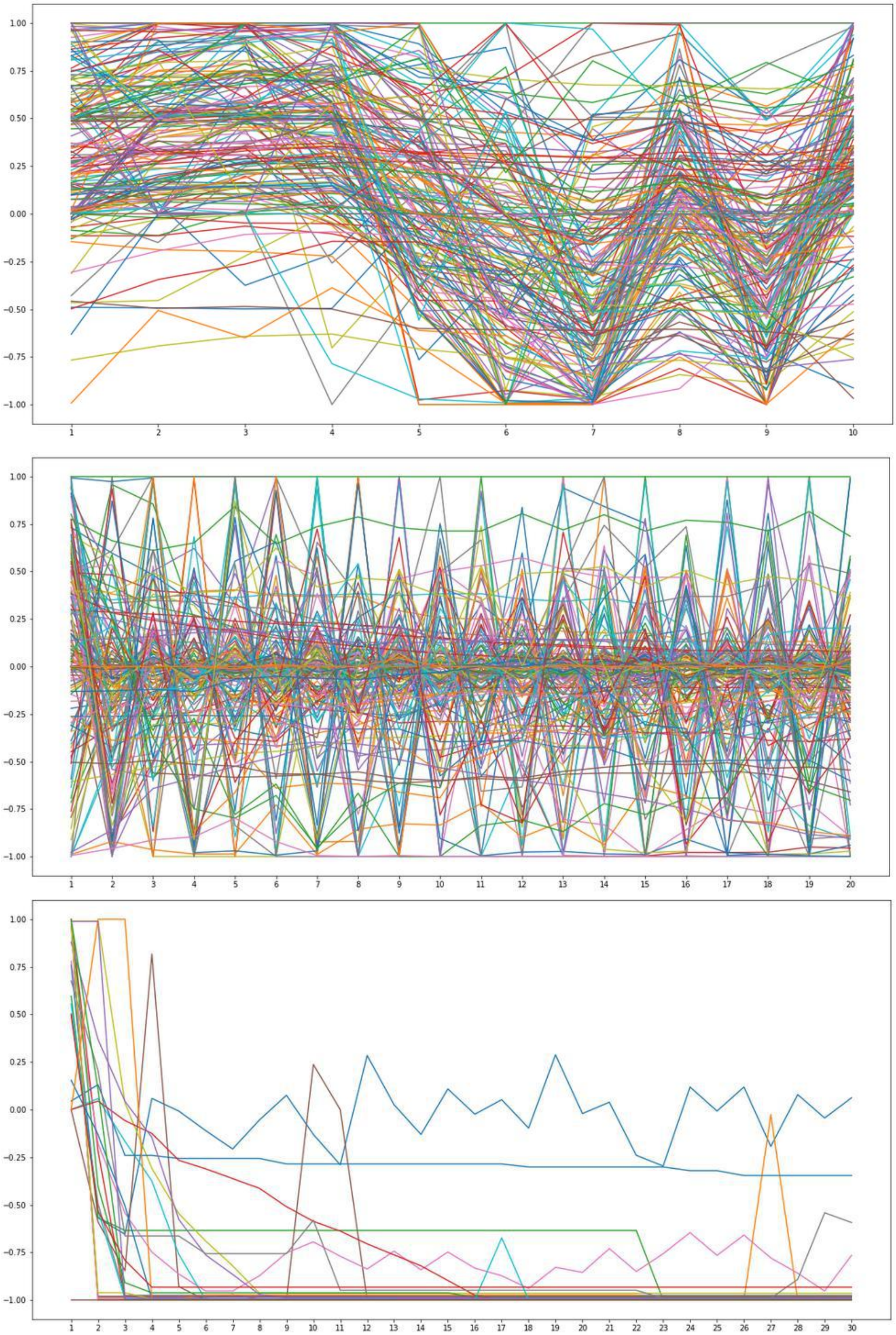

Figure 1. Task Validation. In the pseudorandom environment (top graph) similar mood courses are observed for the majority of participants. In the paradoxical environment (middle graph), we observe an

oscillatory pattern of mood responses indicating that participants are not exploiting the task for maximum gain. When any mention of mood is removed from the task, maximum gain environment (bottom graph), the majority of participants register extreme negative values which yield maximum task points.

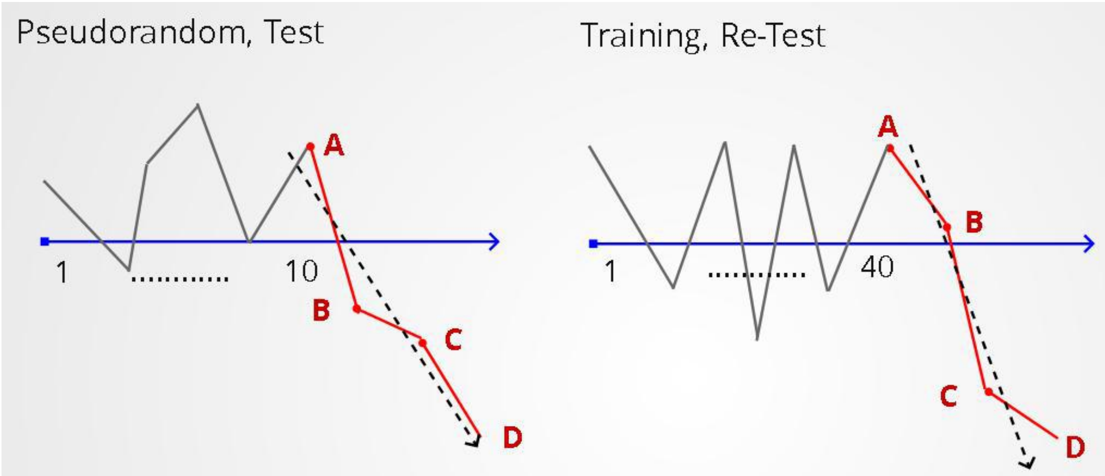

Figure 2. Mood Training. Our task design included an environment of a pseudorandom sequence (10 rounds) followed by the test sequence and 40 rounds of the training environment followed by the retest sequence. The test and retest sequences are identical and consist of three consecutive, negative stimuli of very big value.

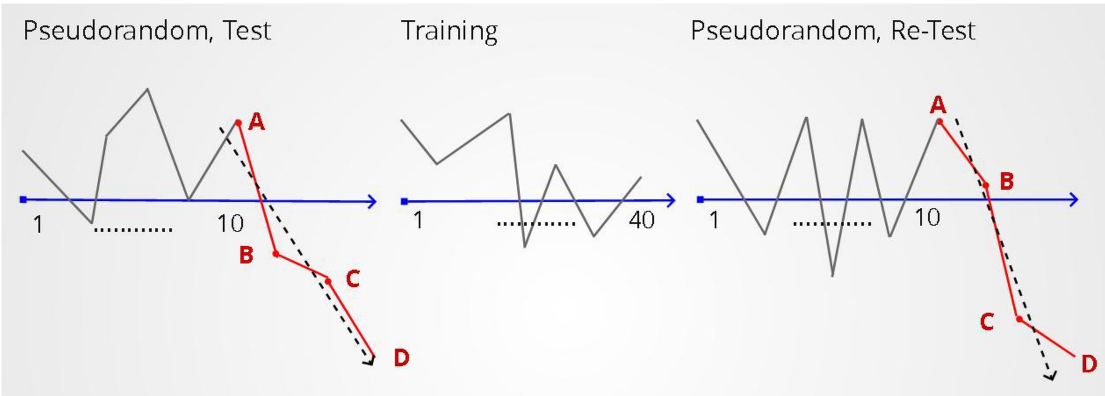

Figure 3. Mood Training Resilience. To test the resilience of the mood training over multiple task rounds, we introduce a new environment of pseudorandom sequences after the training environment. In this study, the pseudorandom sequence consisted of 10 and 20 rounds.

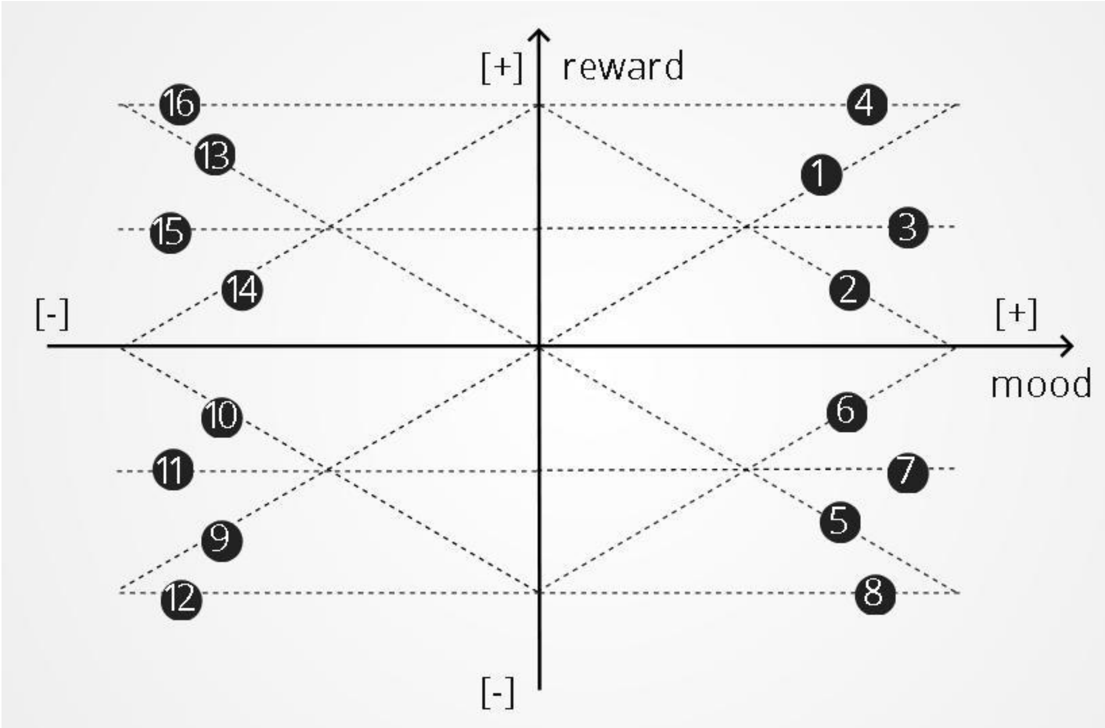

Figure 4. Mood and Reward. We represent mood and reward on a two dimensional space. In this space mood is placed on the x axis and reward is placed on the y axis. Two quarters of this space belong to positive and two quarters to negative mood. For each quarter of this space we distinguish four possible training environments characterized by different mood and reward linear relationships. These relationship include A. a proportional one where mood and rewards have an analogous relationship - lines 1, 5, 9, 13 B. an antiproportional one where mood and rewards have a reversed analogous relationship- lines 2, 6, 10, 14 C. a monotonic one where a medium reward is always administered - lines 4, 8, 12, 16 and D.a monotonic one where a maximum reward is always administered - lines 3, 7, 11, 15

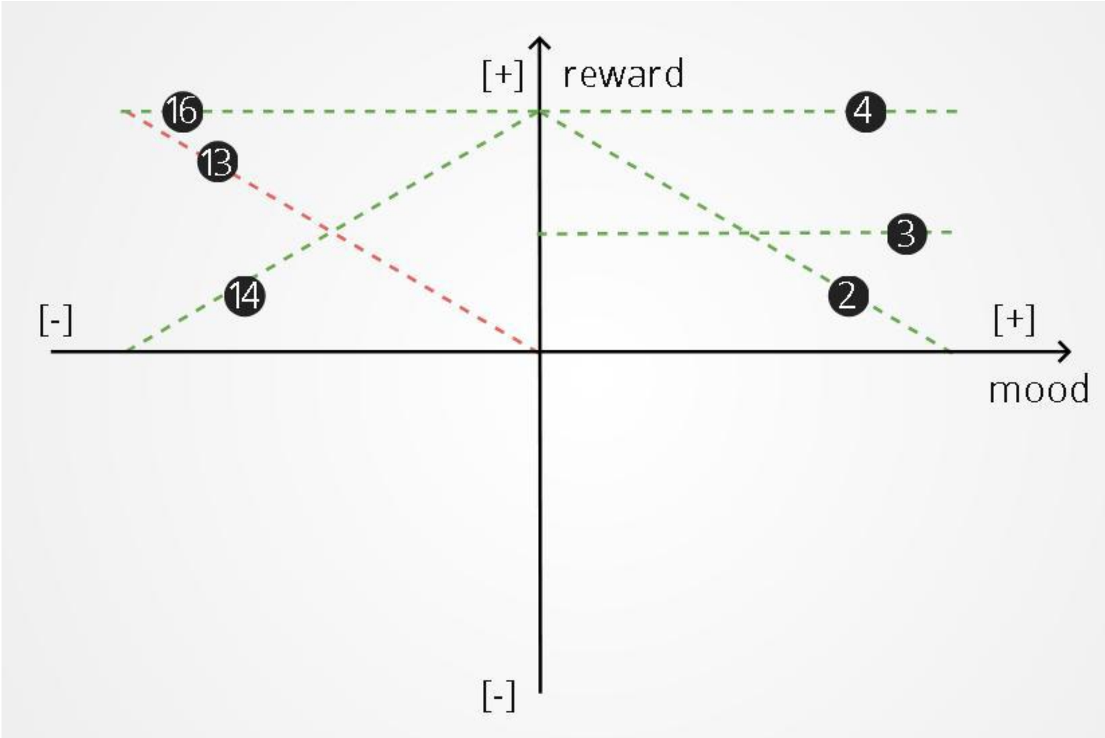

Figure 5. Successful environments for mood training: A. Two monotonic environments where good mood receives the maximum and medium reward – lines 4 and 3 B. The anti-proportional environment where good mood and rewards have a reverse analogous relationship – line 2 C. A monotonic environment where bad mood always receives the maximum reward – line 16 D. An anti-proportional environment where bad mood and rewards have a reverse analogous relationship – line 14 and E. A proportional environment where bad mood and rewards have an analogous relationship – line 13.

Tables

	environment	N	Female(%)	age(mean,std)
Study 1	pseudorandom	187	56	41, 9
	paradoxical	182	53	38, 11
	maximum gain	26	46	40, 10
Study 2	proportional reward of good mood	39	44	36, 9
	antiproportional reward of good mood	37	43	38, 8
	constant medium reward of good mood	31	55	36, 8
	maximum reward of good mood	28	43	42, 12
	proportional punishment of good mood	48	58	37, 12
	antiproportional punishment of good mood	33	52	35, 10
	constant medium punishment of good mood	28	43	36, 9
	maximum punishment of good mood	25	40	41, 10
	proportional punishment of bad mood	38	42	38, 8
	antiproportional punishment of bad mood	44	48	36, 11
	constant medium punishment of bad mood	30	40	37, 10
	maximum punishment of bad mood	26	58	37, 8
	proportional reward of bad mod	29	62	37, 9
	antiproportional reward of bad mod	31	58	38, 9
	constant medium reward of bad mood	32	44	38, 9
	maximum reward of bad mood	24	54	35, 9
Study 3	antiproportional reward of good mood, 10 rounds	30	40	40, 7
	maximum reward of good mood, 10 rounds	36	47	40, 10
	antiproportional reward of good mood, 20 rounds	54	54	40, 9
	maximum reward of good mood, 20 rounds	59	49	38, 11

Table 1. The demographic data for the three studies are included in this table. The total number of participants, the gender balance and mean age are presented for each experiment/environment that was examined for the three studies.

environment	β-coef	CI(2.5,97.5)	SE	p value
proportional reward of good mood	0.194	-0.02,0.408	0.107	>.05
antiproportional reward of good mood	0.411	0.201,0.621	0.105	<.001
constant medium reward of good mood	0.263	0.006,0.521	0.129	<.05
maximum reward of good mood	0.465	0.216,0.715	0.125	<.001
proportional punishment of good mood	-0.038	-0.173,0.098	0.068	>.05
antiproportional punishment of good mood	-0.021	-0.175,0.132	0.077	>.05
constant medium punishment of good mood	-0.059	-0.216,0.097	0.078	>.05
maximum punishment of good mood	0.044	-0.108,0.076	0.075	>.05
proportional punishment of bad mood	0.146	-0.024,0.317	0.085	>.05
antiproportional punishment of bad mood	-0.06	-0.206,0.085	0.073	>.05
constant medium punishment of bad mood	0.137	-0.051,0.325	0.094	>.05
maximum punishment of bad mood	0.128	-0.061,0.316	0.094	>.05
proportional reward of bad mod	-0.17	-0.319,-0.021	0.074	<.05
antiproportional reward of bad mod	0.235	0.099,0.370	0.068	<.01
constant medium reward of bad mood	0.013	-0.14,0.166	0.076	>.05
maximum reward of bad mood	0.201	0.041,0.361	0.079	<.05

Table 2. In this exploratory set, all 16 environments were tested for their efficacy in training mood and the results are presented in here. For each environment and for each participant we computed, mood's falling slope for the test and the retest sequences. We then conduced a simple linear regression including as factors to our analysis, the slope of the test sequence and the the registered mood value before the start of the retest sequence. We also accounted for whether the experiment included an actual training environment or was a control experiment (N=41, Females 54%, Mean Age=42±10).

environment	β-coef	CI(2.5,97.5)	SE	p value
antiproportional reward of good mood	0.175	0.007,0.343	0.083	<.05
maximum reward of good mood	0.228	0.067,0.388	0.080	<.01

Table 3. The resilience of mood training was measured in novel sample for the two environments that had the greatest training efficacy as per Study 2. The effect of each environment after 10 rounds of a pseudorandom sequence is shown. Both environments were compared to the a similar control experiment (N=33, Females 42%, Mean Age=40±9).

environment	β-coef	CI(2.5,97.5)	SE	p value
antiproportional reward of good mood	0.118	−0.024,0.259	0.071	>.05
maximum reward of good mood	0.307	0.172,0.441	0.068	<.001

Table 4. The resilience of mood training was measured in two environments that had the greatest training efficacy as per Study 2. In one of the environments the effect was detectable after 20 rounds of the pseudorandom sequence. Both environments were compared to the a similar control experiment (N=62, Females 44%, Mean Age=34±10).