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The Role of Goal-Directed and Habitual Processes in Food Consumption Under Stress After Outcome Devaluation With Taste Aversion

Eike K. Buabang[1, 2], Yannick Boddez[3, 4], Oliver T. Wolf[5], and Agnes Moors[1, 2]

[1] Research Group of Quantitative Psychology and Individual Differences, KU Leuven

[2] Center for Social and Cultural Psychology, KU Leuven

[3] Department of Experimental Clinical and Health Psychology, Ghent University

[4] Center for the Psychology of Learning and Experimental Psychopathology, KU Leuven

[5] Department of Cognitive Psychology, Institute of Cognitive Neuroscience, Faculty of Psychology, Ruhr-University Bochum

People are more likely to engage in various suboptimal behaviors such as overeating, addictive behaviors, and short-sighted financial decision-making when they are under stress. Traditional dual-process models propose that stress can impair the ability to engage in goal-directed behavior so that people have to rely on habitual behavior. Support for this idea comes from a study by Schwabe and Wolf (2010), in which stressed participants continued to perform a learned instrumental behavior leading to a liquid after the liquid was devalued with a satiation procedure. Based on these findings, suboptimal behavior under stress is often seen as habitual. In the present study, we conducted a conceptual replication of the study by Schwabe and Wolf (2010). Instead of using a satiation procedure to achieve the outcome devaluation, we devalued outcomes through taste aversion. We did not replicate the pattern of findings by Schwabe and Wolf (2010). Our results indicate instead that stressed participants were sensitive to outcome values when the outcomes became truly aversive and hence that their behavior was goal-directed. This suggests either that (a) habitual processes are subject to boundary conditions or (b) the processes responsible for the findings of Schwabe and Wolf (2010) were never habitual to begin with. This may have far-reaching implications for explaining suboptimal behavior under stress in general.

Keywords: goal-directed, habit, stress, outcome devaluation, taste aversion

Stress is associated with various suboptimal behaviors such as overeating, addictive behaviors, and short-sighted financial decision-making (Dallman, 2010; Haushofer & Fehr, 2014; Sinha & Jastreboff, 2013). These behaviors have adverse consequences at the individual level and also present challenges for society at large. In order to effectively change these behaviors, it is crucial to understand the underlying mechanisms.

To explain why behavior under stress is often suboptimal compared to behavior under nonstressful conditions, many researchers have invoked dual-process models that distinguish between goal-directed and habitual processes (Schwabe & Wolf, 2009, 2010; Smeets et al., 2019). The two processes differ in terms of the content of their mental representations (Heyes & Dickinson, 1990). The mental representation in a goal-directed process contains information about the expected utilities of one or more response options. The expected utility of one response option depends on the expectancy that the response will lead to a certain outcome and the value of that outcome given a certain situation (S:R–O^{v}). The mental representation in a habitual process only contains a stimulus–response link (S–R). Because a habitual process does not contain information about the outcomes of responses, responses caused by this process are insensitive to changes in these outcomes and therefore suboptimal if the outcomes do change.

The representations involved in goal-directed and habitual processes can be installed in different ways (see Moors et al., 2017). Typically, it is assumed that an operant conditioning procedure

Eike K. Buabang https://orcid.org/0000-0002-3057-0819
Yannick Boddez https://orcid.org/0000-0002-8067-5969
Oliver T. Wolf https://orcid.org/0000-0002-9320-2124
Agnes Moors https://orcid.org/0000-0002-5137-557X

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Correspondence concerning this article should be addressed to Eike K. Buabang, Research Group of Quantitative Psychology and Individual Differences, KU Leuven, Tiensestraat 102, 3000 Leuven, Belgium. Email: eike.buabang@kuleuven.be

(in which the presence of a stimulus followed by a response leads to a valued outcome) leads to the formation of a goal-directed process when the procedure is repeated a moderate number of times but to the formation of a habit when this procedure is overtrained. However, several researchers assume that in the moderate case, both processes already get installed but that each of them can be deployed under different conditions. In particular, it is sometimes argued that if operating conditions are ample, a goal-directed process is more likely to be deployed and to determine behavior, whereas when operating conditions are poor, such as when attentional resources are depleted or when one is under stress, a habitual process is more likely to be deployed and to determine behavior (e.g., Wood & Rünger, 2016). Support for increased reliance on habitual processes under stress comes from devaluation studies such as that of Schwabe and Wolf (2010). In this study, participants learned two instrumental actions to obtain rewarding liquids, one leading to chocolate milk and another leading to orange juice. One of these two outcomes was then devalued with a selective satiation procedure in which participants either ate chocolate pudding or oranges to satiation. After being exposed to either a stress induction procedure or a control procedure, participants were tested under extinction. Results showed that participants in the control condition responded less for the devalued liquid than for the still valued liquid. Stressed participants, however, continued to perform both responses to the same extent and thus did not show sensitivity to outcome devaluation. The authors concluded that the behavior of control participants was caused by a goal-directed process whereas that of stressed participants was driven by a habitual process.

The findings of Schwabe and Wolf (2010) that stress leads to continued responding for liquids that are no longer valued are taken as evidence that habitual processing is a key process underlying stress-induced eating (Pool et al., 2015). Thus, it is argued that if operating conditions are ample, people can take into account negative outcomes of consuming certain foods (such as gaining weight) and adapt their behavior. If operating conditions are poor, however, such as when one is under stress, they have no other choice but to switch to a habitual process in which these foods trigger an association between food and consumption, steering them directly toward consumption (e.g., Hofmann et al., 2009). In line with this, Maier et al. (2015) found that stressed participants had a preference for unhealthy food even if they had an explicit goal to eat healthily.

In their recent review of the literature, Eder and Dignath (2016) pointed out that in several previous studies in which an insensitivity to devaluation was observed, the method for devaluation was a selective satiation procedure (e.g., Hogarth & Chase, 2011; Watson et al., 2014). They hypothesized that the absence of devaluation effects in these studies was not due to habits but rather to the use of a relatively weak selective satiation procedure as a method for devaluation. In line with their hypothesis, they showed that the use of a taste aversion procedure, which they deemed to be a stronger devaluation method, did produce a devaluation effect. Although it seems plausible that selective satiation is a weaker method for devaluation than taste aversion, their differential strength was not directly tested, and other differences between both devaluation methods may have been responsible for the mixed results (given that both methods might rely on different mechanisms; Schreiner et al., 2020).

Against the background of these mixed results, we set up the present study as a conceptual replication of the study by Schwabe and Wolf (2010) in which we tested if the findings replicate with a different type of devaluation method, namely taste aversion. If the traditional dual-process model is correct, the difference between the control and stress condition should be replicated after outcome devaluation with taste aversion: In the control condition, there should be a devaluation effect; in the stress condition, there should again be no devaluation effect as behavior in this condition is assumed to be caused by a habitual process and therefore insensitive to the outcome devaluation. Thus, replication of the pattern of findings by Schwabe and Wolf (2010) would strengthen the conclusion that stress leads to an increased reliance on habitual processes. Failure to replicate the lack of a devaluation effect in the stress condition, by contrast, would indicate boundary conditions. It would suggest that people under stress are sensitive to outcome values, and hence that processing is goal-directed, if the outcomes become aversive.

The latter result would fit with an alternative dual-process model proposed by Moors et al. (2017) according to which the role of habitual processes in explaining suboptimal behavior (such as overeating) may be overestimated. They pointed out that one of the complexities that is sometimes overlooked is that people have multiple goals so that a single behavior may lead to multiple outcomes. If behavior is insensitive to the devaluation of one outcome, this does not necessarily mean it is caused by a habitual process because it can still be guided by other outcomes. In food choices, certain foods are more likely to satisfy long-term goals such as weight loss, whereas other foods are more likely to grant immediate gratification and satisfy short-term hedonic goals. If eating certain foods does not satisfy long-term goals, it may still satisfy short-term goals. Rather than accepting that stress causes a shift from goal-directed to habitual processing, it is possible that stress leads to a shift in the priorities of long-term and short-term goals. Stress-induced eating may be directed towards the short-term goal of stress regulation, for example, which could take priority over a long-term health or weight loss goal (see also Kopetz et al., 2018).

This alternative model would explain the original findings of Schwabe and Wolf (2010) as follows. In the control condition, the goal that guided the participants' behavior may have been to consume foods with certain flavors to satiety. After the selective satiation procedure, this goal was fulfilled for one flavor (the flavor of the food that was eaten until satiation) and therefore participants responded less to receive the corresponding liquid. In the stress condition, on the other hand, the stress protocol may have led participants to prioritize other goals (e.g., the goal to regulate stress, which might be achieved by eating beyond the level of satiation) over the goal to consume foods with certain flavors. Importantly, if behavior is insensitive to the devaluation of one goal (e.g., goal to consume foods with certain flavors), which indicates that it is not guided by this goal, it could still be guided by other goals (e.g., the goal to regulate stress). Although stressed participants ate the food to satiety, the liquid may still have been (liked enough to be) able to satisfy these other goals. It may be noted that the test phase in Schwabe and Wolf's (2010) study was done under extinction, which means that the fluids were no longer delivered. Thus, participants could not *actually* regulate their stress by consuming the liquids. Yet participants were not informed about this fact so they may still have had the expectation that the liquids would be delivered and hence they may still have tried to regulate their stress by consuming the

liquids and hence they may still have *tried* to regulate their stress by consuming the liquids.

Taste aversion should make it less likely that the devalued liquid can be used to serve other goals (e.g., the goal to regulate stress, which may not be achieved by eating bad-tasting food). Therefore, the alternative model predicts that in the present study a similar devaluation effect will occur both in the stress and the control condition. We wish to note that if we observe results in line with the predictions by the alternative model, future research would still be required to directly examine why different types of devaluation methods yield different results.

The design of the present study closely resembles the design in the study by Schwabe and Wolf (2010). Significant differences between the two studies will be highlighted in the procedure section. In the acquisition phase of the present study, participants learned two instrumental actions to obtain rewarding liquids, one leading to chocolate milk and another leading to orange juice. In the outcome devaluation phase, one of the outcomes was devalued through taste aversion (Eder & Dignath, 2016). Next, participants either underwent the stress or control protocol and were finally tested under extinction.

The traditional model predicts that participants in the control condition will respond less for the devalued liquid than for the still valued liquid in the test phase, but that participants in the stress condition will respond equally for the devalued and still valued liquid because they have switched to a habitual process. The alternative model, by contrast, predicts that participants in both the control and stress condition will respond less for the devalued than for the still valued liquid.

Method

Transparency and Openness

We followed the guidelines outlined by Journal Article Reporting Standards (JARS; Kazak, 2018). The Stage-1 registered report, data, and code are available on the Open Science Framework: https://osf.io/tf7bv

Participants

A total of 158 participants completed the study. After data exclusion (see below), the final sample consisted of 68 participants (34 per condition, 48 female, Age $M = 20.9$, $SD = 3.92$). A power analysis conducted with the MorePower 6.0.4 software (Campbell & Thompson, 2012) showed that this was the required sample size to have 80% power with the statistical significance level defined at the 0.05 level given the effect size ($\eta_p^2 = .07$) reported by Schwabe and Wolf (2010) to detect a potential interaction effect between condition and value. Data were collected until this target sample size was achieved. The study was approved by the KU Leuven ethical committee (G-2018 01 1086) and all participants provided informed consent. Participants were recruited from the participant pool of the psychology department at KU Leuven and received 12 Euros or partial course credits.

Exclusion Criteria

Individuals could not participate if they were smokers or if they had any current or chronic mental or neurological disorder, a heart disease or cardiovascular problems, endocrine problems, lung problems, or a body mass index (BMI) outside of the 17.5–30 kg/m^2 range. In addition, women could not participate if they were pregnant or took oral contraceptives, because these conditions may lead to a blunted cortisol response (Roche et al., 2013). Participants were informed before the study about the liquids (chocolate milk, orange juice, water, peppermint tea) they would have to consume and were asked to only participate if they like the liquids. At the beginning of the experiment, participants reported how much they would like to consume each liquid at the current moment on a scale from 0 (*not at all*) to 100 (*very much*).

Data Exclusion

The data of participants were excluded from further analysis if these participants gave a rating of less than 50 for chocolate milk or orange juice. This criterion is stricter than in the study by Schwabe and Wolf (2010), in which participants were only excluded if they gave a rating for either liquid of less than 10. We chose a stricter criterion to avoid the risk that participants would not learn to select the high-probability actions for chocolate milk and orange juice because they do not like these fluids enough.

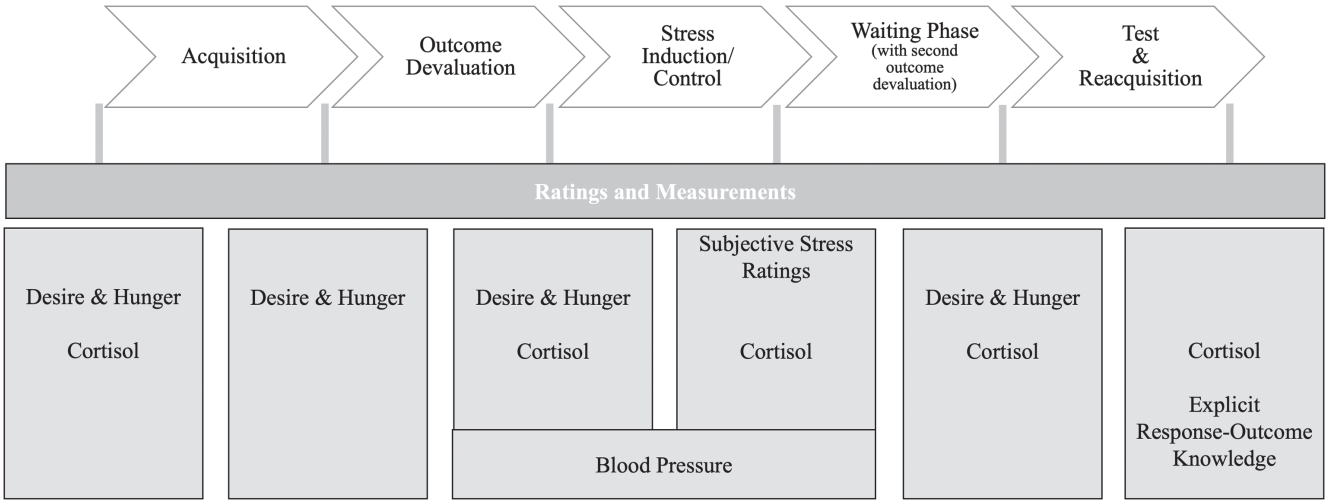
Furthermore, the data of participants were excluded if these participants chose the high-probability action for either chocolate milk, orange juice, or both less than 50% of the time across the last two blocks of the acquisition phase (see below). We note that this criterion is stricter than in the study by Schwabe and Wolf (2010), in which participants were only excluded if they selected the high-probability action less than 20% of the time throughout the whole acquisition phase. We believed the stricter criterion would be crucial to ensure that participants learn the relevant contingencies and choose in line with them by the end of the acquisition phase. We decided to set the criterion at 50% because participants have to choose between two symbols on each trial and, thus, choosing the high-probability action less than 50% of the time can be interpreted as avoiding the liquid.

Procedure

Before coming to the lab, participants were instructed to refrain from consuming alcohol after 7 p.m. and to go to sleep at a time they considered appropriate but in any case before 1 a.m on the day before the experiment. They were further instructed to refrain from consuming alcohol on the day of the experiment and to refrain from eating, drinking anything except still water, smoke, brush their teeth, and workout or undertake strenuous physical effort 2 hr before the experiment. The experiment took place between 1:30 p.m. and 5:30 p.m because cortisol levels are more stable in the afternoon, which makes it easier to detect changes in cortisol levels resulting from a stress induction (Dickerson & Kemeny, 2004).

The experiment comprised the following main phases: an acquisition phase, a first outcome devaluation phase, a stress induction phase (or control phase), a waiting phase with a second outcome devaluation (to reinforce the devaluation), a test phase, and a reacquisition phase. Figure 1 presents a timeline with all phases and additional measures in chronological order. We discuss each of these phases and the measures that were administered in them.

Figure 1
Structure of the Experiment



Note. Structure of the experiment with all phases and additional measures in chronological order.

Acquisition Phase

The task consisted of three trial types: chocolate milk trials, orange juice trials, and water (neutral) trials. In this phase, there were 75 trials per trial type, which were presented in random order. On each trial, two symbols that were distinct for each trial type were presented. Participants were instructed to choose one of the two symbols by clicking on it with the mouse. After participants clicked on a symbol, it was highlighted for 3 s before a liquid was delivered. The liquids (1 mL) were pumped by a machine through tubes, which were connected with straws that participants kept in their mouth. Once the liquid was delivered, the screen turned black and the next trial began.

On chocolate milk trials and orange juice trials, selecting one symbol delivered chocolate milk and orange juice, respectively, with a probability of $p = .50$, and peppermint tea with a probability of $p = .20$ (high-probability action). Selecting the other symbol only delivered peppermint tea with a probability of $p = .20$ (low-probability action). Peppermint tea was the common outcome for these two trial types, which means that it was delivered for both the high- and low-probability action with the same probability. On neutral trials, selecting one symbol delivered water with a probability of $p = .70$ (high-probability action), and selecting the other symbol delivered water with a probability of $p = .20$ (low-probability action). The symbols (vertical rectangle, horizontal rectangle, circle, pentagon, star, and triangle) were randomly assigned to each trial type at the beginning of the phase, so that selecting one symbol was the high-probability action and selecting the other symbol was the low-probability action for each trial type. Symbols could appear in one of the four corners of the screen, which was randomly assigned at the beginning of the test phase. Both the symbols and their position for each trial type remained the same throughout the experiment.

First Outcome Devaluation Phase

Participants were instructed to drink four cups (20 mL each), two containing chocolate milk and two containing orange juice. One of these liquids was devalued (counterbalanced between participants) by mixing it with Tween 20 (Polysorbate 20), a colorless and odorless substance that creates a bad taste (Baeyens et al., 1995; Eder & Dignath, 2016). The Tween 20/liquid concentration was 2.5 mL/100 mL. Participants had to drink the cups in a randomized order as presented on a computer screen.

Desire Ratings. Participants reported how much they would like to consume each liquid (chocolate milk, orange juice, water, peppermint tea) at the current moment on a scale from 0 (*not at all*) to 100 (*very much*). Ratings were obtained before the acquisition phase to exclude the data of participants whose desire to consume the liquids was too low. The ratings before and after the first outcome devaluation phase were collected to assess whether the first outcome devaluation was successful. Finally, ratings were obtained after the second outcome devaluation phase (see below) to assess whether the devaluation effect persisted.

Hunger Ratings. Participants reported their hunger on a scale from 0 (*not hungry at all*) to 100 (*very hungry*). Ratings were obtained before the acquisition phase as a baseline measure. The hunger ratings were obtained to control for potential differences between the control and stress conditions. The ratings before and after the first outcome devaluation phase were collected to assess the effect of the first outcome devaluation. Finally, ratings were obtained after the second outcome devaluation phase to capture potential effects of the second outcome devaluation.

Stress Induction/Control Phase

This phase followed the protocol of the socially evaluated cold pressor test (SECPT; Schwabe et al., 2008). Participants were assigned to either a stress or a control condition. Participants in the stress condition were instructed to put their right hand up to and including the wrist for 3 min (or until they could no longer tolerate it) into ice water (0–4 °C). During hand immersion, participants were videotaped and monitored by the experimenter. Participants signed a separate informed consent form to agree that they would be

videotaped. Participants in the control condition put their right hand up to and including the wrist for 3 min in warm water (35–37 °C); they were neither videotaped nor monitored by the experimenter. To verify whether the stress induction procedure was successful, we measured subjective ratings, salivary cortisol levels, and blood pressure.

Subjective Ratings. Subjective ratings of stressfulness, painfulness, and unpleasantness were collected after the stress induction phase. Participants indicated on a scale from 0 (*not at all*) to 100 (*very much*) how stressful, painful, and unpleasant they experienced the previous situation.

Salivary Cortisol. Saliva samples were collected as an objective measure of stress, using synthetic Salivettes (Sarstedt, Etten–Leur, the Netherlands). These samples were stored at −20 °C until the analysis. A first sample was taken before the acquisition phase. This allowed us to check for differences in cortisol levels between the control and stress conditions. Based on Schwabe and Wolf's (2009) findings that stress before the acquisition phase did not affect performance in the acquisition phase, but did impair explicit response-outcome knowledge measured after the test phase, it is uncertain whether and to what extent differences in stress influence learning. Further saliva samples were taken immediately before and immediately after the stress induction to assess the effect of the stress induction. However, cortisol levels have been shown to reach their peak approximately 20 min after stress induction with the SECPT (Schwabe et al., 2008). Thus, another sample was taken 20 min after the stress induction, immediately before the test phase. To assess how long the effect of the stress induction lasted, a final sample was taken after the reacquisition phase.

Blood Pressure. To measure blood pressure, we placed an arm cuff on participants' left upper arm and a double-finger sensor on their left index and left middle finger. The cuff and sensor were connected to a NIBP100D blood pressure unit. This unit was connected to an ADA100C amplifier, which transmitted the signals to a MP150 system. A continuous blood pressure measure was taken starting three min before until three min after immersion of the right hand. The measure before the stress induction phase served as a baseline measure for systolic and diastolic blood pressure. The measure during the stress induction assessed the influence of the induction. Finally, the measure after the stress induction assessed the lasting effect of this induction.

Waiting Phase With Second Devaluation

Because it takes approximately 20 min for cortisol levels to reach their peak after stress induction with the SECPT (Schwabe et al., 2008), the stress induction phase was followed by a waiting phase of 20 min. During this time, however, the effect of the first devaluation may weaken (Eder & Dignath, 2016).[1] Therefore, the waiting phase was combined with a second devaluation in which participants were asked to drink one additional cup of the valued and devalued liquids at 5, 10, and 15 min after the stress induction.

Test Phase

The aim of the test phase was to determine whether a devaluation effect would occur in both conditions based on the mental representations of the outcomes. Testing of the two outcomes (chocolate milk and orange juice) was therefore done under extinction. This means that the high- and low-probability actions on chocolate milk and orange juice trials no longer delivered the respective liquids, but both still delivered peppermint tea with a probability of $p = .20$. On neutral trials, water was delivered with a probability of $p = .20$ for both the high- and low-probability action. This phase consisted of 15 trials per trial type. Although this is fewer than the 75 trials in the study of Schwabe and Wolf (2010), it should be sufficient to determine whether a devaluation effect occurred. In fact, Schwabe and Wolf (2010) only found an effect in the first 15 trials.

Reacquisition Phase

In contrast to the test phase, the reacquisition test assessed responding based on the experience of the outcomes. In this phase, the outcomes were delivered again according to the schedule of the acquisition phase. The aim of the reacquisition test was to assess if the participants acquired an aversion to the devalued outcome. As such, it served as a behavioral measure of the effectiveness of the outcome devaluation procedure in addition to the self-report measure used in the desire ratings. This behavioral measure was not included in the study by Schwabe and Wolf (2010). This phase also consisted of 15 trials per trial type.

Explicit Response-Outcome Knowledge

Explicit response–outcome knowledge was assessed with multiple choice questions. Participants were asked for each liquid in random order which symbol they had to select (out of all six symbols) and where the symbol was positioned (out of the four corners of the screen).

Results

The analyses were conducted using the R software (R Core Team, 2021) with the packages afex (Singmann et al., 2021) and ggplot2 (Wickham, 2016). For mixed analysis of variances (ANOVAs), the sphericity assumption was checked with Mauchly's test of sphericity. The Greenhouse–Geisser correction was applied when the sphericity assumption was violated. For pairwise comparisons following up significant effects of ANOVAs, the Tukey-correction was applied to correct for multiple comparisons. For the acquisition phase, the test phase, and the reacquisition phase, the proportion of high-probability actions for each trial type was averaged per block (i.e., across every 15 trials).

Acquisition Phase

The aim of the acquisition phase was to make participants learn which actions to select to have the highest probability to obtain chocolate milk and orange juice (i.e., the high-probability actions), which should be reflected in a higher proportion of high-probability action selections. To ensure that this aim is achieved, we excluded participants from further analyses if they did not choose the high-probability action for chocolate milk and orange juice at least 50% of the time across the last two blocks. Thus, successful learning was ensured through data exclusion. We conducted a mixed model

[1] In a previous study that we conducted, the effect of the devaluation on the desire ratings did not persist until the test phase, which is why we strengthened the devaluation in this way.

ANOVA for the proportion of high-probability actions with Block (1–5) and value (valued, to-be-devalued, neutral) as within-subjects factors, and condition (control, stress) as a between-subjects factor to check for potential differences in the proportion of high-probability actions on valued, to-be-devalued, and neutral trials, and potential differences between the control and stress conditions.

Results indicated a significant main effect of value, $F(1.57, 103.80) = 19.79$, $p < .001$, $\eta_p^2 = .231$. Post hoc comparisons showed that participants made significantly more high-probability actions on valued ($M = .72$, $SD = .22$) than on neutral trials ($M = .60$, $SD = .28$), $t(66) = 4.53$, $p < .001$, and more high-probability actions on to-be-devalued ($M = .74$, $SD = .21$) than on neutral trials, $t(66) = 5.07$, $p < .001$. There was no significant difference in the proportion of high-probability actions on valued and to-be-devalued trials, $t(66) = -1.32$, $p = .392$. This suggests that participants considered chocolate milk and orange juice as equally rewarding, and as more rewarding than water.

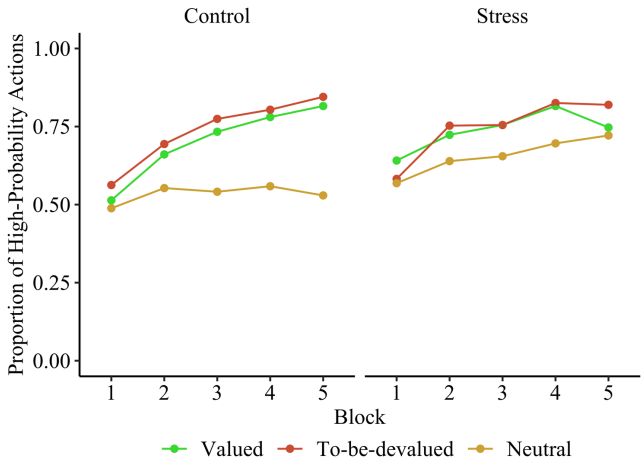
There was also a significant main effect of block, $F(3.09, 204.06) = 27.62$, $p < .001$, $\eta_p^2 = .295$. Post hoc comparisons showed that compared to Block 1 ($M = .56$, $SD = .28$), participants made significantly more high-probability actions in Block 2 ($M = .67$, $SD = .22$), $t(66) = 5.97$, $p < .001$, in Block 3 ($M = .70$, $SD = .25$), $t(66) = 5.63$, $p < .001$, in Block 4 ($M = .75$, $SD = .24$), $t(66) = 8.39$, $p < .001$, and in Block 5 ($M = .75$, $SD = .26$), $t(66) = 7.17$, $p < .001$. Further, compared to Block 2, participants made significantly more high-probability actions in Block 4, $t(66) = 4.44$, $p < .001$, and in Block 5, $t(66) = 3.63$, $p = .005$. All other comparisons did not reach significance (all ts < .2.61). This suggests that the proportion of high-probability actions increased over the first two blocks.

Results further indicated a significant interaction between value and block, $F(5.53, 365.05) = 4.01$, $p < .001$, $\eta_p^2 = .057$. Post hoc comparisons showed that the number of high-probability actions was higher on valued than on neutral trials in Block 2 ($M_{valued} = .69$, $SD = .21$; $M_{neutral} = .60$, $SD = .23$), $t(66) = 2.98$, $p = .011$, Block 3 ($M_{valued} = .74$, $SD = .22$; $M_{neutral} = .60$, $SD = .27$), $t(66) = 4.13$, $p < .001$, Block 4 ($M_{valued} = .80$, $SD = .17$; $M_{neutral} = .63$, $SD = .31$), $t(66) = 4.49$, $p < .001$, and Block 5 ($M_{valued} = .78$, $SD = .20$; $M_{neutral} = .63$, $SD = .33$), $t(66) = 3.86$, $p < .001$, but not in Block 1. This number was also higher on to-be-devalued than on neutral trials in Block 2 ($M_{to\text{-}be\text{-}devalued} = .72$, $SD = .21$), $t(66) = 3.93$, $p < .001$, Block 3 ($M_{to\text{-}be\text{-}devalued} = .77$, $SD = .21$), $t(66) = 4.55$, $p < .001$, Block 4 ($M_{to\text{-}be\text{-}devalued} = .82$, $SD = .17$), $t(66) = 4.95$, $p < .001$, and Block 5 ($M_{to\text{-}be\text{-}devalued} = .83$, $SD = .17$) $t(66) = 5.42$, $p < .001$. None of the other comparisons reached significance (all ts < .2.35). The fact that participants increasingly selected high-probability actions on valued and to-be-devalued trials, suggests that they considered chocolate milk and orange juice as rewarding outcomes, and as more rewarding than water (see Figure 2).

However, results also indicated a significant interaction between condition, value, and block, $F(5.53, 365.05) = 3.05$, $p = .008$, $\eta_p^2 = .044$. Post hoc comparisons showed that there were differences between the control and the stress conditions, which were situated in Block 5. In the control condition, the number of high-probability actions was higher on valued ($M = .82$, $SD = .17$) than on neutral trials ($M = .53$, $SD = .36$), $t(66) = 5.01$, $p < .001$, as well as higher on to-be-devalued ($M = .85$, $SD = .21$) than on neutral trials, $t(66) = 5.85$, $p < .001$. In the stress condition, on the other hand, these differences were not significant. This suggests that participants in the control condition considered chocolate milk and orange juice to be rewarding outcomes, and to be more rewarding than water until the end of the acquisition phase. Participants in the stress condition considered chocolate milk, orange juice, and water to be equally rewarding at the end of acquisition. Although we cannot meaningfully interpret these differences between the conditions, they do not create an advantage for any of the accounts under study here.

Figure 2

Acquisition Performance



Note. Proportion of high-probability actions during the acquisition phase (Block 1–5) split by the between-subjects factor condition (control, stress) and the within-subjects factor value (valued, to-be-devalued, neutral). See the online article for the color version of this figure.

First and Second Outcome Devaluation Phases

Desire Ratings

The first desire ratings, obtained before the acquisition phase, served as an exclusion criterion. Participants were excluded from further analyses if they rated either chocolate milk or orange juice less than 50 on the scale. The analysis of the remaining desire ratings (before and after the first devaluation phase and after the second devaluation phase) served to assess the effectiveness of the first outcome devaluation procedure and to check whether the devaluation effect persisted until after the second outcome devaluation procedure. To test this, we conducted a mixed model ANOVA for the desire ratings with time (before the first devaluation phase, after the first devaluation phase, after the second devaluation phase) and value (valued, [to-be-]devalued, neutral, common) as within-subjects factors, and condition (control, stress) as between-subjects factor.

Results indicated a significant main effect of value, $F(2.46, 162.33) = 49.52$, $p < .001$, $\eta_p^2 = .429$. Post hoc comparisons showed that participants reported the highest desire ratings for the valued liquid ($M = 78.00$, $SD = 19.00$), which was higher than the rating for the neutral liquid ($M = 69.40$, $SD = 24.60$), $t(66) = 2.65$, $p = .048$, which in turn was rated higher than the devalued liquid ($M = 49.70$, $SD = 32.70$), $t(66) = 5.60$, $p < .001$, which in turn was rated higher than the common liquid ($M = 37.10$, $SD = 28.70$), $t(66) = 2.70$, $p = .043$.

Results also indicated a significant main effect of time, $F(1.91, 125.87) = 29.78$, $p < .001$, $\eta_p^2 = .311$. Post hoc comparisons showed that participants reported the highest desire ratings before the first devaluation phase ($M = 62.70$, $SD = 28.30$), which was higher than the rating after the first devaluation phase, ($M = 59.50$, $SD = 30.70$), $t(66) = 2.77$, $p = .019$, which in turn was higher than the rating after the second devaluation phase ($M = 53.40$, $SD = 33.70$), $t(66) = 5.30$, $p < .001$.

Crucially, results indicated the predicted interaction between value and time, $F(3.73, 246.25) = 75.61$, $p < .001$, $\eta_p^2 = .534$. Post hoc comparisons showed that before the first devaluation, desire ratings between the valued ($M = 78.80$, $SD = 16.90$) and to-be-devalued liquid ($M = 78.60$, $SD = 17.10$) did not differ significantly, $t(66) = 0.12$, $p = .999$, suggesting they liked the two liquids to the same degree at this time. Moreover, desire ratings were higher for the valued than for the neutral liquid ($M = 58.70$, $SD = 24.80$), $t(66) = 5.19$, $p < .001$, and higher for the to-be-devalued than for the neutral liquid, $t(66) = 5.25$, $p < .001$. Furthermore, desire ratings were higher for the neutral than for the common liquid ($M = 34.80$, $SD = 26.70$), $t(66) = 6.63$, $p < .001$. As predicted, after the first devaluation, desire ratings were lower for the devalued liquid ($M = 42.70$, $SD = 28.40$) than for the valued liquid ($M = 80.40$, $SD = 17.20$), $t(66) = -8.77$, $p < .001$. This suggests that the devaluation procedure was effective (see Figure 3). Desire ratings were also lower for the devalued liquid than for the neutral liquid ($M = 74.80$, $SD = 22.00$), $t(66) = -7.38$, $p < .001$, but they did not significantly differ between the valued and the neutral liquid, $t(66) = 1.65$, $p = .357$, nor between the devalued and the common liquid, ($M = 40.10$, $SD = 29.50$), $t(66) = 0.46$, $p = .967$. Note that this pattern is similar to that found by Schwabe and Wolf (2010).

As predicted, desire ratings were still significantly lower for the devalued liquid ($M = 27.90$, $SD = 27.70$) than for the valued liquid ($M = 74.70$, $SD = 22.40$) after the second devaluation, $t(66) = -10.60$, $p < .001$. This suggests that the devaluation effect persisted. Again, desire ratings were lower for the devalued than for the neutral liquid ($M = 74.50$, $SD = 23.80$), $t(66) = -10.11$, $p < .001$, but they did not significantly differ between the valued and neutral liquid, $t(66) = 0.04$, $p = .999$, nor between the devalued and the common liquid, ($M = 36.50$, $SD = 29.80$), $t(66) = -1.53$, $p = .428$. Thus, the overall pattern confirms the persistent effectiveness of the devaluation procedure. No other effects were significant (all Fs < 1.40).

Hunger Ratings

We conducted a mixed model ANOVA for the hunger ratings with time (before the acquisition phase, before the first devaluation phase, after the first devaluation phase, after the second devaluation phase) and value (valued, [to-be-]devalued, neutral, common) as within-subjects factors, and condition (control, stress) as between-subjects factor to check for potential differences between the control and stress conditions.

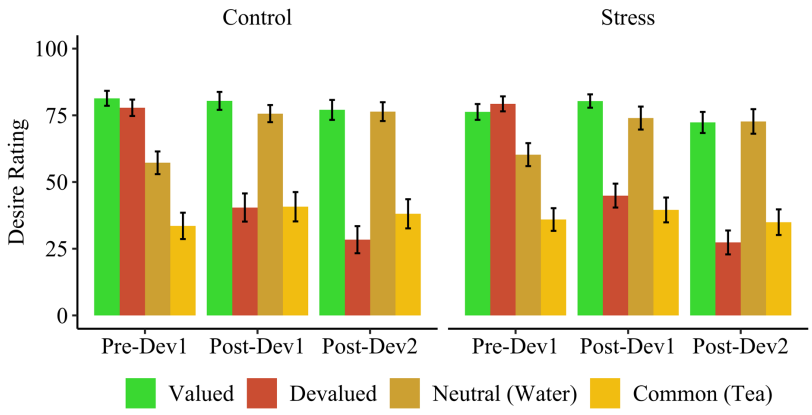
Results indicated a significant main effect of time, $F(1.73, 114.09) = 25.21$, $p < .001$, $\eta_p^2 = .276$. Post hoc comparisons showed that hunger levels were the highest before the acquisition phase ($M = 43.90$, $SD = 25.60$), which was significantly higher than before the first devaluation phase ($M = 39.80$, $SD = 26.60$), $t(66) = 2.91$, $p = .025$, which in turn was significantly higher than after the first devaluation phase ($M = 36.00$, $SD = 25.30$), $t(66) = 3.88$, $p = .001$, which in turn was significantly higher than after the second devaluation phase, ($M = 27.50$, $SD = 24.20$), $t(66) = 4.16$, $p < .001$. Thus, participants' hunger decreased over time.

Stress Induction/Control Phase

Subjective Ratings

We conducted separate t tests to compare the stressfulness, painfulness, and unpleasantness ratings between conditions (control vs. stress). Compared to the control condition, the stress condition rated the stress induction/control phase as more stressful ($M_{control} = 16.40$,

Figure 3
Desire Ratings



Note. Desire ratings over time (before the first devaluation phase, after the first devaluation phase, after the second devaluation phase) split by the between-subjects factor condition (control, stress), and the within-subjects factor value (valued, [to-be-] devalued, neutral, common). Error bars represent standard errors. See the online article for the color version of this figure.

$SD = 21.20$; $M_{stress} = 47.50$, $SD = 28.10$), $t(66) = -5.16$, $p < .001$, as more painful, ($M_{control} = 6.29$, $SD = 10.40$; $M_{stress} = 61.20$, $SD = 24.70$), $t(66) = -11.90$, $p < .001$, and as more unpleasant ($M_{control} = 18.70$, $SD = 20.10$; $M_{stress} = 77.40$, $SD = 18.30$), $t(66) = -12.60$, $p < .001$ (see Figure 4, Panel A). This is in line with our predictions.

Salivary Cortisol

The analysis of the salivary cortisol levels served two aims. The first aim was to check for potential (but unpredicted) differences in cortisol levels between the conditions at the start, before the acquisition phase (first sample). The second aim was to assess the effectiveness and persistence of the stress induction procedure by comparing cortisol levels immediately before the stress induction/control phase (second sample, baseline) with cortisol levels at three time points after this phase: immediately after (third sample), 20 min after (fourth sample), and after the reacquisition phase (fifth sample). To this end, we conducted a mixed model ANOVA for the salivary cortisol level with time (before the acquisition phase, immediately before, immediately after, and 20 min after the stress induction/control phase, and after the reacquisition phase) as within-subjects factor, and condition (control, stress) as between-subjects factor. Ten participants (three from the stress condition) had to be excluded from the analysis because they had at least one sample that had not enough saliva after centrifugation.

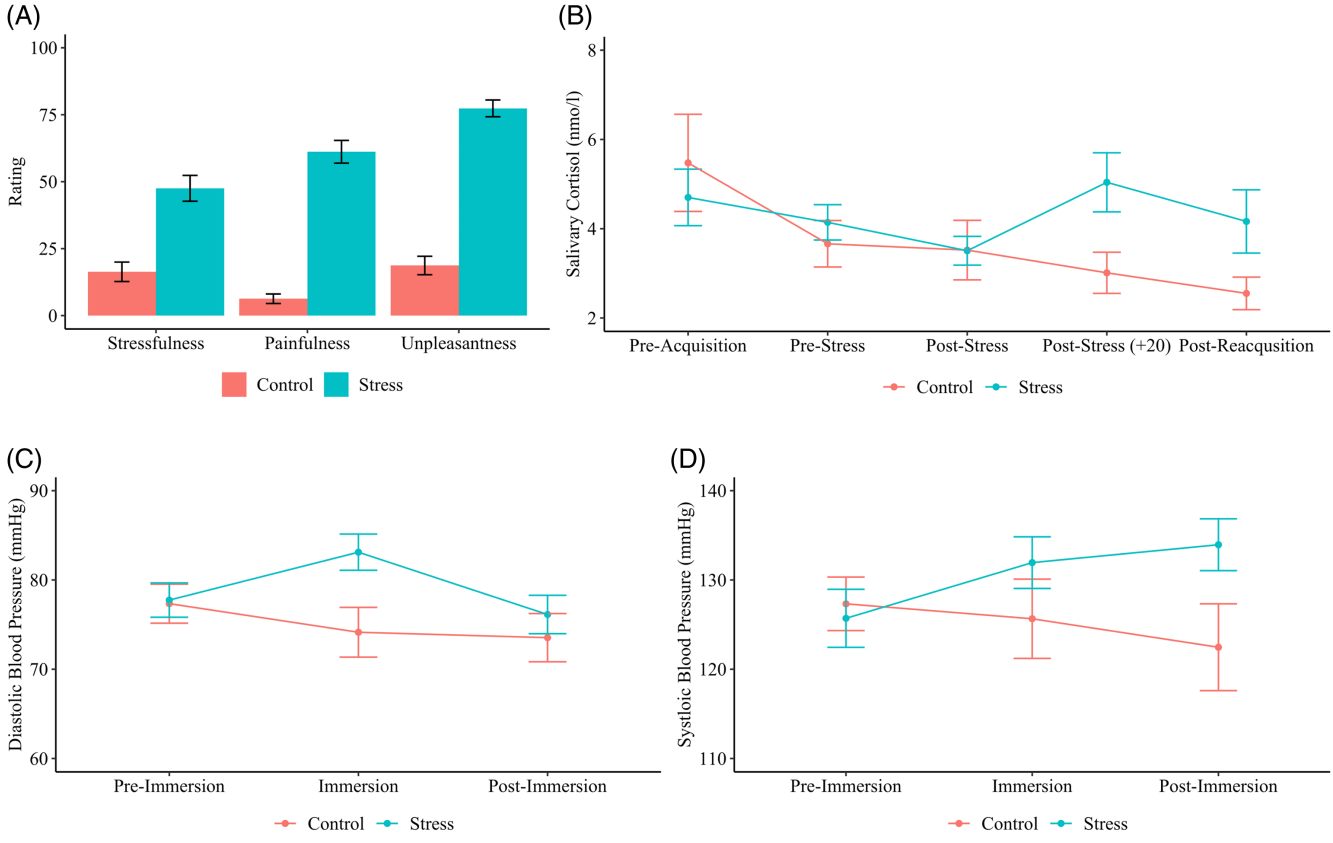
Results indicated a significant main effect of time, $F(2.14, 119.68) = 4.26$, $p = .014$, $\eta_p^2 = .071$. Post hoc comparisons showed that cortisol levels were higher before the acquisition phase ($M = 5.06$, $SD = 4.61$) than immediately after the stress induction/control phase, ($M = 3.51$, $SD = 2.68$), $t(56) = 2.94$, $p = .037$, and higher 20 min after the stress induction/control phase ($M = 4.10$, $SD = 3.29$) than after the reacquisition phase ($M = 3.41$, $SD = 3.24$), $t(56) = 3.24$, $p = .017$. No other comparisons were significant ($ts < 2.65$).

Crucially, the predicted interaction between condition and time was significant, $F(2.14, 119.68) = 3.07$, $p = .047$, $\eta_p^2 = .052$. Post hoc comparisons showed that the stress condition ($M = 5.02$, $SD = 3.68$) had higher cortisol levels than the control condition ($M = 3.01$, $SD = 2.40$) 20 min after the stress induction/control phase, $t(56) = 2.44$, $p = .017$. No other comparisons were significant ($ts < 1.94$). This indicates that the stress induction procedure was effective (Figure 4, Panel B). The difference in cortisol levels did not persist until after the reacquisition phase (fifth sample), but this is in line with the results of Schwabe and Wolf (2010).

Blood Pressure

The aim of the analyses for (diastolic and systolic) blood pressure was to again verify the effectiveness of the stress induction procedure. We conducted separate mixed model ANOVAs for the systolic and diastolic blood pressure values with time (before, during, after

Figure 4
Stress Indicators



Note. (A) subjective stress ratings, (B) salivary cortisol, (C) diastolic blood pressure, and (D) systolic blood pressure. Error bars represent standard errors. See the online article for the color version of this figure.

the stress induction/control phase) as within-subjects factor and condition (control, stress) as between-subjects factor. Due to technical issues, we failed to collect blood pressure values for three participants (one participant from the stress condition).

For diastolic blood pressure, results indicated a significant main effect of time, $F(1.53, 96.65) = 4.29$, $p = .025$, $\eta_p^2 = .065$. Post hoc comparisons showed higher values during the stress induction/control phase ($M = 78.7$, $SD = 14.4$) than after this phase ($M = 74.9$, $SD = 13.8$), $t(63) = 3.79$, $p < .001$. Crucially, the predicted interaction between condition and time was significant, $F(1.53, 96.65) = 5.56$, $p = .010$, $\eta_p^2 = .081$. Post hoc comparisons showed no significant differences between the conditions before the stress induction/control phase, ($M_{control} = 77.3$, $SD = 12.4$; $M_{stress} = 77.7$, $SD = 11.0$), $t(63) = -0.14$, $p = .891$. During this phase, values were significantly higher in the stress than in the control condition, ($M_{control} = 74.1$, $SD = 15.8$; $M_{stress} = 83.1$, $SD = 11.6$), $t(63) = 2.61$, $p = .011$. After this phase, there were again no differences between the conditions ($M_{control} = 73.5$, $SD = 15.3$; $M_{stress} = 76.1$, $SD = 12.4$), $t(63) = -0.75$, $p = .454$.

For systolic blood pressure, results also indicated the predicted interaction between condition and time, $F(1.50, 94.21) = 6.45$, $p = .005$, $\eta_p^2 = .093$. Post hoc comparisons showed no significant differences between the conditions before the stress induction/control phase, ($M_{control} = 127$, $SD = 17$; $M_{stress} = 126$, $SD = 18.7$), $t(63) = 0.37$, $p = .715$, nor during this phase ($M_{control} = 126$, $SD = 25.1$; $M_{stress} = 132$, $SD = 16.6$), $t(63) = -1.19$, $p = .237$. After this phase, values were significantly higher in the stress than in the control condition, ($M_{control} = 122$, $SD = 27.5$; $M_{stress} = 134.1$, $SD = 16.7$), $t(63) = 2.02$, $p = .045$. Taken together, these results suggest that diastolic and systolic blood pressure increased as a result of the stress induction in the stress condition (see Figures 4, Panels C and D).

Test Phase

The predictions of the traditional dual-process model were that participants in the control condition would select the high-probability action less on devalued than on valued trials, indicating that their behavior is governed by a goal-directed process. Participants in the stress condition, on the other hand, were expected to select the high-probability action equally often on devalued and valued trials, suggesting that their behavior is governed by a habitual process. The alternative dual-process model, by contrast, predicted that participants in both the control and stress conditions would select the high-probability action less on devalued than on valued trials, indicating that both conditions selected their behavior based on a goal-directed process. We conducted a mixed model ANOVA of the proportion of high-probability actions with value (valued, devalued, and neutral) as a within-subjects factor, and condition (control, stress) as a between-subjects factor.

Results indicated a significant main effect of value on action selection, $F(1.89, 124.33) = 7.43$, $p = .001$, $\eta_p^2 = .101$. Post hoc comparisons showed that participants selected less high-probability actions on devalued ($M = .62$, $SD = .23$) than on valued trials ($M = .72$, $SD = .18$), $t(66) = -3.17$, $p = .006$. Participants also selected less high-probability actions on neutral ($M = .60$, $SD = .24$) than on valued trials, $t(66) = 3.88$, $p < .001$. The difference between the proportion of high-probability actions on devalued and neutral trials was not significant, $t(66) = 0.51$, $p = .867$. There was also no significant effect of condition, $F(1, 66) = 0.43$, $p = .513$, $\eta_p^2 = .007$, and no significant interaction between condition and value, $F(1.89, 124.33) = 1.10$, $p = .333$, $\eta_p^2 = .016$. These results suggest that both the control condition and the stress condition responded in a goal-directed way, thereby providing support for the alternative dual-process model (Figure 5).

Reacquisition Phase

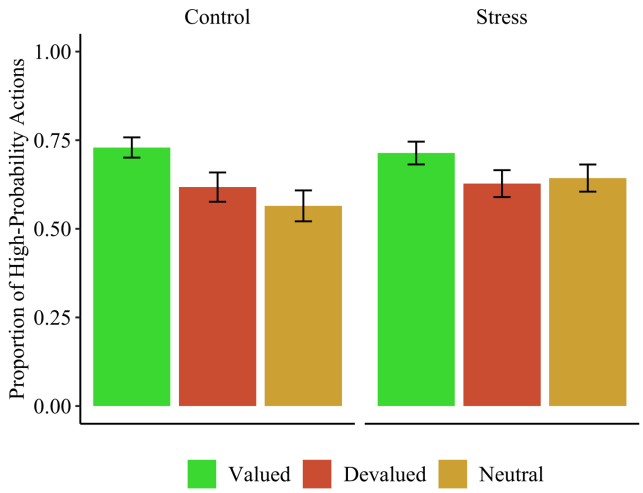
If the outcome devaluation procedure was effective in lowering the value of the devalued compared to the valued outcome, participants should respond less to obtain the devalued outcome than the valued outcome when these outcomes are again delivered in the reacquisition phase. We conducted a mixed model ANOVA of the proportion of high-probability actions with value (valued, devalued, and neutral) as a within-subjects factor, and condition (control, stress) as a between-subjects factor.

Results indicated a significant main effect of value, $F(1.64, 108.17) = 8.50$, $p < .001$, $\eta_p^2 = .114$. Post hoc comparisons showed that participants selected less high-probability actions on devalued ($M = .60$, $SD = .30$) than on valued trials ($M = .73$, $SD = .25$), $t(66) = -4.00$, $p < .001$. Participants also selected more high-probability actions on valued than on neutral trials ($M = .57$, $SD = .30$), $t(66) = 3.89$, $p < .001$. The difference between the proportion of high-probability actions on devalued and neutral trials was not significant, $t(66) = 0.73$, $p = .748$. This suggests that the devaluation indeed made the outcome aversive (Figure 6). No other effects were significant (Fs < 0.84).

Final Acquisition Block Versus Test Versus Reacquisition

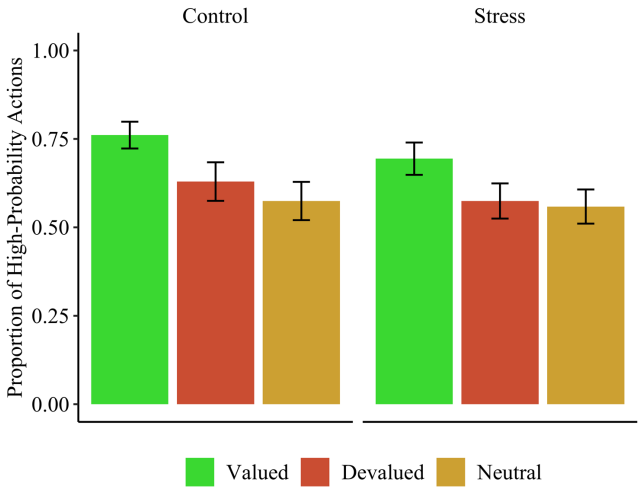
Similar to Schwabe and Wolf (2010), we also compared performance in the final acquisition block to the test and reacquisition

Figure 5
Test Performance



Note. Proportion of high-probability actions during the test phase split by the between-subjects factor condition (control, stress) and the within-subjects factor value (valued, devalued, neutral). Error bars represent standard errors. See the online article for the color version of this figure.

Figure 6
Reacquisition Performance



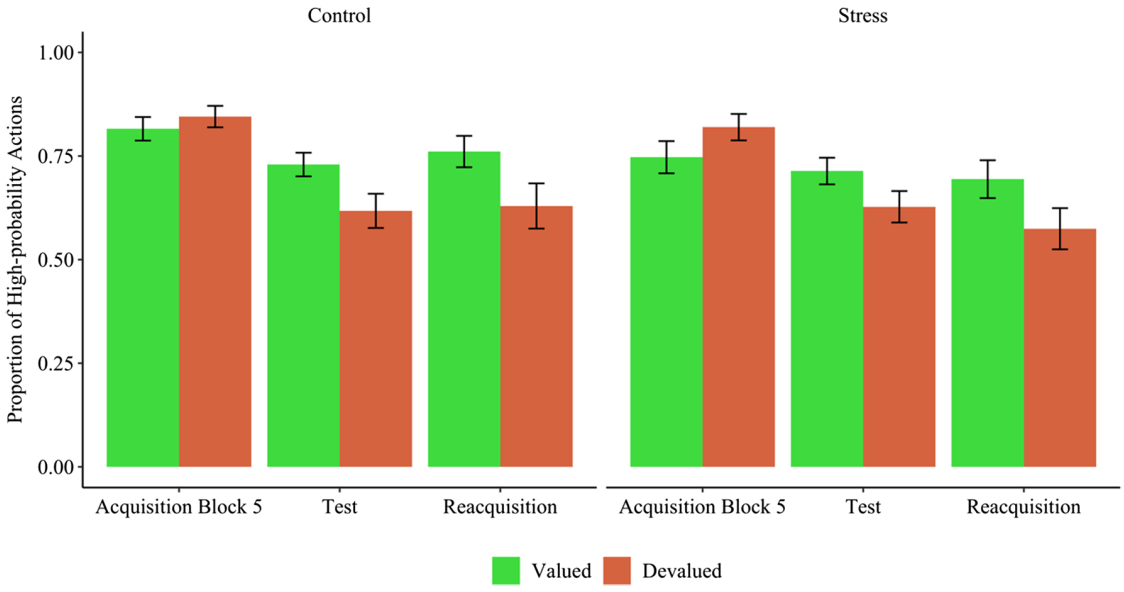
Note. Proportion of high-probability actions during the reacquisition phase split by the between-subjects factor condition (control, stress) and the within-subjects factor value (valued, devalued, neutral). Error bars represent standard errors. See the online article for the color version of this figure.

phases, thereby accounting for differences in the acquisition. To this end, we conducted a mixed model ANOVA of the proportion of high-probability actions with value (valued, devalued) and phase (acquisition Block 5, test, reacquisition) as within-subjects factors, and condition (control, stress) as a between-subjects factor.

Results indicated a significant main effect of value, $F(1, 66) = 8.60$, $p = .005$, $\eta_p^2 = .115$, suggesting more high-probability actions on valued ($M = .74$, $SD = .21$) than on devalued trials ($M = .69$, $SD = .26$). Results also indicated a significant main effect of phase, $F(1.76, 116.07) = 16.35$, $p < .001$, $\eta_p^2 = .199$. Post hoc comparisons showed that participants selected less high-probability actions during the test phase ($M = .67$, $SD = .21$) than during acquisition Block 5 ($M = .81$, $SD = .19$), $t(66) = -5.60$, $p < .001$, and less high-probability actions during the reacquisition phase ($M = .67$, $SD = .28$) than during acquisition Block 5, $t(66) = -4.36$, $p < .001$. The difference between the test and reacquisition phases was not significant, $t(66) = 0.28$, $p = .959$.

Crucially, results indicated a significant interaction between value and phase, $F(1.76, 116.07) = 14.34$, $p < .001$, $\eta_p^2 = .178$. For devalued trials, post hoc comparisons showed that participants selected less high-probability actions during the test phase ($M = .62$, $SD = .23$) than during acquisition Block 5 ($M = .83$, $SD = .17$), $t(66) = -6.42$, $p < .001$, and less high-probability actions during the reacquisition phase ($M = .60$, $SD = .30$) than during the acquisition Block 5, $t(66) = -5.83$, $p < .001$. The difference between the test and reacquisition phases was not significant, $t(66) = 0.66$, $p = .786$. For valued trials, no comparisons were significant ($ts < 1.98$). These results suggest that compared to acquisition Block 5 in which the devalued liquid was still to-be-devalued, participants decreased responding for the devalued liquid in the test and reacquisition phases after the devaluation occurred, providing support for goal-directed control (Figure 7). The value of the valued liquid was not diminished, and in line with this, responding for the valued liquid did not significantly change throughout the experiment. No other effects were significant (all $Fs < 1.20$).

Figure 7
Performance in Acquisition Block 5, Test, and Reacquisition



Note. Proportion of high-probability actions during the phases (acquisition Block 5, test, reacquisition) split by the between-subjects factor condition (control, stress) and the within-subjects factor value (valued, devalued). Error bars represent standard errors. See the online article for the color version of this figure.

Explicit Response-–Outcome Knowledge

The stress induction only took place after the acquisition phase, which is why we did not predict differences in explicit response–outcome knowledge between the stress and control conditions. A *t* test comparing the proportion of correct responses between the two conditions revealed no significant difference in the proportion of correct responses between the control ($M = .76$, $SD = .25$) and stress conditions ($M = .73$, $SD = .31$), $t(66) = 0.50$, $p = .619$.

Discussion

People sometimes engage in behaviors that are not in line with their explicit goals and they may even do so despite being aware of this. Examples are the consumption of unhealthy food, substance abuse, and short-sighted financial decision-making. These suboptimal behaviors, moreover, are more likely to occur under stress (Dallman, 2010; Haushofer & Fehr, 2014; Sinha & Jastreboff, 2013). To explain suboptimal behavior, researchers frequently invoke traditional dual-process models in which behavior can be the result of either a goal-directed or a habitual process. A widely held view is that suboptimal behavior is the result of increased reliance on habits, especially when operating conditions are poor (Wood & Rünger, 2016; Wood et al., 2022). The condition that has arguably received the most attention in empirical studies of traditional dual-process models is stress, which is supposed to cause a switch to habitual processing (Hartogsveld et al., 2020; Schwabe & Wolf, 2009, 2010, 2011; Smeets & Quaedflieg, 2016; Smeets et al., 2019; Wirz et al., 2018). This supposed switch is undergirded by an increased reliance on striatal memory, thought to encode S–R memories (Goldfarb & Phelps, 2017). According to these models then, suboptimal behavior under stress is caused by an increased reliance on habitual processes.

Support for this model was provided by devaluation studies such as that of Schwabe and Wolf (2010). In this study, sensitivity to outcome devaluation was tested with a selective satiation procedure. Results showed that participants in the control condition responded less for the devalued than for the valued outcome (i.e., devaluation effect), leading to the conclusion that the outcome values were mentally represented and adjusted in line with the devaluation and hence that responding was goal-directed. Stressed participants, by contrast, continued to respond equally for the valued and devalued outcomes (i.e., absence of a devaluation effect), leading to the conclusion that outcome values were not represented and hence that responding was habitual. The findings of Schwabe and Wolf (2010) have been replicated in a study by Schwabe et al. (2011), which also showed that the effect can be prevented by propranolol intake. Furthermore, outcome-insensitive behavior has been observed after acute stress induction before acquisition (Schwabe & Wolf, 2009) and after intake of hydrocortisone in combination with yohimbine (Schwabe, Tegenthoff, et al., 2012).

Here, we conducted a conceptual replication of the Schwabe and Wolf (2010) study, in which we used taste aversion instead of selective satiation as the method for outcome devaluation. This was inspired by Eder and Dignath (2016), who showed that previous findings of insensitivity to outcome devaluation with selective satiation did not replicate with taste aversion, which suggests that taste aversion is a stronger outcome devaluation method than selective satiation. We therefore reasoned that the selective satiation procedure used by Schwabe and Wolf (2010) may have been too weak. A replication of the pattern of findings by Schwabe and Wolf (2010) with a stronger outcome devaluation method would have provided further support for the conclusion that stress leads to an increased reliance on habitual processes. However, the present study did not replicate the original findings. Instead, it showed a devaluation effect in both the control and the stress condition. Thus, our results suggest that people under stress are sensitive to outcome values if the outcomes become truly aversive, thereby providing support for the idea that people continue to behave in a goal-directed manner even under stress.

At the very least, the current findings point to boundary conditions of the traditional dual-process account. If stress indeed (invariably) causes a switch to habitual processing, the pattern of Schwabe and Wolf (2010) should have been replicated. The fact that the pattern was not replicated in the present study calls for an explanation. Proponents of traditional dual-process models may argue that habitual processes installed in a single session in the lab may not have been as robust as those that have been established over years in daily life. Indeed, some studies found that sensitivity to outcome devaluation depends on the amount of training (Adams, 1982; Hardwick et al., 2019; Tricomi et al., 2009), which has been taken as evidence for the idea that overtraining of operant conditioning installs habitual processes. Note, however, that other studies found that behavior was still sensitive after overtraining, thereby providing evidence for goal-directed processes even after overtraining (de Wit et al., 2018; Garr et al., 2021; LaFlamme et al., 2022; Pool et al., 2022).

We proposed a goal-directed explanation based on the alternative dual-process model by Moors et al. (2017), which is able to make sense of both the findings of the study by Schwabe and Wolf (2010) and the findings of the present study. Schwabe and Wolf (2010) found that participants in the control condition responded less for the liquid that was devalued through satiation than for the still valued liquid, whereas stressed participants continued to perform both responses to the same extent. A limitation of outcome devaluation tests is that evidence for habitual processes relies on the absence of a devaluation effect for one condition, and thus a null effect for the comparison within that condition (De Houwer et al., 2018). It is possible, however, that behavior is still goal-directed and does not change for other reasons (Moors et al., 2017). In particular, we proposed that suboptimal behavior under stress may not result from a switch to habits but rather from a switch to a less obvious goal, for instance, the goal to regulate one's stress. If behavior is insensitive to the devaluation of one goal (e.g., goal to consume foods with certain flavors due to satiation), then it indicates that it is not guided by this goal, but it could still be guided by another goal (e.g., to regulate stress). Although stressed participants ate the food to satiety, the liquid may still have been liked enough to be chosen as a means to regulate stress. Taste aversion should make it less likely that the devalued liquid can still serve the goal to regulate stress, based on the assumption that eating bad-tasting food does not produce hedonic feelings and may not help to alleviate stress. In line with this, we found in our study that stressed participants were sensitive to outcome devaluation with taste aversion.

Another reason for why selective satiation but not taste aversion produces a devaluation effect also relies on a shift toward the goal to regulate stress. Stress may cause participants to prioritize the goal to regulate stress over the goal that is under study and this may

lead to reduced time, attention, and motivation to engage in a goal-directed process that is at the service of the latter goal, thereby leading to mistakes to the focal task. In the Schwabe and Wolf (2010) study, a shift toward the goal to regulate stress (via any possible strategy) may have detracted stressed participants from the goal to avoid tasting satiated flavors, leading to mistakes in action selection at the service of the latter goal. In line with the idea that stress detracts from the focal task, Raio et al. (2020) showed that (impulsive) people who were under stress showed more outcome-insensitive behavior but also responded faster. This suggests that stress encourages people to self-impose time pressure, which causes them to make more mistakes on the focal task. Likewise, Plessow et al. (2017) showed that stress made people less motivated to engage in the goal-directed process under study and therefore made more mistakes on the focal task. Crucially, it could be argued that the use of an aversive devaluation method in the present study installed the goal to avoid tasting aversive liquids and that this goal has a higher value than the goal to avoid tasting satiated liquids in the Schwabe and Wolf (2010) study. Thus, the goal to regulate stress may have detracted less from the goal to avoid tasting aversive liquids in our study compared to the goal to avoid tasting satiated liquids in the Schwabe and Wolf (2010) study. As a result, participants in our study may have made less mistakes on the focal task than those in the Schwabe and Wolf (2010) study. The proposed alternative explanations need to be taken with caution, however. Although they account for both Schwabe and Wolf's (2010) and the current findings, they were not directly tested in the present study and therefore constitute avenues for future research.

A further limitation worth pointing out is that although our study was based on Eder and Dignath's (2016) suggestion that selective satiation is a weaker method for devaluation than taste aversion, we did not compare the strength of these two methods directly in the present study. Thus, there may still be other reasons for the difference in results between the Schwabe and Wolf (2010) study and our own study (see Schreiner et al., 2020).

In this regard, it is worth pointing out that our study had an additional outcome devaluation phase after the stress induction took place (during the waiting time). This was done to ensure the effectiveness of the devaluation. It could be argued that this challenges the assumption that taste aversion is a strong outcome devaluation method per se as it may derive its strength from repeating it. However, rather than demonstrating that taste aversion is a stronger outcome devaluation than selective satiation, it was our aim to find an outcome devaluation method that left less room for the possibility that consuming the devalued liquid could still be at the service of other goals (e.g., stress regulation). Moreover, if behavior under stress is truly habitual, there seems no apparent reason why an additional devaluation phase should cause a switch to goal-directed processing.

An important strength of the present study compared to other studies in humans using selective satiation (e.g., Schwabe & Wolf, 2010; Tricomi et al., 2009) is the inclusion of a reacquisition phase as a measure of the effectiveness of the devaluation method in addition to desire ratings (e.g., Dickinson, 1985). The results of this reacquisition phase show that participants responded less to the devalued outcome when it was again delivered, suggesting that the outcomes had indeed become aversive. It is unclear whether the same results would be observed with selective satiation. In any case, we consider it advisable to include a reacquisition phase in future research.

The finding that behavior under stress can be goal-directed also has practical implications for changing suboptimal behavior. An obvious approach may be to pair suboptimal behaviors with aversive outcomes. Some existing interventions already follow this approach. For instance, alcohol intake may be reduced through Antabuse, which causes an aversive reaction to alcohol consumption, or nail biting may be reduced through applying chemicals that create an aversive taste (Gaval-Cruz & Weinshenker, 2009; Halteh et al., 2017). A limitation of this approach is that people have to be willing to consume or apply these deterrents in the first place. Furthermore, a key characteristic of suboptimal behavior is that people often seem willing to incur the negative consequences of their behavior.

If future research would confirm that some suboptimal behaviors are indeed the result of stress regulation, then this would provide additional targets for behavior change. For instance, people are more likely to select a stress regulation strategy if they expect that it will be effective in reducing their stress (Mezuk et al., 2017). Some stress regulation strategies are health-promoting (e.g., physical exercise) whereas others are health-harming (e.g., overeating, alcohol, drugs, smoking). The latter strategies may be effective to reduce people's momentary stress (i.e., short-term goal), but they do so at the expense of their health (i.e., long-term goal; Kopetz et al., 2018). Thus, a promising approach may be to change the beliefs that people have about the various outcomes of these strategies. However, suboptimal behavior may not only depend on beliefs but also on the availability of different stress-regulation strategies. This has been illustrated in the socioeconomic deprivation model of drug addiction by Hogarth (2022), according to which individuals consume substances to cope with stress, which is often caused by socioeconomic deprivation. Strategy selection may depend on availability insofar that health-harming strategies (like alcohol use) are often more available in low socioeconomic contexts.

In sum, we conducted a conceptual replication of the study by Schwabe and Wolf (2010) in which we used taste aversion instead of selective satiation as an outcome devaluation method. We did not replicate the pattern that stress leads to responding for liquids that were devalued. Therefore, our results provide no support for habits under stress. Instead, we found that stressed participants reduced responding for liquids that were devalued, thereby providing support for the operation of goal-directed processes under stress. These findings are in line with other recent theoretical and empirical work (Buabang, Boddez, et al., 2021; Buabang, Köster, et al., 2021; De Houwer et al., 2018; Hogarth, 2020, 2022; Hommel & Wiers, 2017; Kruglanski & Szumowska, 2020).

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