**Costly habitual avoidance is reduced by concurrent goal-directed approach
in a modified devaluation paradigm**

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Data availability statement

Data and analysis are available at <https://osf.io/bs8fq/>.

Abstract

Avoidance habits potentially contribute to maintaining maladaptive, costly avoidance behaviors that persist in the absence of threat. However, experimental evidence about costly habitual avoidance is scarce. In two experiments, we tested whether extensively trained avoidance impairs the subsequent goal-directed approach of rewards. Healthy participants were extensively trained to avoid an aversive outcome by performing simple responses to distinct full-screen color stimuli. After the subsequent devaluation of the aversive outcome, participants received monetary rewards for correct responses to neutral object pictures, which were presented on top of the same full-screen colors. These approach responses were either compatible or incompatible with habitual avoidance responses. Notably, the full-screen colors were not relevant to inform approach responses. In Experiment 1, participants were not instructed about post-devaluation stimulus-response-reward contingencies. Accuracy was lower in habit-incompatible than in habit-compatible trials, indicating costly avoidance, whereas reaction times did not differ. In Experiment 2, contingencies were explicitly instructed. Accuracy differences disappeared, but reaction times were slower in habit-incompatible than in habit-compatible trials, indicating low-cost habitual avoidance tendencies. These findings suggest a small but consistent impact of habitual avoidance tendencies on subsequent goal-directed approach. Costly habitual responding could, however, be inhibited when competing goal-directed approach was easily realizable.

Key words: costly avoidance, habit, goal-directed behavior, devaluation paradigm

Introduction

Learning to avoid threatening stimuli and situations is crucial for organisms' survival and well-being as it prevents harm and danger. Goal-directed avoidance enables flexible behavioral adaptations to ever-changing environments. However, persistent, inflexible, and intense avoidance in the absence of threat constitutes a core symptom of anxiety disorders (American Psychiatric Association, 2013) and results in functional impairments and quality of life reductions (e.g., Hendriks et al., 2016; Pittig, Brand, Pawlikowski, & Alpers, 2014). Moreover, inflexible avoidance can impede learning that a formerly threat-predicting stimulus or situation is now safe and may be approached without harm (Lovibond et al., 2009; Pittig, 2019). Inflexible avoidance therefore plays an important role in maintaining anxiety disorders (e.g., Krypotos, Vervliet, & Engelhard, 2018; Pittig, Treanor, LeBeau, & Craske, 2018; Pittig, Wong, Glück, & Boschet, 2020). As avoidance can persist in the absence of threat and even in the absence of fear (i.e., after successful extinction of fear; Vervliet & Indekeu, 2015; Xia, Dymond, Lloyd, & Vervliet, 2017), it has been suggested that avoidance is not exclusively maintained and reinforced by fear reduction (Krypotos, Eftting, Kindt, & Beckers, 2015; Pittig et al., 2020). One potential further explanation for the maintenance of avoidance is that avoidance behavior may acquire habitual features over the course of individual learning histories (Arnaudova, Kindt, Fanselow, & Beckers, 2017; LeDoux & Daw, 2018; LeDoux, Moscarello, Sears, & Campese, 2017; Pittig et al., 2020).

A core characteristic of habitual behavior is its insensitivity to changes in response-outcome contingencies. Specifically, habitual behaviors are assumed to be insensitive to degraded response-outcome contingencies and reversed outcome values (Wood & Rnger, 2016). The insensitivity to outcome changes develops gradually through the extensive repetition of reinforced behavior (e.g., Adams & Dickinson, 1981, but see de Wit et al., 2018). In early learning stages, outcomes strongly modulate instrumental responses towards stimuli (S-R-O behavior). Through extensive repetition, outcomes guide action control less and less, while stimuli preceding the behavior gain more importance (S-R behavior, see Tricomi, Balleine, & O'Doherty, 2009, for a review, see Balleine & O'Doherty, 2010). Habitual responses are adaptive in stable environments because they reduce the amount of cognitive control needed to maximize rewards and to minimize harm (e.g., concerning the encoding and retrieval of outcome values, see Dolan & Dayan, 2013). However, habitual behavior may impede the effective adaption of behavior when outcome values or response-outcome contingencies change. A potential over-reliance on habitual relative to goal-directed action control may thus help explain the persistence of maladaptive behaviors such as persistent maladaptive avoidance (e.g., Wood & Rnger, 2016). The mechanisms involved in the

reduction of maladaptive habits are important topics in habit research (Luque & Molinero, 2020).

Experimental evidence about habitual action control originates mainly from contingency degradation paradigms and outcome devaluation paradigms (Balleine & O'Doherty, 2010; Voon, Reiter, Sebold, & Groman, 2017). In comparison with the wealth of paradigms available for the study of habitual approach, only a few paradigms examined habitual avoidance (see de Wit et al., 2018; Flores, López, Vervliet, & Cobos, 2018; Gillan et al., 2014; Gillan et al., 2015; Zwosta, Ruge, Goschke, & Wolfensteller, 2018). Typical outcome devaluation paradigms measuring habitual avoidance implement Pavlovian fear conditioning, followed by instrumental avoidance acquisition. During Pavlovian fear acquisition, two formerly neutral conditioned stimuli (CSs+) are repeatedly paired with aversive unconditioned stimuli (USs; e.g., electrical stimulation or loud noise). Afterward, two instrumental avoidance responses preventing the aversive USs are extensively trained. Next, one of the USs is devalued by either minimizing its intensity (Flores et al., 2018) or eliminating the possibility of US deliverance (e.g., by removing the electrode delivering the stimulation; see de Wit et al., 2018; Gillan et al., 2014). In the final devaluation test, which is usually carried out in extinction, both extensively trained behavioral options are still available. Importantly, performing the instrumental response to the stimulus which had before predicted the now devalued aversive outcome is now unnecessary. The strength of habitual responding is then analyzed by comparing response rates to the CS that predicts the now devalued outcome with response rates to the CS that still predicts the valuable outcome. Habitual responding is assumed when the rate of responding to the former CS is *not lower* than to the latter CS. Habits are thus inferred from null effects (i.e., no difference between devalued and devalued stimuli, see de Houwer, Tanaka, Moors, & Tibboel, 2018). Of note, devaluation studies often did not find completely outcome-insensitive responding. Stronger habitual responding has been inferred in a group of participants even when a devaluation effect was apparent (i.e., less responding to devalued than to valued stimuli), but was less pronounced than in another group (Gillan et al., 2014, 2015). Alternatively, individual response rate differences between devalued and valued stimuli have been associated with other psychological measures (Flores et al., 2018). These studies, thus, usually did not apply the criterion of complete outcome insensitivity and instead used the relative difference between responding to valued and devalued stimuli as a continuous measure of habit strength.

While devaluation paradigms have been widely adopted, their measurement specificity has been questioned (de Houwer et al., 2018; de Wit et al., 2018). First, the use of null effects to infer habitual behavior may lead to erroneous classifications of behaviors as habitual when, in fact, the behaviors are driven by goals that are not captured by the experimental design (de

Houwer et al., 2018), or by an aberrant goal-directed process (Balleine & Dezfouli, 2019). Second, in habitual avoidance paradigms, avoidance in the devaluation test is commonly operationalized as low-cost avoidance for which the sole cost is the motor action needed to press a button (see de Wit et al., 2018; Flores et al., 2018; Gillan et al., 2014; Gillan et al., 2015; Zwosta et al., 2018). While selective non-responding to devalued CSs may enable participants to obtain some goals (e.g., refraining from redundant responses), it also involves cognitive costs (Pezzulo, Rigoli, & Chersi, 2013; Shenhav et al., 2017). Participants might explicitly decide against investing the cognitive effort needed to adjust responding to changed outcome values, hence displaying a behavioral pattern resembling habitual avoidance. Additionally, selective non-responding introduces some risks in paradigms with real aversive outcomes. For example, participants may conceive the devaluation procedure as potentially ineffective or expect that aversive outcomes might still be administered by the experimenter (e.g., when participants are merely instructed about outcome changes). Such perceived potential risks may be especially problematic for the investigation of habitual avoidance in risk-averse, anxious individuals who may decide to follow a “better safe than sorry” strategy (i.e., sticking to actions that have been safe in the past rather than exploring potentially more rewarding behaviors, see Schulz, Huys, Bach, Speekenbrink, & Krause, 2016). Although resulting from an explicit, goal-directed cognitive strategy, such responding would produce behavioral patterns resembling habitual avoidance (i.e., continuing avoidance after devaluation). In conclusion, when devaluation paradigms involve low-cost avoidance behaviors only, various possible causes may explain rigid post-devaluation responding, habitual behavior being only one of them.

When investigating maladaptive habitual avoidance, critique concerning the validity of low-cost avoidance for researching maladaptive avoidance processes should also be considered (Krypotos et al., 2018; Pittig et al., 2020). One recent study demonstrated that trait anxiety is related to costly avoidance but not to low-cost avoidance (Pittig & Scherbaum, 2020), supporting the notion that specifically costly avoidance, and not avoidance per se, is associated with anxious psychopathology. Accordingly, costly avoidance paradigms have been suggested to increase the external validity of experimental avoidance research approaches (Krypotos et al., 2018). Habitual avoidance can be expected to persist in the absence of threat and even in the presence of concurring rewards due to its property of outcome insensitivity. However, manifest costs of habitual avoidance have not been implemented in the experimental literature so far. Based on the study of Zwosta et al. (2018), which tested the strength of habitual behavior in direct competition with an assigned goal-directed behavior, we aimed to investigate whether avoidance habits impact competing

approach responses, i.e., whether habitual avoidance to an aversive US persists despite competing incentives to not avoid.

To this end, we developed a modified habit-goal competition paradigm in which habitual avoidance is acquired and subsequently competes with the goal-directed approach of rewards, based on the study of Zwosta et al. (2018). This procedure was previously effective in detecting habitual tendencies after extensive training of approach or avoidance. Initially, avoidance of an aversive electrical US was extensively trained for habit acquisition. Next, the aversive US was devalued by removing the electrode delivering the US. In a subsequent habit-goal competition phase, participants were instructed to approach rewards, thereby implementing meaningful goals in the test phase (see Zwosta et al., 2018). Taken together, we aimed to examine a) habitual avoidance without relying on null effects and b) the degree of low-cost and costly habitual avoidance in the presence of rewards. Here, low-cost habitual avoidance was defined as habitual responding that did not result in monetary costs, indicated by either slower reaction times in habit-compatible than in habit-incompatible responses to approach rewards, or by a preference of habitual responding when all stimulus-related responses predicted the same outcome. Costly habitual avoidance was defined as habitual responses resulting in monetary costs, indicated by impaired accuracy in goal-directed, habit-incompatible approach of rewards. We hypothesized that, as a result of extensive avoidance training, habitual avoidance behavior would impair the competing goal-directed approach of rewards in both a costly and a low-cost way.

Experiment 1

Methods

Participants

The experiment was conducted in accordance with the latest update of the Declaration of Helsinki (WHO, 2001) and was approved by the local ethics committee. Participants were recruited via an online recruitment platform run by the Department of Psychology at the University of Würzburg. Exclusion criteria were age under 18 or over 55 years, any current self-reported psychological and/or psychiatric disorder (including substance abuse), cardiovascular or respiratory diseases, medical advice to avoid stressful situations, current psychopharmacological medication, central nervous system medication, and pregnancy. Volunteers participated in return for course credit or 9 € compensation per hour and a monetary bonus dependent on their performance during the task. We estimated a sample size of $N = 55$ for Experiment 1 based on a previous study (Zwosta et al., 2018). Sixty-six participants took part in the experiment. Eleven participants had to be excluded from all

analyses: Five due to technical failures, five due to deviations from the standard operation procedure, and one due to insufficient response accuracy during the first phase of the experiment (46 %), which was considered to preclude habit acquisition. The final sample consisted of 55 participants: 39 females (70.9 %), seven left-handed (12.7 %), and mean age 24.9 years ($SD = 6.9$, range: 18 – 51 years).

Procedure and materials

All experimental sessions were conducted with one single participant at a time. After having provided written informed consent and sociodemographic data, participants completed a standardized calibration procedure to adjust the individual intensity of the aversive unconditioned stimulus (US). Participants were instructed to choose a US level that was “unpleasant, but not painful”, corresponding to a rating of “4” on a rating scale from “0” (*no sensation*) to “5” (*painful sensation*). The US was an electro-tactile stimulation consisting of 125 consecutive stimulations with a duration of 3 ms each and a temporal distance of 2 ms between consecutive stimulations (i.e., total duration 625 ms). The US was delivered using a bar electrode (diameter 8 mm, spacing 30 mm) that was attached to the participant’s non-dominant forearm. USs were generated by a Digitimer DS7R stimulator (Digitimer Ltd). The mean US intensity was 0.7 mA ($SD = 0.4$). After the US calibration procedure, the habit-goal competition task was completed. Participants were seated in front of an HDMI monitor (resolution: 1080x1920 px, diameter: 24 inches) on which all instructions and the experimental paradigm were presented. Centrally in front of the monitor, a customary computer keyboard with two marked buttons (left and right Windows button) was positioned for participants to navigate through instructions as well as to respond during the experiment. The experiment was programmed and delivered, and data were recorded, with Presentation 18.1 (Neurobehavioral Systems, Berkeley, USA).

Habit-goal competition task

The paradigm consisted of two phases: 1) Extensive avoidance training, 2) competition phase (see Figure 1). Between extensive training and competition, the experiment was paused for an outcome devaluation procedure. Exploratorily, we added two further phases (i.e., revaluation and reinstatement phase) after the competition phase. These exploratory phases were not included in the main analysis of habitual responding. Further methodological information and data analyses concerning these exploratory experimental phases can be found in the Supplemental Material.

Extensive avoidance training

The goal of this phase was to extensively train avoidance responses to the aversive US. Avoidance responses consisted of button presses (left or right) in response to one of two different full-screen color stimuli (orange and blue). Both full-screen color stimuli were presented 100 times each. The trial sequence was pseudo-randomized so that each full-screen color stimulus was presented four times in eight consecutive trials. Participants were instructed that the aversive US would occur after each presentation of a full-screen color stimulus but that they could avoid the US by pressing one of the two designated keyboard buttons as fast as possible following the onset of the full-screen color stimulus. Participants were also instructed that they needed to find out by trial-and-error learning which of the two response buttons worked to prevent the US for each of the two color stimuli. Each full-screen color stimulus was presented for a maximum duration of 1000 ms or until a response was performed. Afterward, an outcome was presented depending on the response. Correct responses within 1000 ms were followed by no US, and US omission was highlighted with the presentation of an image of a grey, crossed-out lightning on a white background (1000 ms). Incorrect responses or misses (i.e., no response within 1000 ms) were followed by the US in combination with the presentation of a picture of yellow lightning on a white background (1000 ms). A black fixation cross on a white background was presented for 2000 ms between trials (inter trial interval, ITI). The associations between correct response buttons (left and right) and full-screen color stimuli (orange and blue) did not change within an individual participant and were counterbalanced across participants.

Outcome devaluation

Following the extensive avoidance training, the US outcome was devalued by removing the US electrode from the participant's arm, rendering subsequent US administration impossible. The electrodes were then put away from the participant's table. This removal of the electrode by the examiner was clearly visible for the participants. To ensure that all participants were aware of the devaluation of the aversive US, the removal was emphasized both verbally by the examiner and by on-screen instructions to assure that no participant missed the devaluation procedure (i.e., "I will now remove the electrode").

Habit-goal competition phase

The main question of this phase was whether extensively trained avoidance behavior influenced subsequent goal-directed responses even in the absence of threat (i.e., after devaluation). At the beginning of this phase, participants were instructed that they needed to press the same two buttons as in the previous phase and that they could now gain rewards

that would be converted into real money and paid at the end of the experiment. Participants were paid 1 cent per correct approach response but were unaware of this ratio during the experiment. Participants were instructed to continue responding as fast as possible. Participants were not instructed about the new stimulus-response-outcome contingencies or about the different trial type conditions.

The trial sequence was similar to the trial sequence in extensive avoidance training. Each trial consisted of an ITI (black mid-screen fixation cross on a white background, 2000 ms), followed by the presentation of a compound stimulus consisting of a full-screen color with the addition of one of nine neutral object pictures in the middle of the screen (see Figure 1). Compound stimuli were presented for a maximum duration of 1000 ms or until a response was made and were followed by a response-dependent outcome. Following correct responses, a reward outcome (picture of realistically colored 50 cent coin, duration 1000 ms) was presented. Following incorrect responses and misses, a no-reward outcome (picture of a grey, crossed-out 50 cent coin, duration 1000 ms) was presented. The neutral object pictures were simple, black, symmetric depictions (anchor, ball, car, cow, house, lungs, scissors, snowflake, and tree; all widths: 2.1-2.4 cm, all heights: 2.0-2.5 cm), presented vertically and horizontally centered on top of one of three full-screen colors (orange, blue, and green as novel color). The compound stimuli had two important properties: First, two of the full-screen colors of the compound stimuli were identical to the colors in the preceding extensive avoidance training phase (i.e., orange and blue). Second, the full-screen colors were irrelevant for correct responding, i.e., whether the left or the right button was the correct response was determined by the respective object pictures. Thus, the full-screen colors that had been used in extensive avoidance training may elicit habitual responding, either facilitating (i.e., in habit-compatible trials) or impairing (i.e., in habit-incompatible trials) goal-directed responses to the object pictures. Additionally, a third full-screen color (i.e., green) was used, which had not previously been associated with an avoidance response. Responses to this novel full-screen color were not influenced by prior training (i.e., neutral control trials).

Each full-screen color was paired with three different objects, resulting in nine different compound stimuli in four conditions: 1) habit-compatible trials, 2) habit-incompatible trials, 3) neutral control trials, and 4) free choice trials. For the compound stimuli with colors that were used during extensive avoidance training (i.e., orange and blue), the correct response for *habit-compatible trials* was the same as the previously extensively trained avoidance response. One distinct object stimulus was presented in compound with each previously used full-screen color stimulus to create two habit-compatible compound stimuli. The correct response for *habit-incompatible trials* was not the same as the previously extensively trained avoidance response, i.e., the other button was correct. Again, one distinct object stimulus was

presented in compound with each previously used full-screen color stimulus to create two habit-incompatible compound stimuli. In *neutral control trials*, a novel full-screen color (green) was used. Thus, stimulus-response-outcome associations needed to be learned in the absence of competing previously extensively trained responses. The neutral control condition was added to exploratorily create a reference category for individual learning without prior extensive training. In one neutral control compound stimulus, pressing the left button led to the reward, and in the other neutral control compound stimulus, pressing the right button led to the reward. Neutral control trials were included in the experiment to explore whether extensive training impaired or facilitated subsequent responding as compared with responding without previous training and were used for explorative analyses only. In *free choice trials*, pressing any of the two buttons within the time window of 1000 ms led to the reward outcome. One compound stimulus was implemented for each of the three full-screen background colors. Summarized, the nine different compound stimuli included: two habit-compatible (one for each previously used full-screen color), two habit-incompatible (one for each previously used full-screen color), two neutral control (left and right as correct response for the novel full-screen color), and three free choice stimuli (one for each full-screen color). The trial sequence was pseudo-randomized so that each compound stimulus was presented twice in 18 consecutive trials. The competition phase consisted of 270 trials in total.

Costly habitual avoidance was operationalized as accuracy difference between compatible and incompatible trials (i.e., accuracy compatibility effect), which indicates a failure to inhibit habitual avoidance even when habitual responding produces costs in incompatible trials. Low-cost avoidance habits (i.e., habitual responding without monetary costs) were operationalized as a) reaction time differences between compatible and incompatible trials (i.e., reaction time compatibility effect) and b) extensively trained responses in free trials with the colors that had been presented in the extensive training phase (i.e., orange and blue).

Figure 1*Experimental phases and stimuli*

Note. The mapping of colors to correct responses in the extensive training phase and the matching of object symbol stimuli and full-screen colors in the competition phase were counterbalanced across participants. l = left-side button, r = right-side button.

After the experiment, participants rated the perceived unpleasantness of the US ($M = 62.56$, $SD = 21.25$) as well as their motivation to avoid the US ($M = 83.65$, $SD = 17.67$) and their motivation to approach the rewards ($M = 84.84$, $SD = 18.78$) (all Visual Analogue Scales from 0 to 100), and were debriefed.

Statistical analyses

Accuracy data were recorded trial-wise as either correct response, incorrect response, or miss. The mean percentage of correct responses was then calculated block-wise in each condition. Reaction times were recorded on every trial as the interval between stimulus onset and button press. Only reaction time data from correct responses were analyzed. Reaction times lower than 100 ms were excluded from the data analysis. Average reaction times were calculated block-wise for each condition.

Main analyses. In the overtraining phase, accuracy and reaction time data were analyzed in five blocks with 40 consecutive trials each, using repeated measures ANOVAs

with the factor Block (block 1, block 2, block 3, block 4, block 5), and subsequent t tests for dependent samples.

Data in the competition phase were analyzed in three blocks with 90 consecutive trials each. We hypothesized a priori that 1) accuracy in habit-compatible trials would be higher than accuracy in habit-incompatible trials, 2) reaction times in habit-compatible trials would be lower than in habit-incompatible trials, and 3) habit-compatible responses in free trials would be more frequent than chance. The hypotheses were generated and the sample size was based on an earlier devaluation study (Zwosta et al., 2018), and were tested one-sided with an α -level of .05. We tested the first two hypotheses including potential changes of the effects over time with repeated measures ANOVAs with factor Trial Type (compatible and incompatible) and Factor Block (block 1, block 2, block 3). The third hypothesis was tested with a Wilcoxon test and change of the strength of the effect over time was tested with a repeated measures ANOVA with factor Block (block 1, block 2, block 3). Data were checked for the assumption of normality with Shapiro-Wilk tests. When non-normality was assumed, nonparametric tests were conducted. We report matched rank biserial correlations r_{bs} as effect sizes for the Wilcoxon test, η^2 for ANOVAs, and Cohen's d for t tests. Data were tested for sphericity with Mauchly's tests. When sphericity could not be assumed, we report Greenhouse-Geisser corrected degrees of freedom. When multiple comparisons were performed, we report Bonferroni-Holm corrected p values. Data were aggregated with IBM SPSS Statistics 24 and analyzed with JASP 0.13.1.0.

Exploratory analyses. We added three exploratory analyses for effects for which we could not formulate a priori assumptions. First, as participants' preferred handedness may impact responding in free trials (see Zwosta et al., 2018), we compared the proportion of preferred hand usage in habitual vs. non-habitual responses in free trials with a Wilcoxon test. Second, to investigate whether extensive avoidance facilitated or impaired subsequent goal-directed responding relative to goal-directed responding without extensive training, we compared accuracy and reaction times in learning control trials with compatible and incompatible trials, using ANOVAs and t tests. A facilitation effect through extensive training would be indicated by higher accuracy or faster response times in habit-compatible than in neutral control trials, while an impairment effect would be indicated by lower accuracy or higher response times in habit-incompatible as compared with neutral control trials. We calculated t tests to compare overall accuracy and response times in neutral control trials with habit-compatible trials and habit-incompatible trials. Third, we exploratorily examined associations between low-cost and costly habitual avoidance. We therefore calculated Pearson's correlations between the accuracy difference scores (i.e., accuracy difference between habit-compatible and habit-incompatible trials, in %; indicating costly habitual

avoidance) and the two indicators of low-cost habitual avoidance (i.e., a) reaction time difference scores as the difference in reaction time between habit-compatible and habit-incompatible trials, in ms) and b) the proportion of habit-compatible responses in free trials, in %).

Results

Extensive avoidance training

Accuracy

The mean accuracy in the extensive avoidance training phase was high, $M = 96.34\%$ ($SD = 3.01$), with individual accuracies ranging from 88% to 100%. The average accuracy rate differed significantly between the five blocks, $F(1.359, 73.402) = 47.895$, $p < .001$, $\eta^2 = .470$. Pairwise comparisons revealed a lower average accuracy rate in the first block ($M = 88.77\%$, $SD = 10.15$) than in all other blocks, $p_{\text{holm}} < .001$, $ds \geq 0.957$, but no differences between the second ($M = 97.82\%$, $SD = 3.05$), third ($M = 98.14\%$, $SD = 2.32$), fourth ($M = 98.27\%$, $SD = 2.40$) and fifth block ($M = 98.68\%$, $SD = 2.14$), all $p_{\text{holm}} \geq .272$, $ds \leq 0.276$. In sum, accuracy increased early during avoidance overtraining and then remained at a consistently high level (see Figure 2A).

Reaction times

The average overall reaction time during extensive avoidance training was very fast, $M = 418.01$ ms ($SD = 49.15$), with a range from 297.35 ms to 516.69 ms. The average reaction times differed significantly between blocks, $F(2.176, 117.512) = 12.754$, $p < .001$, $\eta^2 = 0.191$. Pairwise comparisons between blocks showed that the average reaction times in the first ($M = 401.67$ ms, $SD = 67.66$) and second block ($M = 404.76$ ms, $SD = 47.99$) were lower than in the third ($M = 420.11$ ms, $SD = 50.09$), fourth ($M = 427.81$ ms, $SD = 55.30$) and fifth block ($M = 435.59$ ms, $SD = 57.30$), $p_{\text{holm}} \leq .042$, $ds \geq 0.358$. Also, the average reaction time was faster in the third than in the fifth block, $t = 3.299$, $p_{\text{holm}} = .010$, $d = 0.445$. Reaction times did not differ between the first and second, third and fourth, and fourth and fifth block, $p_{\text{holm}} \geq .131$, $ds \leq 0.358$. These findings indicate that reaction times slowed down over the course of the extensive avoidance training (see Figure 2B), presumably because participants noticed that slightly slower responses were still effective to avoid the US.

Figure 2

Mean accuracy rates (A) and mean reaction times (B) during extensive avoidance training

Note. Black dots depict average values. Error bars depict standard errors. Points in color depict individual data points.

Habit-goal competition

Accuracy

The ANOVA with the factors Block (block 1, block 2, and block 3) and Trial Type (habit-compatible and habit-incompatible) yielded a significant interaction between Trial Type and Block, $F(1.479, 91.529) = 8.094$, $p = .002$, $\eta^2 = .016$ (see Figure 3A). Post-hoc tests revealed a larger compatibility effect in the first block than in the second ($t(54) = 3.029$, $p_{holm} = .009$, $d = 0.408$) and third block ($t(54) = 3.085$, $p_{holm} = .009$, $d = 0.416$), but no difference between the second and the third block, $t(54) = 3.296$, $p_{holm} = .647$, $d = 0.062$. Thus, costly avoidance as indexed by the accuracy compatibility effect decreased after the first block and remained at a constant level afterward. Follow-up one sample t tests revealed higher average accuracy rates in habit-compatible trials than in habit-incompatible trials within each block, all $p_{holm} \leq .022$, all $ds \geq 0.400$ (one-sided testing), indicating that costly habitual responding prevailed until the end of the competition phase.

In free trials with color stimuli which had been presented in the extensive avoidance training (i.e., orange and blue), the previously reinforced response was performed in 55.70% ($SD = 29.44$), which missed to differ significantly from chance, $W = 803.500$, $p = .055$, $r_{bs} = .123$ (one-sided testing). The proportion of low-cost habitual responding in free trials did not significantly differ between blocks, $F(1.510, 81.559) = 0.369$, $p = .633$, $\eta^2 = .007$.

Therefore, a low-cost avoidance habit as operationalized by responding in free trials cannot be confirmed, although there was a trend towards significance.

Habitual responses in free trials were carried out predominantly with individuals' preferred hands. Of all habitual responses in free trials, $M = 61.12\%$ were carried out with the preferred hand ($SD = 32.03$), and $M = 38.88\%$ were carried out with the non-preferred hand ($SD = 32.03$). This difference was significant, $W = 402.500$, $p = .024$, $r_{bs} = .369$. The percentage of preferred handedness responses did not differ between free trials in which preferred handedness converged with extensively trained response choices (e.g., for right-handed participants in trials where the right-side button had been extensively trained, $M = 61.82\%$, $SD = 38.51$) and free trials in which preferred handedness diverged from extensively trained response choices (e.g., for right-handed participants in trials where the left-side button had been extensively trained, $M = 49.27\%$, $SD = 42.19$), $W = 819.500$, $p = .080$, $r_{bs} = .285$. In neutral free choice trials (i.e., green color), participants tended to press the button corresponding to their preferred hand more often than chance ($M = 57.79\%$, $SD = 40.36$), $W = 1004.00$, $p = .050$, $r_{bs} = .457$.

Accuracy in habit-compatible trials was higher than in neutral control trials ($M = 80.70\%$, $SD = 13.27$), $t(54) = 3.724$, $p_{holm} = .002$, $d = 0.502$. Accuracy did not differ between habit-incompatible trials and neutral control trials, $W = 417.500$, $p_{holm} = .081$, $r_{bs} = .290$. These results may indicate that, relative to novel learning, habit-compatible responding was facilitated through extensive training, while habit-incompatible responses were not impaired.

Reaction times

Reaction time did not differ between habit-compatible ($M = 581.93$ ms, $SD = 61.95$) and habit-incompatible trials ($M = 588.98$ ms, $SD = 66.54$), as indicated by a non-significant effect of Trial Type (see Figure 3B), $F(1, 52) = 3.746$, $p = .058$, $\eta^2 = .010$, in an ANOVA with factors Block (block 1, block 2, block 3) and Trial Type (compatible and incompatible). There was no significant interaction between Block and Trial Type, $F(1.762, 71.172) = 2.202$, $p = .123$, $\eta^2 = .006$, indicating that the strength of the reaction time compatibility effect did not vary over time (see Figure 3B). These findings indicate no low-cost avoidance habit as operationalized by reaction time differences.

Reaction time in neutral control trials ($M = 577.19$ ms, $SD = 55.98$) did not differ from habit-compatible trials, $t(54) = 0.895$, $p_{holm} = .375$, $d = 0.121$, or habit-incompatible trials, $t(54) = 2.277$, $p_{holm} = .054$, $d = 0.344$.

Associations between costly and low-cost avoidance measures were exploratorily tested with Pearson's correlations. Costly habitual avoidance correlated positively with both indicators

of low-cost habitual avoidance, i.e., with the proportion of habitual responding in free trials, $r(55) = .628$, $p_{\text{holm}} = .002$, and with the reaction time difference between incompatible and compatible trials, $r(55) = .633$, $p_{\text{holm}} = .002$, suggesting that low-cost and costly habitual avoidance measures are associated.

Figure 3

Data distribution and means for accuracy (A) and reaction times (B) during the competition phase

Note. Black dots depict average values. Error bars depict standard errors. Points in color depict individual data points. * $p < .05$, ** $p < .001$.

Discussion of experiment 1

We used a modified outcome devaluation paradigm to capture costly and low-cost avoidance habits. To this end, behavior was tested in the presence of positive rewards that

could be obtained by habitual (habit-compatible trials) or non-habitual responses (habit-incompatible trials). Goal-directed approach responses were more often correct in habit-compatible trials than in habit-incompatible trials in all three competition phase blocks. Our results, therefore, indicate that extensively trained instrumental avoidance altered subsequent goal-directed approach and created monetary costs. The extensive training effect was strongest in the first block after devaluation, which may hint at stronger avoidance habits directly following extensive avoidance training, but may also be a by-product of the reliance on exploitation during initial stages of trial and error learning, which was strongest at the beginning of the competition phase and declined after S-R-O contingencies were encountered and learned. As participants needed to explore new S-R-O contingencies in the first trials after the devaluation through trial and error learning, the measurement of habitual behavior may be confounded with the exploitation of previously learned associations between stimuli and avoidance responses. Such exploitation can be expected to be most pronounced at the beginning of the competition phase, and should decline after the new S-R-O contingencies are encountered and learned. In other words, higher accuracy in habit-compatible relative to habit-incompatible trials at the beginning of the competition phase may reflect the use of the explicit strategy to exploit the previously beneficial (i.e., preventing the aversive US) habit-compatible responses. Such exploitation of the pre-devaluation contingencies may be an advantageous strategy, as participants had no available information guiding their response choices in the first post-devaluation trials. Importantly, however, the accuracy compatibility effect was observed throughout the entire competition phase, including its last block. The high overall response accuracy in the third block of the competition phase (i.e., 91% in incompatible and neutral control trials vs. 95% in compatible trials) indicates that S-R-O contingencies were successfully acquired, while, simultaneously, an influence of the extensive avoidance training persisted. Arguably, therefore, the accuracy differences in the competition phase did not result solely from trial-and-error learning, but reflect habitual responding. The habit effect in the third block after devaluation may therefore indicate that avoidance habits prevailed. However, only the exclusion of strategic exploration at the beginning of the competition phase would justify to confidently infer an impact of habitual avoidance. To this end, we conducted a second experiment in which contingencies in the habit-goal competition phase were explicitly instructed.

Experiment 2

To disentangle potential habitual responding from strategy-driven responding, such as the deliberate exploitation of previously advantageous contingencies, we used a similar design as in Experiment 1. However, we added post-devaluation instructions about stimulus-response-outcome contingencies in the subsequent habit-goal competition phase.

Methods

Participants

Eighty participants took part in the experiment in exchange for 9€ and additional monetary rewards obtained during the experiment. The recruitment process and the exclusion criteria were the same as in Experiment 1. Participants who had taken part in Experiment 1 were not eligible for participation in Experiment 2 and vice versa. The estimation of the expected effect size was based on the accuracy compatibility effect size of $d = 0.502$ in Experiment 1 and on the assumption that the compatibility effect in Experiment 2 may be smaller due to the lower task difficulty. We, therefore, estimated the sample size based on an expected effect size of $d = 0.3$ for the main compatibility effect (i.e., mean accuracy difference between compatible and non-compatible trials), one-sided hypotheses testing and a statistical power of .80, resulting in an estimated sample size of $N = 71$. From the 80 participants tested in the laboratory, seven participants were excluded from the statistical analysis: one due to technical failure, five due to deviations from the standard operation procedure, and one due to self-reported frequent substance use. The final sample consisted of 73 participants: 55 female (75.3%), 66 right-handed (90.4%), mean age of 24.7 years ($SD = 6.1$, range: 18-53 years).

Procedure, materials, task, and data analysis

The procedure, design, and materials were the same as in Experiment 1. The paradigm consisted of the same phases as in Experiment 1, except that we explicitly instructed stimulus-response-outcome contingencies after outcome devaluation to preclude exploratory trial-and-error learning during the competition phase. Participants were instructed on-screen that they would see symbolic depictions of objects which belonged into three categories. For each category, one correct button press response was assigned. During the presentation of objects in the first category, right-side button presses produced the reward. During the presentation of objects in the second category, left-side button presses produced the reward. During the presentation of objects in the third category, pressing any of the two buttons produced the reward; participants were asked to spontaneously decide which button they pressed in these trials. The assignment between categories and buttons (left/right/both) was counterbalanced across individuals. All object pictures were presented in the instruction on-screen to eliminate ambiguity about their assignment to the categories. To be able to classify the pictures into meaningful categories, we used different object stimuli than in Experiment 1. Object stimuli were nine symbolic, symmetrical, black depictions of neutral objects (category “furniture”: bed, chair, cupboard; category “transport”: airplane, car, train; category “tools”: drill, pliers, wrench; all heights: 0.8 cm – 2.5 cm, all widths: 1.5 cm – 2.3 cm). After the experiment, we assessed the perceived general unpleasantness of the US ($M = 69.86$, $SD = 13.82$), the

motivation to avoid the US ($M = 86.44$, $SD = 12.57$), and the motivation to approach the reward ($M = 79.89$, $SD = 20.78$) as in Experiment 1. Average US intensity was 0.78 mA ($SD = 0.57$). Data were aggregated and analyzed in the same manner as in Experiment 1.

Results

Extensive avoidance training

Accuracy

As expected, average accuracy during extensive avoidance training was high, $M = 96.33\%$ ($SD = 3.87$, range 73% to 100%). Average accuracy rates differed significantly between the five blocks, $F(1.770, 127.416) = 45.51$, $p < .001$, $\eta^2 = .387$. Pairwise comparisons revealed that accuracy in the first block ($M = 90.16\%$, $SD = 9.23$) was lower than in all other blocks, $p_{\text{holm}} < .001$, $ds \geq 1.198$. However, accuracy did not differ between the second ($M = 97.57\%$, $SD = 3.89$), third ($M = 97.71\%$, $SD = 4.82$), fourth ($M = 97.77\%$, $SD = 4.85$) and fifth block ($M = 98.36\%$, $SD = 2.09$), all $p_{\text{holm}} \geq .999$, all $ds \leq 0.127$. These findings indicate that accuracy rates increased early during extensive avoidance training and then remained at a consistently high level (see Figure 4A).

Reaction times

The mean overall reaction time in extensive avoidance training was 392.73 ms ($SD = 52.99$, range 286.71 ms to 518.31 ms). The average reaction time differed between blocks, $F(2.415, 173.914) = 19.63$, $p < .001$, $\eta^2 = .214$. Pairwise comparisons revealed that the average reaction time in the first block ($M = 368.58$ ms, $SD = 57.19$) was shorter than in all other blocks, $p_{\text{holm}} \leq .006$, $ds \geq 0.376$. Additionally, the average reaction time in the second block ($M = 384.77$ ms, $SD = 58.91$) was shorter than in the third, fourth, and fifth block, all $p_{\text{holm}} \leq .006$, all $ds \geq 0.382$. Reaction times did not differ between the third ($M = 401.24$ ms, $SD = 62.75$), fourth ($M = 403.48$ ms, $SD = 58.48$) and fifth ($M = 405.55$ ms, $SD = 60.48$) block, $p_{\text{holm}} \geq .999$, $ds \leq 0.382$. These differences indicate faster responses in the first 80 trials than in the last 120 trials. Similarly to Experiment 1, responses decelerated during the course of the avoidance overlearning phase (see figure 4B), potentially as participants noticed that slightly slower responses were still effective to avoid the US.

Figure 4

Data distribution and average accuracy rates (A) and reaction times (B) during extensive avoidance training

Note: Black dots depict average values. Error bars depict standard errors. Points in color depict individual data points. Error bars depict standard errors.

Habit-goal competition

Accuracy

The ANOVA with factor Block (block 1, block 2, and block 3) and factor Trial Type (habit-compatible and habit-incompatible) yielded no significant main effect of Trial Type, $F(1, 72) = 0.192$, $p = .663$, $\eta^2 < .001$, and no interaction between Block and Trial Type, $F(1.844, 132.770) = 0.157$, $p = .855$, $\eta^2 < .001$. Thus, accuracy in habit-compatible trials ($M = 96.83\%$, $SD = 3.48$) did not differ from habit-incompatible trials ($M = 96.60\%$, $SD = 3.46$), indicating no costly avoidance habit (see Figure 5A). Given the high accuracy rates, contingency instructions seemed to produce a ceiling effect.

In free trials with full-screen color stimuli which had been presented in extensive avoidance training (i.e., orange and blue), habitual responses were significantly more frequent than chance (51.69%, $SD = 8.68$), $W = 884.000$, $p = .019$, $r_{bs} = .345$ (one-sided testing). The proportion of this low-cost habitual responding did not change over the course of the competition phase, $F(2, 144) = 0.660$, $p = .518$, $\eta^2 = .009$. These findings indicate stable low-cost habitual avoidance in free trials.

Accuracy in neutral control trials ($M = 95.89\%$, $SD = 5.28$) did not differ from habit-compatible trials, $W = 963.500$, $p_{holm} = .352$, $d = 0.207$, or from habit-incompatible trials, $W = 1084.000$, $p_{holm} = .212$, $d = 0.185$.

Looking closer at the habitual responses in free trials, we found that habitual responses were carried out mostly with individuals' preferred hands. Of all habitual responses in free trials, $M = 71.60\%$ ($SD = 32.73$) were performed with the preferred hand, while $M = 28.40\%$ ($SD = 32.73$) were performed with the non-preferred hand. This difference was significant, $W = 2174.500$, $p < .001$, $r_{bs} = .610$. The proportion of responding with the preferred hand did not differ between free trials in which preferred handedness and extensively trained responding converged ($M = 72.24\%$, $SD = 32.09$) and trials where preferred handedness and extensively trained responding diverged ($M = 68.86\%$, $SD = 33.74$), $W = 861.100$, $p = .063$, $r_{bs} = .299$. In neutral free choice trials with the green color, participants used their preferred hand in 71.14% ($SD = 33.68$), which was above chance level, $W = 2073.00$, $p_{holm} = .003$, $r_{bs} = .767$.

Reaction times

Responding in habit-compatible trials ($M = 513.99$ ms, $SD = 47.63$) was significantly faster than responding in habit-incompatible trials ($M = 519.85$ ms, $SD = 49.32$), as indicated by a significant effect of Trial Type, $F(1,72) = 4.473$, $p = .038$, $\eta^2 = .012$ (see Figure 5B). There was no significant interaction between Block and Trial Type, $F(2, 144) = 1.244$, $p = .291$, $\eta^2 = .003$, indicating that the strength of the reaction time compatibility effect did not vary over time.

Response time did not differ between neutral control trials ($M = 515.41$ ms, $SD = 44.93$) and habit-compatible trials, $t(72) = 0.605$, $p_{holm} = .547$, $d = 0.071$, or between neutral control trials and habit-incompatible trials, $W = 1593.000$, $p_{holm} = .366$, $r_{bs} = .180$.

Costly habitual avoidance (i.e., accuracy differences between habit-compatible and habit-incompatible trials) correlated positively with low-cost habitual avoidance (i.e., reaction time differences between habit-incompatible and habit-compatible trials), $r(73) = .424$, $p_{holm} = .002$, indicating that low-cost and costly avoidance habits were associated. The low-cost habit effect in free trials did not correlate with the reaction time compatibility effect, $r(73) = .205$, $p_{holm} = .081$.

Figure 5

Data distribution and means for accuracy (A) and reaction times (B) during the competition phase

Note: Black dots depict average values. Error bars depict standard errors. Points in color depict individual data points. * $p < .05$.

Discussion of experiment 2

Explicit instructions about stimulus-response-outcome contingencies after extensive avoidance training and outcome devaluation produced compatibility effects that differed from those in Experiment 1. In contrast to Experiment 1, we did not observe any impact of the extensive training on the accuracy rates in habit-compatible versus habit-incompatible trials. However, habit-incompatible responses were modestly slower than habit-compatible responses, indicating reaction time costs due to extensive avoidance training. Interestingly, an additional low-cost avoidance habit effect in free choice trials emerged. These findings again suggest an impact of avoidance habits on the subsequent goal-directed approach of rewards.

General discussion

Habitual responding is assumed to play a pivotal role in maintaining maladaptive avoidance behavior, but the evidence for this assumption is scarce. Using a modified devaluation paradigm, the present study tested the strength of costly and low-cost avoidance habits following extensive training of avoidance responses. Costly habits were defined when extensively trained avoidance influenced goal-directed approach at the cost of monetary reward (i.e., response accuracy in habit-compatible vs. habit-incompatible trials). Low-cost habits were defined as extensively trained avoidance influencing goal-directed approach without inflicting costs (i.e., reaction time compatibility effect and habitual response preference in free trials). The main results indicate that extensively trained avoidance affected subsequent goal-directed approach differentially in the two experiments. Evidence for costly, but not low-cost avoidance was found in Experiment 1, whereas evidence for low-cost habitual avoidance tendencies but not costly habitual avoidance was found in Experiment 2. As both experiments differed only in the instructions about and complexity of the stimulus-response-reward contingencies during the competition phase, the differential effects cannot be explained by differences in avoidance training. The strength of inflexible avoidance was thus modulated by the complexity and ambiguity of the competing goal-directed approach behavior.

Our findings demonstrate that extensive avoidance training resulted in low-cost habitual avoidance under specific circumstances. First, low-cost habitual tendencies as indicated by a reaction time compatibility effect emerged in Experiment 2, but not in Experiment 1. This reaction time delay in habit-incompatible trials is in line with data from earlier devaluation studies (Luque, Molinero, Watson, López, & Le Pelley, 2019; Zwosta et al., 2018), corroborating the notion that reaction time compatibility effects can be used as an indicator for competing habitual and goal-directed action control when habitual control is not strong enough to generate accuracy habit effects (see Luque et al. 2019). However, it should be noted that the reaction time compatibility effect in Experiment 2 was relatively small. As a separate indicator for low-cost avoidance habits, we used the percentage of habit-compatible responses, which was significantly higher than chance in free trials in Experiment 2. This result is in line with previous devaluation studies on low-cost avoidance habits (e.g., Flores et al., 2018; Gillan et al., 2014; Gillan et al., 2015; Zwosta et al., 2018, but see de Wit et al., 2018). Low-cost habitual avoidance can be assumed to adaptively guide actions when stimulus-response-outcome contingencies are stable, i.e., when extensively trained stimulus-response associations still lead to a favorable outcome and do not create costs. In such stable environments, the exploitation of previously trained responses (i.e., habitual responding) reduces the cognitive costs of action control and therefore may be beneficial (Kane & Engle, 2003).

Importantly, evidence for costly avoidance habits was found under specific circumstances. In Experiment 1, extensive training resulted in costly avoidance (i.e., lower accuracy in habit-incompatible than habit-compatible trials). The accuracy compatibility effect in the last block of Experiment 1 suggests that this costly avoidance was not the sole product of trial-and-error learning and goal-directed exploitation of previously beneficial stimulus-response-outcome contingencies, but had habitual characteristics. In Experiment 2, however, no costly habitual avoidance was found (i.e., accuracy rates did not differ). Thus, although our study suggests that extensively trained avoidance responses may impair subsequent goal-directed approach, this effect seems to depend on the characteristics of the competing goal-directed behavior.

Indeed, goal-directed responding's complexity differed between the two experiments, and these differences may help explain the diverging effects. In Experiment 1, participants had to explore and learn stimulus-response-outcome contingencies for nine stimuli through trial and error. In contrast, in Experiment 2, the contingencies between only three object categories and the corresponding correct responses needed to be learned and were explicitly instructed. This resulted in more frequent and faster correct responses during the competition phase in Experiment 2 as compared with Experiment 1 (e.g., accuracies in habit-incompatible trials > 95% vs. < 85%, average reaction time in habit-incompatible trials 518 ms vs. 589 ms). These differences in complexity of the stimulus-response-outcome associations guiding the goal-directed behavior may have affected the expression of habitual avoidance.

Goal-directed control more effectively inhibits habitual behavior when this inhibition requires low effort (see Otto, Gershman, Markman, & Daw, 2013). When stimulus-response-outcome contingencies are complex rather than simple, goal-directed responding can be expected to require more cognitive resources for monitoring behaviorally relevant stimuli and their associations with outcomes and advantageous responses. Goal-directed control may, then, less effectively inhibit competing, disadvantageous, habitual responses elicited by environmental stimuli. Our results show that costly avoidance (i.e., less accuracy in compatible versus incompatible trials) was apparent in the difficult task version (i.e., in Experiment 1), but not in the easy task version (i.e., in Experiment 2). Potentially, costly avoidance may be more pronounced when goal-directed control requires more cognitive control, such as under more complex environmental contingencies, or when subjective uncertainty about stimulus-response-outcome contingencies is high, for example, early in trial-and-error learning.

The findings indicate a mixture of costly and low-cost habitual responding after extensive training. Although any costly effect of extensive training on subsequent goal-directed responding was eliminated in Experiment 2, low-cost habitual tendencies were found. This

indicates that habitual responding was acquired to some extent but could be inhibited when interfering with goal-directed control (see also Hardwick, Forrence, Krakauer, & Haith, 2019; Luque et al., 2019). Of note, costly and non-costly avoidance measures positively correlated in both experiments, potentially suggesting a general individual propensity to respond habitually after extensive training. In summary, a costly impact of habitual avoidance on subsequent approach seems more likely when stimulus-response-outcome contingencies guiding goal-directed behavior are complex or ambiguous. In consequence, costly habitual avoidance may be reduced by competing rewards when the goal-directed approach responses to obtain these rewards are simple and clearly instructed.

Different mechanisms may cause habitual responding in this devaluation paradigm. Theoretically, extensive training can facilitate habit-compatible responding, impede habit-incompatible responding, or facilitate habit-compatible responding and impede habit-incompatible responding simultaneously. We observed higher accuracy in habit-compatible compared with neutral control trials in Experiment 1, potentially suggesting a facilitating effect of extensive training, which is not in line with previous findings (Zwosta et al., 2018). No further differences in comparison with neutral control trials were found, rendering it difficult to draw conclusions about potential mechanisms underlying reaction time and accuracy compatibility effects. Further studies may shed light on these mechanisms, for example, by trying to boost differences between conditions by adding time pressure (see Luque et al., 2019) or by using more complex instructed S-R-O contingencies.

Low-cost avoidance in free trials was predominantly carried out with participants' preferred hands. When the preferred handedness effect superimposed on habitual tendencies acquired through extensive training, the combination of these two habitual tendencies may thus have led to elevated habitual responding. Responding with the preferred hand itself may include a habitual component that interacts with other habitual response tendencies. For example, habits are amplified when carried out with individuals' dominant hand, whereas behaviors performed with the non-dominant hand tend to be less influenced by habitual tendencies (Neal, Wood, Wu, & Kurlander, 2011). A dominance of responding with the dominant hand in free trials has accordingly been found in one earlier study (Zwosta et al., 2018). Future devaluation studies may include more systematic examinations of the impact of preferred handedness on habitual responding.

Devaluation paradigms are commonly implemented standard procedures to evaluate habit strength. Devaluation procedure implementations vary widely in the literature and include the satiation with favorable outcomes (e.g., Schwabe & Wolf, 2010), the mere instruction of stimulus-response-outcome contingency changes (e.g., Luque et al., 2017; Luque et al., 2019;

Zwosta et al., 2018), and the removal of electrodes used to deliver electrical stimulations (e.g., Gillan et al., 2014; Gillan et al., 2015). The removal of the electrodes for electrical stimulations has been shown to reliably decrease participants' avoidance motivation (see Gillan et al., 2015). In our experiments, we did not measure the self-reported effect of the removal of the electrodes on participants' subsequent avoidance motivation. As the electrodes were completely removed, and the removal was emphasized prior to the competition phase verbally and on-screen, however, any remaining expectation of shock during the competition phase is very unlikely. Future studies may, however, control for the change of threat expectancy or avoidance motivation after the devaluation.

The reduction of costly habitual avoidance behavior through a clearly instructed approach of rewards introduces some potential clinical implications. Previous research demonstrated that goal-directed avoidance can be reduced by reinforcing avoidance-incompatible approach behavior (Pittig, 2019). Our findings suggest that competing rewards can similarly reduce costly habitual avoidance. As habit-incompatible rewards reduced costly avoidance only when the contingencies for obtaining these rewards were clear (i.e., in Experiment 2), potentially, simple and transparent approach goals and reward contingencies facilitate the reduction of avoidance habits. For example, patients and therapists may identify such simple responses for obtaining motivating rewards, which are incompatible with avoidance habits, in the context of exposure-based therapies. In general, early interventions to support goal-directed approach may be especially effective since goal-directed action control can be expected to be stronger in early learning stages. Such early interventions may be feasible for some patients seeking treatment in the first year after disorder onset (Christiana et al., 2000; Kessler, Olsson, & Berglund, 1998). However, studies with clinically relevant samples are needed to investigate further the role of costly habitual avoidance in anxiety disorders to provide evidence-based recommendations. The robustness of the effectiveness of rewards in reducing costly habitual avoidance in different tasks and environments needs to be confirmed in further studies.

In conclusion, our experimental findings indicate that in partly habitual avoidance, some degree of goal-directedness remained and could overrule habitual tendencies to obtain concurrent rewards. Thus, the potential for adaptive behavior change remained in partly habitual avoidance. Implementing rewards for habit-incompatible responses may therefore be applicable to counteract costly habitual, maladaptive avoidance.

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