The impact of arousal levels on reversal learning

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Abstract

Introduction: Avoidance is a key symptom in several psychiatric disorders, therefore it is important to reduce maladaptive avoidance. Reversal learning is a way to reduce maladaptive avoidance behaviour. Since arousal impacts learning processes, it is likely that reversal learning is also impacted by arousal. Here, we explored how different levels of arousal may influence reversal learning. It is hypothesized that high levels of arousal lead to more exploitation of a known option, whereas lower arousal levels are expected to lead to more explorative behaviour.

Methods: Ninety-nine participants retrieved a memory that was either painful or fearful and rated their memory on arousal. The participants performed the Probabilistic Reversal Learning Task (PRLT), where they learn to respond to one predominantly reinforced stimulus, and then must learn to respond according to the opposite, previously irrelevant, stimulus. Performance measures are the rates of explorative and exploitative stimulus choices and the number of perseveration errors. The number of perseveration errors is used as indication of the learning speed in the PRLT.

Results: No differences were found between the painful versus fearful memory groups on the rates of explorative and exploitative behaviour nor on the number of perseveration errors. Both conditions performed similarly on the PRLT.

Discussion: A memory with a either a painful or fearful emotional load did not have a different impact on the rates of explorative and exploitative behaviour in reversal learning. It is likely that punishment-driven learning is not effected by emotional arousal.

Keywords: avoidance, reversal learning, emotional arousal, exploitation, exploration

Introduction

Maladaptive avoidance is a common symptom in several psychiatric disorders (American Psychiatric Association, 2013) and chronic pain conditions (Dowell et al., 2016). People in these conditions typically avoid several seemingly innocuous stimuli (LeDoux et al., 2017). For example, a person with chronic pain might avoid exercising, because he/she is afraid that exercising may trigger pain, although exercising can be helpful for a person with chronic pain (Dowell et al., 2016). Such avoidance, does not give him/her the opportunity to check whether exercising causes pain or not. So, maladaptive avoidance reactions block the way of exploring the avoided, but innocuous, stimulus or behaviour and the realisation that the stimulus/behaviour is safe (Yaple & Yu, 2019). In this way, avoidance plays a causal role in the maintenance of anxiety (e.g., Rudaz et al., 2017). Therefore, it is important to understand maladaptive avoidance behaviour and especially the reduction of avoidance behaviour, since the reduction of maladaptive avoidance is thought to alleviate other symptoms of patients (Treanor & Barry, 2017). The current study aims to contribute to the knowledge of the reduction of maladaptive avoidance.

Avoidance is related to decision making, especially to the concepts of exploiting and exploring (Morris et al., 2015). Exploitation is, in this context, that people commit to a known option, whereas exploration involves probing alternatives with unknown outcomes (Humphreys et al., 2015). Life requires a balance between exploration and exploitation by benefitting from a particular choice and finding out alternatives that might be better. The optimal balance between exploitation and exploration is situation-dependent (Cohen, MacClure, & Yu, 2007). In a nonoptimal trade-off a person might show more exploiting than exploring behaviour, which can become a form of maladaptive avoidance (Greening et al., 2011), for example a socially anxious person exploiting his/her house and avoids exploring busy places. Exploitative behaviour can be expressed to avoid expected aversive or uncertain outcomes (Morris et al., 2015). So, maladaptive avoidance can be defined as a maladaptive imbalance between exploitation and exploration in a situation, with more exploitation than exploration (Vlaeyen & Crombez, 2020).

In balancing between exploration and exploitation, people take into account the expected consequences of a stimulus (Beylergil et al., 2017). Stimuli often have rewarding or punishing consequences for an individual (Chen & Bargh, 1999). The consequences of several stimuli, however, can reverse from rewarding to punishing or vice versa. For example, an individual likes hiking and experiences the rewarding consequences of feeling relaxed and refreshed. After a hernia, hiking gets the negative consequence of pain for the individual. In these situations, people will have to adapt to the changed meaning and consequences of the stimulus (Schutte et al., 2017). So, in our example, the person will have to adapt to the, temporarily, reversed meaning of hiking for him/her by trying other spare time activities (exploration) and hiking (exploitation) to learn the consequences of these activities. Usually this adaptation to shifting consequences is an ongoing process, although the ability to adapt to reversals can be impaired in people with addictions (Beylergil et al., 2017) and anorexia nervosa (Hildebrandt et al., 2018). Reversal procedures encourage explorative behaviour, since the exploitation of the previous rewarding stimulus now receives negative consequences. In this way, reversal procedures can be helpful in decreasing maladaptive exploitation behaviour (Greening et al., 2011) and maladaptive avoidance (Metha et al., 2019; Krypotos et al., 2020).

An experimental way to study reversal learning is by using the Probabilistic Reversal Learning Task (PRLT; Cools et al., 2002). In the PRLT participants choose one out of multiple stimuli and are probabilistically rewarded for choosing the correct stimulus. For example, in the study by Den Ouden et al., (2013), a red pattern was rewarded with a smiling emoticon in 70% of the cases, where a blue pattern was punished with an angry emoticon with a 70% probability. After several trials, the contingencies reverse, so that the red pattern becomes the usual punished stimulus. Participants were not aware of this reversal and had to learn by exploration that the reversal took place (Cools et al., 2002; Den Ouden et al., 2013; Skandali et al., 2018). Participants were expected to learn that they should choose the usually rewarded stimulus, in other words, they had to exploit this stimulus in the first phase. In the reversal phase, exploiting that same stimulus had a punishing consequence, therefore participants were expected to explore the other stimulus to get the rewarding consequence (Metha et al., 2019), which also means that the avoidance of that stimulus is discouraged (Greening et al., 2011). So, the PRLT is a way to study exploration and exploitation in an experimental setting.

Threat plays a role in reversal learning, although it is unclear what the exact role of threat on reversal learning is (Paret & Bublatzky, 2020). In the study of Paret and Bublatzky (2020) participants learned slower that a reversal in the PRLT took place when they expected an electric shock compared to participants who did not expected something threatening. However, arousal elicited by a decision making task can also provoke curiosity and explorative behaviour (Murphy et al., 2014) and seeing a face with a fearful expression accelerated reversal learning (Watanabe et al., 2013). Murphy et al. (2014) conclude that the relation between arousal and performance is a U-inverted relation, where moderate levels of arousal increase focus and task engagement, but with high levels of arousal an individual becomes easily distracted on the one end or drowsy and demotivated on the other end. There are some differences in methodology between these studies, because Watanabe et al. (2013) induced arousal before their participants performed a task, Murphy et al. (2014) measured the arousal provoked by the difficulty of the task, whereas Paret and Bublatzky (2020) used the expected arousal of the possible consequences in the PRLT. To link the expected consequence and arousal to the theory of the U-inverted relation of Murphy et al. (2014), different levels of arousal evoked by the expected consequence should be compared to assess the effect on reversal learning. Nevertheless, in the context of reversal learning most research compares arousal versus non-arousal conditions (e.g., Paret & Bublatzky, 2020; Clark et al., 2012; Watanabe et al., 2013) or positive versus negative arousal (Nusbaum et al., 2018). Little is known about the effect of different levels of arousal about the expected consequence in reversal learning.

The aim of the current study is to assess the role of arousal levels in reversal learning. To this end, participants will perform the PRLT in a between group study with participants assigned to one of two conditions. In the pain-condition participants have to recall a situation where they experienced physical pain, whereas the fear-condition recalls a fear evoking memory. Pain-related memories should evoke more arousal than fear-related memories. Based on the possible link of reversal learning and the U-inverted relationship between arousal and learning (Murphy et al., 2014; Paret & Bublatzky, 2020), it is hypothesized that high arousal, in the pain-condition, leads to slower reversal learning, compared to less arousal, in the fear-condition. Slower reversal learning is operationalised as more perseveration errors after the contingency reversal. A perseveration error is a sequence of at least two responses with the usually non-rewarded stimulus. Perseveration errors suggest that someone does not understand the revalued meaning of that stimulus (Den Ouden et al., 2013)**.** The second hypothesis is based on another aspect of reversal learning, namely the exploration-exploitation trade-off, because learning in the PRLT is a combination of both exploitation and exploration (Yaple & Yu, 2019). Since arousal influences the learning process in the PRLT (Paret & Bublatzky, 2020) and reversal learning requires both explorative and exploitative behaviour (Greening et al. 2011), it might be that different levels of arousal have a different impact on the behaviour pattern of more explorative or more exploitative behaviour. Higher levels of arousal are suggested to impact reversal learning by showing more exploitative behaviour than explorative, which makes it more difficult to learn the rule of which stimulus is the most rewarded at the two phases of the PRLT (Paret & Bublatzky, 2020; Murphy et al., 2014). Therefore, it is hypothesized that participants in the pain-condition show a higher exploitation rate than exploration compared to participants in the fear-condition. Exploration is conceptualised as lose-shift trials, where a stimulus is punished and the participant switches to the other stimulus. Exploitation is conceptualised as win-stay trials, trials where a participant chooses the same stimulus when he/she was rewarded for the previous one.

Methods

Participants

A total of 101 people completed the online experiment. The data of two participants were excluded, because they did not report a pain- or fear related memory. Participants were randomly assigned to one of the experimental conditions. In the pain condition there were n = 47 participants and in the fear condition n = 52 participants. Most of them were European (79.8%), right-handed (91.9%), female (73,7%; male 26,3%), and received education at least at a bachelor level (89.9%). The age of the participants ranged from 18 till 55, with M = 25.01, SD = 7.64. Inclusion criteria were the absence of the following criteria: pregnancy, psychiatric disorders, cardiovascular conditions, neurological disorders and current usage of medication that could influence memory or attention. The study was approved by the faculty ethics review comittee (FERB; case 20-622).

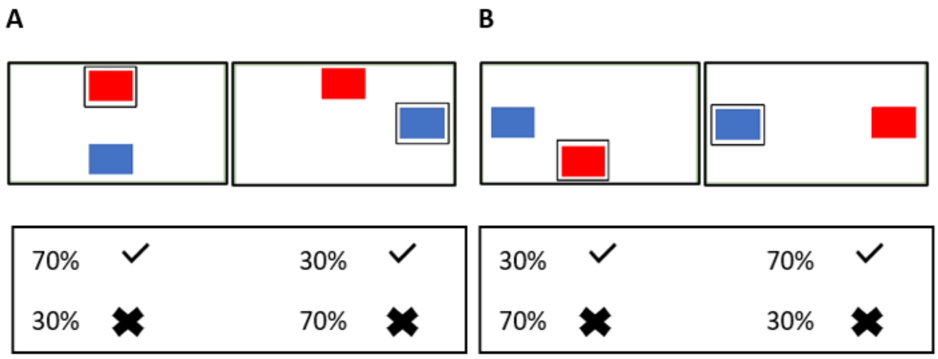
Materials

The following questions are used to measure the experienced arousal of the recalled memory: “How emotionally arousing do you find the memory you reported?” which participants could answer on a VAS-scale ranging from 0 (not arousing at all) to 10 (very arousing). “How fearful is this memory for you?” and “How painful is this memory for you?” were answered on a VAS-scale from 0 (not at all) to 10 (very much). The motivation level was asked with “How high was your motivation to complete the experiment?”, on a VAS-scale from 0 (very low) to 10 (very high). The question “How easy was it for you to recall the memory during the learning task?” was answered on a VAS-scale as well, from 0 (not easy at all) to 10 (very easy).

The Probabilistic reversal learning task (PRLT) consisted of three practice trials and two blocks with each 40 trials, namely *acquisition*, and *reversal*. Participants were not aware of these two phases, but received the instruction that the identity of the correct stimulus could change (for exact instructions see *Procedure*). They had to choose the usually rewarded stimulus and switch when they were sure that the identity of the most rewarded stimulus had changed. Stimulus A was rewarded (70%) with a neutral picture in the acquisition phase and sometimes punished (30%) with the word “PAIN” or “FEAR” as sign that a participant recalls the memory dependent on condition, whereas stimulus B was punished in 70% and rewarded 30%. After 40 trials the reinforcement contingencies reversed, so stimulus B was usually rewarded and stimulus A punished (70%), see figure 1. Feedback was presented for 2000 ms (Cools et al., 2002).

Figure 1

Reward and punishment in the PRLT



Note. In the acquisition phase (A) one of the stimuli (the red square) is probabilistically rewarded 70%, and punished 30%, whereas the other stimulus (the blue square) is punished 70% of the time and rewarded 30%. In the reversal phase (B), the contingencies change, so that the red square is punished 70% of the time and the blue square is rewarded 70%. 30% of the feedback is thus misleading.

Procedure

Participants filled in questions about inclusion criteria (see *Participants*) and when they met the criteria, they continued the experiment. Next, participants were asked to recall a memory, that was either about experiencing pain or fear, dependent on the condition they were assigned to, with the instruction: *"For the next task, we need you to think of a specific situation where you experienced physical/bodily pain. We would like you to recall this event in detail, remembering how you felt. Imagine this situation as if it is happening now. Keep the image of this situation as vividly as possible in your imagination. Concentrate on the sensations you feel. Take your time to recall the incident and provide a brief description in the textbox on this page."* They rated the memory on arousal by answering the questions (see *Materials*). After these questions, participants performed the PRLT. They received the following instruction: *"Now you will continue with the real task. On the screen two coloured squares will be presented: one red, one blue. One of these colours is correct (i.e. rewarded) more often than the other one. When your choice is correct you will see a green check mark, when you choice is incorrect you will see the word "PAIN". If you see the word "PAIN", then* *bring to mind the memory you wrote down earlier, experiencing all the emotions and sensations of that memory. Choose the colour which tends to be correct more often. You have to find out by trial and error which colour that is. On certain moments the rule can change, i.e. the other colour is now correct more often. Then, switch your response to that colour. This can happen one or more times during the task."* In the fear condition participants saw the word "FEAR" instead of "PAIN". After the PRLT participants answered the questions about motivation and the easiness of retrieving the memory (see *Materials*).

Statistical analysis

In line with Den Ouden et al. (2013), responses were quantified in four different ways: win-stay trials, lose-shift trials, perseverative errors, and chance errors. *Win-stay* trials are trials in which participants chose the same stimulus as the previous, rewarded stimulus, not necessarily the correct one. *Lose-shift* trials are trials where participants shifted after a punishment. *Perseveration* is a sequence of two or more choices of the least-rewarded stimulus in the reversal phase. The single choices for the least-rewarded stimulus in the reversal phase were considered chance errors. Before running any analyses, the data was coded into the mentioned outcome measures. The analyses are performed in SPSS (IBM, version 26).

Two manipulation checks are performed, the first check is to test whether the conditions differed in arousal levels. To this end, an independent samples t-test is used to compare the means per condition on the question about arousal levels. A second manipulation check is performed to check whether participants successfully learned the task and performed above chance. Therefore, a repeated measures analysis of variance (ANOVA) is performed with the proportion of correct responses per phase and per condition as factors. Although in previous research a criterium of eight successive correct responses is used to assess whether participants learned the task (Chamberlain et al., 2006), this criterium is considered too strict and not necessarily reflecting whether participants learned the task well (Den Ouden et al., 2013; Brolsma et al., 2020).

The first hypothesis that more arousal leads to slower reversal learning compared to less arousal is tested with a factorial ANOVA. The number of perseveration errors is the dependent variable and condition the within-subjects variable. Learning criterion attainment is also included as factor. This analysis was repeated with chance errors instead of perseveration errors to ensure that possible effects are selective for perseveration errors and not for chance errors. In other words, that a possible effect is the result of slower reversal learning, which is operationalised as the number of perseveration errors. The expected result is that the pain condition shows more perseveration errors compared to the fear condition.

The analyses of the second hypothesis, more arousal leads to more exploitation than exploration behaviour compared to less arousal, are based on the study by Den Ouden and colleagues (2013). A factorial ANOVA with the within-subject factor win-stay rates is used to test the second hypothesis. The between-subject factors are condition and learning criterion attainment. The same analysis is repeated with lose-shift rates instead of win-stay rates as within-subjects factor. Significant effects of condition will be specified by the following follow-up analyses. For a significant effect of condition on win-stay or lose-shift rates, two univariate ANOVA were conducted with lose-shift or win-stay rates as dependent variable and condition and learning criterion attainment as independent variables, including all pairwise interactions. For significant effects, the specificity was assessed with two mixed repeated-measures ANOVAs respectively regarding the phase (acquisition or reversal) of the experiment and the feedback validity (valid or invalid trial). Included were the factors condition, learning criterion attainment and the phase or the feedback validity. A trial was considered invalid when a response received misleading feedback. Support for the second hypothesis is found when the pain condition shows more win-stay trials and less lose-shift trials than the fear condition.

Results

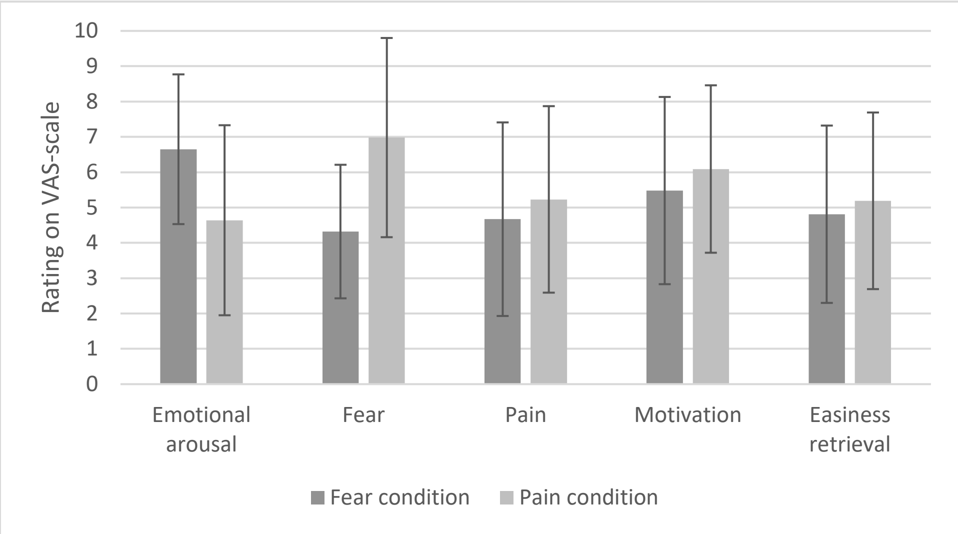
Manipulation checks

Participants in the fear condition (*M* = 6.65, *SD* = 2.12) score significant higher on emotional arousal, compared to participants in the pain condition (*M* = 4.64, *SD* = 2.69), *t*(9) = -4.100, $p < .001$, *d* = 0.83. People in the fear condition (*M* = 6.98, *SD* = 1.89) also score higher on the fear rating, compared to the participants in the pain condition (*M* = 4.32, *SD* = 2.82), *t*(79.25) = -5.451, $p < .001$, *d* = 1.12. On the pain rating there is no significant difference between participants in the fear (*M* = 4.67, *SD* = 2.74) and the pain condition (*M* = 5.23, *SD* = 2.64), *t*(97) =1.035, *p* = .303, *d* = 0.21. Thus, emotional and fearful arousal ratings were significantly different per condition, with higher scores in the fear condition, but there were no differences in painful arousal, see also figure 2.

The motivation level to complete the experiment did not differ between participants in the fear condition (*M* = 5.48, *SD* = 2.65) and the pain condition (*M* = 6.09, *SD* =2.37) , *t*(97) =1.193, *p* = .236, *d* = 0.24. Neither was there a significant difference in the easiness of which participants recalled their memory between those in the fear condition (*M* = 4.68, *SD* = 2.51) and the pain condition (*M* = 5.19, *SD* = 2.50), *t*(97) = .762, *p* = .448, *d* = 0.15. So, we found no difference in motivation or the easiness in retrieving the memory between participants in the different conditions, see figure 2.

Figure 2

Means and standard deviations of the self-report questions compared between the conditions.



Nine participants, five in the fear condition and four in the pain condition, did not perform better than chance and therefore did not attain the learning criterium. Learning criterium attainment was added as factor in the main analyses.

Main analyses

The first hypothesis that one condition leads to more perseveration errors in the reversal phase of the PRLT compared to the other condition, was tested with a factorial ANOVA. There is no significant effect found of condition on the number of perseveration errors, F (1, 96) = 0.59, p =.444, η^2 = .01. The variable learning criterium attainment was included as third variable, but shows also no effect on the number of perseveration errors, F (1, 96) =0.95, p =.332, η^2 = .01. The same analysis was repeated with the number of chance errors in the reversal phase, but condition has no effect on chance errors as well, F (1, 96) = .08, p = .784, η^2 = .001 neither does learning criterium attainment, F (1, 96) = 3.07, p = .083, η^2 = .03. Concludingly, there is no evidence found that there are differences in the number of perseveration or chance errors between the conditions.

The second hypothesis is that the participants in the pain condition show more win-stay trials than lose-shift trials compared to participants in the fear condition. A factorial ANOVA did not reveal significant differences between the conditions in the number of win-stay trials, F (1, 96) = .08, p = .776, η^2 = .001. However, there is a significant effect of learning criterium attainment, F (1, 96) = 9.46, p = .003, η^2 = .09. Follow-up simple comparisons show that participants that obtained the learning criterium have more win-stay trials (M = 37.90, SD = 0.85) compared to the participants that did not obtain the learning criterium (M = 29.22, SD = 2.38), t(97) = -3.10, p = .003, d = 4.86. The same analysis was performed for the effect of condition on the number of lose-shift trials. There is no difference found between the conditions, F (1, 95) = 1.14, p = .287, η^2 = .02, but there is a significant difference of the learning criterium attainment on the number of lose-shift trials, F (1, 96) = 5.54, p = .021, η^2 = .05. Follow-up simple comparisons show that participants that obtained the learning criterium have more lose-shift trials (M = 18.50, SD = 0.72) compared to the participants that did not obtain the learning criterium (M = 13.11, SD = 2.40), t(97) = -2.29, p = .025, d = 3.04. So, although there is a difference in both win-stay and lose-shift rates between participants that did or did not obtain the learning criterium, there is no evidence found that there are differences between the conditions in the number of win-stay or lose-shift trials.

Discussion

We investigated the possible influence of arousal on reversal learning with two hypotheses. We found no evidence for the first hypothesis that high arousal, in the pain-condition, leads to slower reversal learning, compared to less arousal, in the fear-condition. Also, the results provide no evidence for the second hypothesis, that participants in the pain-condition show a higher exploitation rate than exploration compared to participants in the fear-condition. Taken together, the results do not provide evidence for the prediction that different levels of arousal have a different effect on reversal learning in this sample.

The finding that arousal has no effect on reversal learning in our study is in line with the STARS-model (Mather & Lighthall, 2012). The STARS-model suggests that acute stress impairs the valuation of reward, but not of punishment. Several studies support that stress does not affect punishment-driven learning, as summarized in the review of Porcelli and Delgado (2017) as well as a very recent study (Carvalheiro et al., 2021). So, in punishment-driven learning, as in our study, arousal may have no effect on learning.

Murphy et al. (2014) suggested that there is a relationship between arousal and performance in reversal learning, where arousal can be either stimulating or disabling reversal learning. However, our results showed no evidence that arousal impacted learning. This finding suggests carefully that the relationship between arousal and reversal learning is not strong, although our study did not compare high versus low arousal. An important difference which shoud be taken into account between Murphy's and our study is the way of provoking arousal. Murphy et al. induced arousal by the difficulty of a task. In our study the expected consequences and emotional loaded memories were used. This difference suggests that another type of arousal leads to a different effect on reversal learning. Indeed, Hanoch and Vitouch (2004) argue that neither arousal or learning should be seen as one construct in conditioning theories.

That we found no differences between the conditions on performance on the PRLT, might be due to the method we used to induce arousal. In our method, it is dependent on the participants whether they remember the arousing component lively during the complete PRLT. If arousal levels are not maintained during the whole learning task, the expected deleterious effect on reversal learning might fade away, because after the removal of a stressor, such as a stressful memory, reversal learning is rapidly restored (Paret & Bublatzky, 2020). In an open question, some participants reported that they indeed found it difficult to maintain the same anxiety levels during the whole task. However, around 90 percent of the participants did not report these problems. In the beginning, however, the arousal measures showed a difference between the conditions in emotional arousal. There were no differences in performance between the conditions in the first part of the PRLT. This supports our conclusion that no evidence is found in performance between the pain and fear condition in our sample.

As every study, our study has some limitations. We tried to improve ecological validity by using a memory to induce instead of providing a more artificial source of arousal (as an electrical shock). However, this also leads to difficulties with maintaining the same arousal level, as mentioned. Future studies can include a more direct way of maintaining emotional arousal. Also, more or different measures for arousal can be used, since we only used self-report questions, but these are maybe less suitable to show differences in arousal between groups (Semmer et al., 2003). However, self-reports can be used to define the conscious experience of arousal, which is more difficult with for example physiological measures, such as skin conductance. Physiological measures on the other hand can provide more detailed information about the time course and the intensity of the more unconscious bodily reaction (Semmer et al., 2003). A combination of measures is therefore advisable.

To conclude, our study showed no difference between different arousal levels on the balance between exploitative and explorative behaviour in reversal learning. Future research can differentiate between the effects of different types of emotional arousal on reversal learning, where arousal is measured with various methods. Our results suggests that painful or fearful memories are not helpful in reducing maladaptive avoidance behaviour, when used as punishment to avoidant behaviour.

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