

Temporal dynamics of costly avoidance in naturalistic fears: Evidence for sequential-sampling of fear and reward information

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ARTICLE INFO

Keywords:

Anxiety Disorders
Phobias
Avoidance
Approach Avoidance
Decision Making

ABSTRACT

Excessive avoidance is characteristic for anxiety disorders, even when approach would lead to positive outcomes. The process of how such approach-avoidance conflicts are resolved is not sufficiently understood. We examined the temporal dynamics of approach-avoidance in intense fear of spiders. Highly fearful and non-fearful participants chose repeatedly between a fixed no spider/low reward and a spider/high reward option with varying fear (probability of spider presentation) and reward information (reward magnitude). By sequentially presenting fear and reward information, we distinguished whether decisions are dynamically driven by both information (*sequential-sampling*) or whether the impact of fear information is inhibited (*cognitive control*). Mouse movements were recorded to assess temporal decision dynamics (i.e., how strongly which information impacts decision preference at which timepoint). Highly fearful participants showed stronger avoidance despite lower gains (i.e., costly avoidance). Time-continuous multiple regression of their mouse movements yielded a stronger impact of fear compared to reward information. Importantly, presenting either information first (fear or reward) enhanced its impact during the early decision process. These findings support sequential sampling of fear and reward information, but not inhibitory control. Hence, pathological avoidance may be characterized by biased evidence accumulation rather than altered cognitive control.

1. Introduction

Functional behavior requires well-balanced decisions between approach and avoidance when rewarding outcomes that motivate approach and threatening outcomes that motivate avoidance are in conflict (Aupperle & Paulus, 2010; Corr, 2013). In anxiety disorders, avoidance is typically excessive and maladaptive (American Psychiatric Association, 2013; Craske et al., 2017). Feared stimuli (e.g., spiders in spider phobia) are persistently avoided although approach would lead to competing positive outcomes (e.g., enjoyable outdoor activities). Such avoidance despite costs (i.e., costly avoidance) can result in severe impairments and the maintenance of fear and anxiety (Craske et al., 2018; Pittig et al., 2020). Accordingly, cognitive-behavioral treatments for anxiety disorders aim to reduce maladaptive avoidance (e.g., Arnaudova

et al., 2017; Treanor & Barry, 2017). To this end, a deeper understanding of how fear governs approach-avoidance behavior is needed.

Approach-avoidance conflicts can be examined under controlled conditions by means of well-established experimental tasks. Typically, approach is concurrently linked to aversive (e.g., electrical stimulation) and rewarding outcomes (e.g., monetary rewards). Choosing to avoid, in contrast, prevents both outcomes. Hence, avoiding not only prevents the aversive outcome, but also results in costs as a potential positive gain is missed. We refer to this type of avoidance as *costly avoidance* (Boschet, Scherbaum, & Pittig, 2022; Pittig, Boschet, Glück, & Schneider, 2021; see also Glogan et al., 2022; Hulsman et al., 2021), which captures the costly nature of pathological avoidance (Kryptos et al., 2018; Pittig et al., 2018). Studies using approach-avoidance tasks revealed that costly avoidance increases with increasing probability of aversive

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<https://doi.org/10.1016/j.janxdis.2024.102844>

Received 14 March 2023; Received in revised form 24 November 2023; Accepted 19 February 2024

Available online 22 February 2024

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outcomes (e.g., Pittig & Scherbaum, 2020; Schlund et al., 2016; Zorowitz et al., 2019) and that avoidance decreases when conflicting rewards for approach are high (e.g., Pittig & Scherbaum, 2020; Sierra-Mercado et al., 2015). However, less is known about the underlying decision process guiding the final decision to approach or avoid, which seems to play an important role in clinical anxiety. Specifically, we demonstrated increased costly avoidance in individuals with anxiety disorders compared to healthy controls, but no increase in low-cost avoidance (i.e., in absence of rewards for approach; Pittig, Boschet, Glück, & Schneider, 2021). Importantly, threat and reward contingencies were simple and quickly acquired, suggesting that biased contingency learning did not (solely) explain elevated costly avoidance in individuals with anxiety disorders. Similarly, preliminary evidence showed elevated costly avoidance, but not low-cost avoidance, in high compared to low-anxious individuals when information on all outcomes was provided and did not have to be learned (Pittig & Scherbaum, 2020). These findings suggest that maladaptive avoidance originates at least partly from altered decision-making (Pittig et al., 2020). A better understanding of this decision process may thus allow for a better understanding of anxiety disorders and targeted interventions to reduce pathological avoidance.

Computer mouse-tracking, i.e., recording participants' mouse movements during decision-making, can deliver valuable insights into how decisions unfold over time (for an overview, see Stillman et al., 2018). To this end, movements are typically recorded during two-choice tasks in which a decision is made by moving the mouse cursor from the bottom center to the upper left or right corner of the screen (Schoemann et al., 2021; Stillman et al., 2018). The acquired continuous movement data reflect choice preferences during the decision process that can be examined using various analytical techniques (Hehman et al., 2015; Kieslich et al., 2019). Importantly, to use the full potential of the continuous movement data, time-continuous multiple regressions (TCMRs; Scherbaum & Dshemuchadse, 2020) can be applied. TCMR analyses follow an approach that is similar to approaches in fMRI research based on the general linear model (GLM; e.g., Friston et al., 2007): In fMRI, a regression model is applied to each voxel in brain-space to examine how strongly these voxels (and hence spatially located brain processes) are activated in relation to a trial's properties. TCMR transfers this approach to time: It applies the regression model not to voxels but to time-points of mouse movements. It hence analyses how strongly the mouse movement (and hence the decision process leaking into the movement) is affected at each time-point by each trial's properties of interest (i.e., predictors). Similar to fMRIs results of spatially spreaded patterns of brain activations, TCMR yields the strength, duration, and timing of each predictor's impact during the decision process (Scherbaum & Dshemuchadse, 2020). While the general strength of threat and reward information on final decisions can also be analyzed by choice data, their temporal impact would remain unknown (e.g., latency and duration of the impact). These insights are, however, essential to disentangle the underlying decision process, e.g., whether inhibition of one type of information is evident at later stages of the decision process. Thus, TCMR analyses provide richer and more direct insights into decision-making compared to merely assessing final decisions or compared to simpler mouse-tracking analyses that reduce the dynamics of the decision process to a single static value (Scherbaum & Dshemuchadse, 2020; see also Kieslich et al., 2019). In past research, TCMR analyses have been applied, for instance, to advance research on dietary self-control (Sullivan et al., 2015), cognitive flexibility (Dshemuchadse et al., 2015), and intertemporal decision-making (Dshemuchadse et al., 2013). Importantly, recent evidence further highlighted that TCMR analyses can assess the timing and strength of predictors' impact with good to very good reliability, and that this information represents a psychometrically valid dynamic measure of cognitive processes (Scherbaum & Dshemuchadse, 2020).

In a recent study, we examined the temporal impact of fear and reward information when avoiding a newly acquired Pavlovian fear

stimulus (CS) conflicted with gaining rewards (Boschet et al., 2022). TCMR analyses revealed a stronger and faster impact of CS probability compared to reward magnitude during the decision process, ultimately resulting in costly avoidance decisions. These results are supported by two other studies (Pittig & Scherbaum, 2020; Garcia-Guerrero et al., 2023), highlighting a stronger weighting of threat and fear information compared to reward information. Yet, it remains to be tested whether similar temporal dynamics emerge in (sub-)clinical fear and anxiety, e.g., when avoidance is directed at more naturalistic fear stimuli (instead of Pavlovian fear CSs or aversive USs). More importantly, these previous findings do not allow to disentangle competing theoretical models of the underlying decision process.

There are competing models of how decisions unfold until a final decision is made and it is not yet clear which model best describes approach-avoidance decision processes in intense fears. According to *sequential-sampling models*, individuals arrive at decisions by accumulating information until a boundary of evidence is reached (for an overview, see Forstmann et al., 2016). For example, threat and reward information may be dynamically accumulated until either the approach or avoidance boundary is reached (Pedersen et al., 2021; Rolle et al., 2022). *Cognitive control accounts*, in contrast, typically posit that adaptive decision-making requires inhibitory control to prevent impulsive behavior (e.g., Bari & Robbins, 2013; Goschke, 2014). In specific fears, threat information is assumed to trigger impulsive avoidance tendencies, which need to be inhibited, for example, by reward information. Understanding whether *sequential-sampling* or *cognitive control accounts* offer better insights into approach-avoidance decisions may have important clinical implications. For instance, *sequential-sampling models* may trace maladaptive costly avoidance back to deficient evidence accumulation, while according to *cognitive control accounts* maladaptive avoidance may be a consequence of deficient cognitive control. Combining TCMR analyses with the sequential presentation of choice-relevant information allows to distinguish which of these models better describes a given decision process (Scherbaum et al., 2018). This way, an earlier study highlighted the role of cognitive control processes during intertemporal decision-making (Scherbaum et al., 2018). In an intertemporal decision task, participants chose repeatedly between two options: a smaller but sooner and a larger but later reward. Either the delays or the reward magnitudes of both options were presented first. In line with *cognitive control accounts*, TCMR analyses revealed that options' delays showed a weaker effect during the late phase of the decision process when they were presented first, resulting in less short-sighted choices. This late decrease in impact fits the assumption that inhibitory control can take effect if sufficient time is available. Vice versa, presenting delays later led to a stronger effect of delays during the late phase of the decision process (i.e., less time for inhibitory cognitive control). Importantly, presentation order did not significantly modulate the delays' impact in the early phase of decision-making. In contrast, *sequential-sampling models* would have predicted a stronger effect of the delays right from the start of the decision process when they were presented first (i.e., earlier and prolonged evidence accumulation). These findings highlight the diverging predictions of *sequential-sampling* and *cognitive control accounts* that can be studied using temporal dynamics analyses and a varying presentation order. Thus, combining mouse-tracking and the sequential presentation of fear and reward information may also help to clarify which model better describes fearful approach-avoidance decisions.

The aim of the current study was two-fold: First, we tested the temporal dynamics of approach-avoidance decisions when avoiding naturalistic fear stimuli conflicts with gaining monetary rewards in highly fearful compared to non-fearful individuals. Second, to distinguish between *sequential-sampling* and *cognitive control models*, we tested how the order of presenting fear and reward information affects final decisions and temporal dynamics in intense fears. To this end, highly fearful and non-fearful participants completed a newly adapted approach-avoidance paradigm. In this paradigm, a no spider/low

Table 1
Socio-demographic and questionnaire data.

	Highly fearful individuals (n = 39)		Non-fearful individuals (n = 40)		t or χ^2	p	d or r	95% CI for d or r	
								Lower	Upper
Age	24.59 (4.71)	25.20 (4.19)			0.61 ^a	.544	0.14	-0.30	0.58
Sex = Female (%)	31 (79.5%)	25 (62.5%)			2.76 ^b	.097	0.19	-0.04	0.39
Fear of spiders (FSQ)	49.82 (20.93)	2.85 (5.88)			-13.65 ^a	<.001	-3.07	-3.72	-2.41
Trait anxiety (STAI-Trait)	38.49 (9.80)	34.77 (7.98)			-1.85 ^a	.068	-0.42	-0.86	0.03
State anxiety (STAI-State)	35.05 (6.19)	31.98 (5.44)			-2.35 ^a	.021	-0.53	-0.98	-0.08
Anxiety symptoms (DASS-A)	2.87 (3.83)	2.90 (4.46)			0.03 ^a	.976	0.01	-0.43	0.45
Depression (DASS-D)	5.59 (5.79)	5.60 (6.92)			0.01 ^a	.994	0.00	-0.44	0.44
Stress (DASS-S)	9.08 (8.38)	7.50 (5.97)			-0.96 ^a	.338	-0.22	-0.66	0.23
Psychological flexibility (AAQ-II)	16.31 (7.60)	16.10 (7.25)			-0.12 ^a	.901	-0.03	-0.47	0.41
Risk taking (R-1)	3.95 (1.10)	4.40 (1.30)			1.67 ^a	.100	0.38	-0.07	0.82
<i>Ratings after completion of the approach-avoidance paradigm:</i>									
Motivation to avoid spider images if the task would continue	51.46 (34.99)	12.72 (19.88)			6.07 ^a	<.001	1.37	0.87	1.85
Positive evaluation of monetary rewards during the paradigm	68.82 (13.43)	76.60 (14.95)			-2.43 ^a	.017	-0.55	-0.99	-0.10
Motivation to approach rewards if the task would continue	77.54 (15.82)	84.78 (16.40)			-2.00 ^a	.050	-0.45	-0.89	0.00

Note. Means (and standard deviations) for socio-demographic and questionnaire data. FSQ Fear of Spiders Questionnaire (Rinck et al., 2002); Szymanski & O'Donohue, 1995), STAI State-Trait Anxiety Inventory (Spielberger et al., 1983), DASS Depression Anxiety Stress Scales (Lovibond & Lovibond, 1995), AAQ-II Acceptance and Action Questionnaire II (Bond et al., 2011), R-1 short-scale risk-taking-1 (Beterlein et al., 2014).^a t (77) with Cohen's d. ^b $\chi^2(1, 79)$ with r.

reward option was linked to the absence of spiders and a small monetary reward. A spider/high reward option was associated with varying probabilities of a spider presentation (spider information) but also varying, higher monetary rewards (reward information). In trials of the “reward information first” block, reward information appeared earlier than spider information. In the “spider information first” block, spider information appeared earlier than reward information. Costly avoidance was measured by the frequency of no spider/low reward choices. Computer mouse movements were recorded to examine the temporal impact of reward and spider information. Based on our earlier findings (Boschet et al., 2022; Pittig & Scherbaum, 2020), we predicted a stronger weighting of spider compared to reward information in highly fearful individuals. We further hypothesized that temporal dynamics and final decisions of fearful individuals would provide evidence in favor of *cognitive control accounts* rather than *sequential-sampling models*. Accordingly, we predicted that presenting spider information first (i.e., more time for inhibitory control) would result in a weaker effect of this information during the late phase of the decision process, resulting in reduced costly avoidance. In contrast, when spider information is presented later, less time is available for inhibitory control, which should lead to a stronger impact of spider information during the late phases of the decision process and stronger costly avoidance.

2. Methods and materials

2.1. Participants

Based on the sample sizes of our previous studies (Boschet et al., 2022; Pittig & Scherbaum, 2020), a total of 82 participants was recruited. Participants were preselected using the German Fear of Spiders Screening (SAS; Rinck et al., 2002). This four-item questionnaire measures the four criteria relevant for diagnosing spider phobia according to DSM-5 (American Psychiatric Association, 2013): fear of spiders, physiological arousal, avoidance of spiders, and the subjective burden caused by fear. Individuals with scores equal to or less than four were invited and included as non-fearful healthy controls, those with scores equal to or greater than 15 as highly fearful participants (cf. Becker & Rinck, 2004; Rinck et al., 2005). More details on in-/exclusion criteria and recruitment are provided in Appendix A.

Three participants were removed from data analysis, two for revealing an exclusion criterion during the assessment, and one due to technical issues. Accordingly, the final sample comprised 39 highly fearful individuals and 40 non-fearful individuals. SAS scores suggest that 33 out of the 39 participants in the fearful sample met all four criteria relevant for diagnosing spider phobia. The remaining 6 individuals fulfilled all criteria except for the criterion of significant subjective burden. In specific fears, impairment is typically low if the fear stimulus occurs infrequently or if avoidance is well integrated into daily life (Becker & Rinck, 2004; LeBeau et al., 2010; Rinck et al., 2005). But importantly, all participants in the fearful sample met the diagnostic criteria of phobic fear, physiological arousal, and avoidance. Written informed consent was provided by all participants. All procedures were approved by the ethics committee of the Technische Universität Dresden (EK304072015, project B3) and performed following the ethical guidelines of the German Psychological Society (DGPs).

Table 1 presents socio-demographic and questionnaire data. As expected, highly fearful participants reached significantly higher scores on the Fear of Spiders Questionnaire (FSQ; Szymanski & O'Donohue, 1995; German version by Rinck et al., 2002) compared to individuals recruited as non-fearful.

2.2. Procedure

Following written informed consent, participants completed a questionnaire battery (for details, see Appendix B and Table 1). Next, highly fearful and non-fearful individuals performed an approach-

avoidance decision paradigm that was identical for all participants.

2.3. Stimuli

During the approach-avoidance paradigm, four pictures of spiders were used as naturalistic fear stimuli (e.g., a picture of a spider on a green leaf). In addition, four images showing similar pictures but without spiders were included as neutral stimuli (e.g., a blank green leaf). Pleasantness ratings confirmed that fear stimuli were highly unpleasant for highly fearful participants, but not for non-fearful participants (for details, see Appendix C).

2.4. Approach-avoidance paradigm

The approach-avoidance paradigm was adapted from our previous studies (Boschet et al., 2022; Pittig & Scherbaum, 2020). It comprised two blocks with 180 trials each (i.e., 360 in total). In each trial, participants chose between two options that were shown counterbalanced on the right and left side of the screen: A no spider/low reward option was associated with the certain absence of spider images (0%) and a fixed, small monetary reward (25 Cents). A spider/high reward option was linked to varying probabilities of a spider image presentation (0%, 10%, 25%, 45%, 70% or 100%) and varying, higher monetary rewards (28, 36, 50, 83 or 125 Cents). In each of the two blocks, all possible combinations of spider probability and reward magnitude (30 combinations) were shown 6 times in a randomized order (i.e., each reward magnitude was paired with each spider probability). Importantly, both blocks differed in which information was presented first: In trials of the “reward information first” block, information about rewards appeared earlier than spider probabilities. In the “spider information first” block, spider probabilities appeared earlier than reward information. Participants were informed that, across blocks, three random trials would be

drawn and that the monetary rewards selected in these trials would be summed up and paid out at the end of the session. Costly avoidance was measured by the frequency of no spider/low reward choices.

To examine the temporal decision process preceding approach-avoidance decisions (i.e., the temporal impact of spider probability and reward magnitude), we further recorded participants’ computer mouse movements. For this purpose, each trial sequence was standardized (see Fig. 1): First, either the rewards or the spider probabilities of both options appeared on screen, depending on the current block (“reward information first” vs. “spider information first”). Participants then started each trial by clicking into a small box at the bottom middle of the screen within a time limit of 3 s, which ensured a fixed starting position (Alignment stage). Next, an upward movement was required until the mouse cursor exceeded an invisible horizontal line 50 pixels above the starting position within a time limit of 1.5 s (Start stage). This stage was not restricted to vertical movements, i.e., participants could freely move the mouse cursor. This assured that a naturalistic movement was initiated prior to the next stage. As soon as the mouse cursor crossed this horizontal line, the missing reward or spider probability information was presented for both options (i.e., previously missing information appeared). Next, participants had to select one of the options by continuously moving the mouse cursor to one of the response boxes in the left or right corner of the screen within a time limit of 1.5 s (Response stage). Depending on the chosen option, an image of a spider was presented for 2 s with the indicated probability followed by an inter-trial interval of 0.5 s. In trials in which no spider was presented, a neutral image without spider was shown for 2 s. If participants exceeded a time limit, an error message was shown for 0.75 s and the trial was cancelled. These failed trials were repeated once at the end of the corresponding block to obtain data for as many trials as possible.

Time limits were introduced to ensure continuous mouse movements (i.e., there was no time to pause the movement during decision-making).

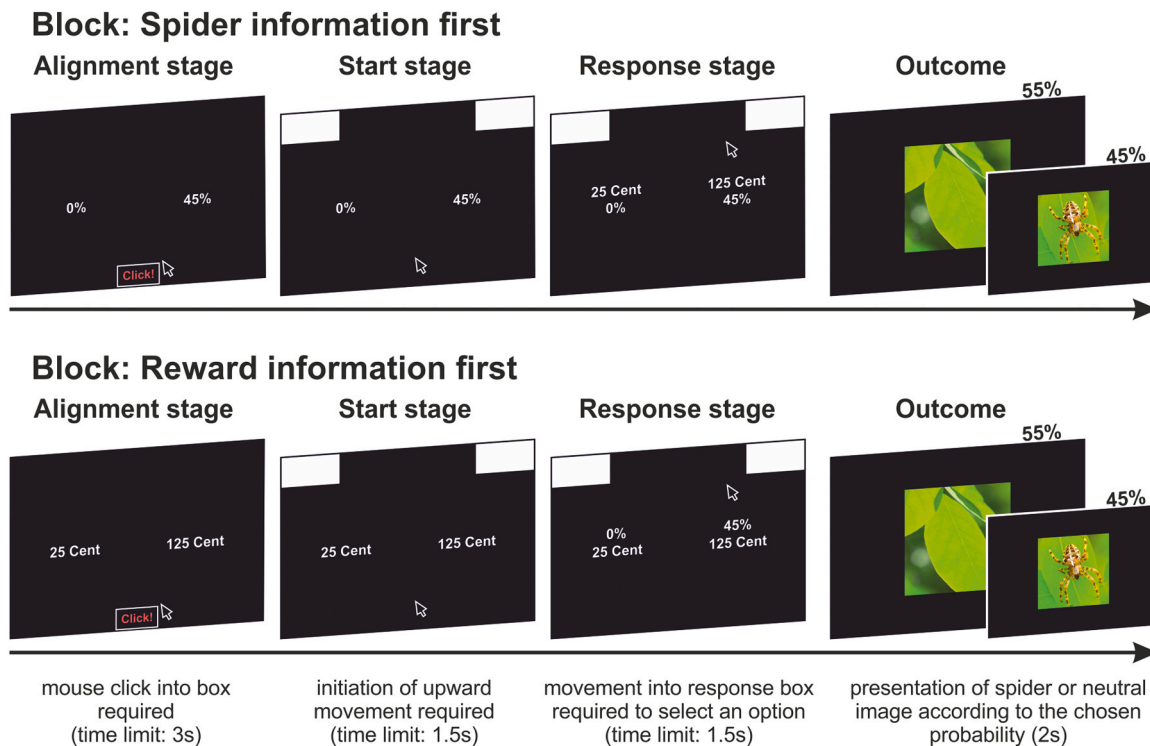


Fig. 1. Schematic representation of the trial sequence for the “spider information first” block and the “reward information first” block. First, either the rewards or the spider probabilities of both options were presented, and participants had to click into a small box at the bottom of the screen (time limit: 3 s). Second, an upward mouse movement was required until the mouse cursor crossed an invisible horizontal line 50 pixels above the starting position (time limit: 1.5 s). Third, monetary rewards and spider probabilities were presented for both options, and participants could choose one of the options by moving the mouse cursor to the response box of their preferred option (time limit: 1.5 s). Finally, an image of a spider was presented with the chosen probability (duration: 2 s). In trials without a spider presentation, a neutral image without spider was shown.

In addition, participants were instructed to perform smooth, upward mouse movements without stopping until they reached the response box of their preferred option. Before starting the approach-avoidance paradigm, the experimenter demonstrated the correct execution of the mouse movements and participants completed 20 practice trials without spider images and without the possibility of gaining monetary rewards.

2.5. Data preprocessing and statistical analysis

2.5.1. Approach-avoidance decisions

Participants' final decisions during the paradigm are a binary outcome (i.e., either a no spider/low reward or a spider/high reward choice), thus generalized linear mixed models (GLMMs) were used for analysis. GLMMs were implemented using R (R Core Team, 2020) as well as the packages *lme4* (Bates et al., 2015) and *afex* (Singmann et al., 2021). To account for the binary nature of the data, GLMMs were fit by maximum likelihood (Laplace Approximation) with binomial error distribution and the logit link function. Continuous predictors were centered ($M = 0$) and scaled ($SD = 1$) prior to analysis. Correlations among random terms were disabled. Likelihood ratio tests were applied to obtain p-values for fixed effects. Follow-up analyses were calculated using the R package *emmeans* (Lenth, 2022).

First, final decisions of all participants were analyzed using a GLMM. Fixed effects included the continuous predictors *Reward Magnitude* and *Spider Probability* of the spider/high reward option, the categorical predictor *Group* and all two-way interactions. The model further comprised a by-participant random intercept and by-participant random slopes for *Reward Magnitude* and *Spider Probability*. A more complex model including the three-way interaction of all predictors yielded the same significant main effects and two-way interactions, however the three-way interaction was non-significant and thus not included in the final model.

Next, to examine how the order of presenting spider and reward information affects decisions in fearful and non-fearful individuals, we ran the same GLMM with the additional categorical predictor *Block*. Fixed effects included all two- and three-way interactions as well as the four-way interaction of all predictors. In addition, a by-participant random slope for *Block* was introduced. Since the model yielded a significant four-way interaction, a separate follow-up model for each group was computed. In both follow-up models, fixed effects included the continuous predictors *Reward Magnitude* and *Spider Probability*, the categorical predictor *Block* and all two-way interactions. More complex follow-up models including the three-way interaction of all predictors yielded the same significant main effects and two-way interactions, however the three-way interactions were non-significant in both groups and thus not included in the final models.

2.5.2. Mouse movement trajectories

For temporal dynamics analyses, mouse movement trajectories (i.e., time series of x and y-coordinates) were recorded during the Response Stage of the paradigm. The resolution was set to 10 ms (i.e., a sampling rate of 100 Hz). Preprocessing and statistical analysis of movement trajectories were performed using Matlab 2015b (The MathWorks Inc., Natick, Massachusetts, United States) and followed the procedures applied in our previous study (Boschet et al., 2022).

During preprocessing, trajectories ending on the right side were mirrored to the left so that all movements end in the same direction. Next, all movement trajectories were realigned to a common starting position on the x-axis and each trajectory was time-normalized to 100 time slices of equal length. The angle of movement relative to the y-axis was calculated for each time slice. Each movement angle represents the momentary movement tendency towards or away from the spider/high reward option (i.e., the instantaneous direction of the mouse cursor during a specific time slice; for details, see Scherbaum & Dshemuchadse, 2020). Movement angles were then entered as dependent variable into statistical analyses.

To analyze the temporal impact of spider and reward information during decision-making in intense fears, movement angles of highly fearful participants were entered as dependent variable into a time-continuous multiple regression (TCMR; for details, see Scherbaum & Dshemuchadse, 2020). Further, to explore the temporal impact of spider and reward information in absence of fear, a second TCMR was conducted with movement angles of non-fearful participants as dependent variable. All TCMRs were conducted using the TCMR toolbox for Matlab (Scherbaum, 2020; Scherbaum & Dshemuchadse, 2020). For each TCMR, *Spider Probability* and *Reward Magnitude* of the spider/high reward option were used as continuous predictors. To obtain comparable beta weights, both continuous predictors were normalized to an interval of -1 to 1 . Next, a multiple regression with these two predictors and movement angle as dependent variable was computed for each time step within each individual (i.e., 100 multiple regressions per participant), resulting in two time-varying beta weights for each participant (2 predictors \times 100 time steps). One-sided *t*-tests were calculated to test the beta weights for each predictor at each time step against zero. Positive beta weights were expected for the predictor *Reward Magnitude* (i.e., higher rewards should predict movements towards the spider/high reward option). Negative beta weights were expected for *Spider Probability* (i.e., higher spider probabilities should predict movements towards the no spider/low reward option). As in previous research, only segments of more than 10 consecutive time steps with significant beta weights were considered meaningful to correct for multiple comparisons (Boschet et al., 2022; Pittig & Scherbaum, 2020; Garcia-Guerrero et al., 2023; for Monte Carlo analyses on this issue, see Scherbaum et al., 2015; Dale et al., 2007). Taken together, these analyses reveal how strong the impact of reward and fear information is at different time points during the decision process. For highly fearful individuals, we predicted a stronger temporal impact of fear compared to reward information.

Importantly, further TCMR analyses were conducted to examine how the order of presenting spider and reward information affects the temporal dynamics in highly fearful and non-fearful individuals. We conducted a separate TCMR on movement angles with the predictors *Spider Probability* and *Reward Magnitude* for each block of the paradigm ("spider information first" and "reward information first") for highly fearful participants. The resulting beta weights for each time step, each predictor, and each block (2 predictors \times 100 time steps \times 2 blocks per participant) were then entered into within subject *t*-tests to test for changes in the temporal impact of spider and reward information between the two blocks. Next, to explore the effect of presentation order in absence of fear, the same TCMR analysis was conducted for non-fearful participants. As above, only segments of more than 10 successive time steps with significant *t*-tests were considered meaningful. For this analysis, we predicted that presenting spider information first in highly fearful individuals would result in a weaker effect of spider information during the late phase of the decision process compared to when reward information is presented first (in line with *cognitive control accounts*).

2.6. Transparency and openness

We reported all manipulations and procedures, how we determined our sample size, all data exclusions, all dependent measures assessed as well as all hypotheses and statistical analyses conducted for this study. The current study's design and its analysis were not pre-registered. However, sample size, preprocessing, and statistical analyses closely followed the procedures established in our previous study (Boschet et al., 2022). TCMR analyses followed standards established in previous studies (Pittig & Scherbaum, 2020; Garcia-Guerrero et al., 2023; for Monte Carlo analyses, see Scherbaum et al., 2015; Dale et al., 2007). There were no performance-based exclusion criteria.

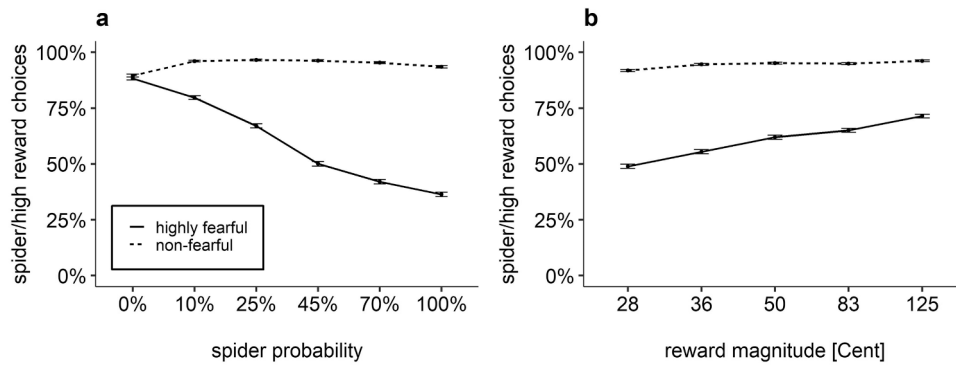


Fig. 2. Mean percentage of spider/high reward choices (with standard error) in relation to (a) spider probability and (b) reward magnitude of the spider/high reward option for highly fearful and non-fearful individuals.

3. Results

3.1. Costly avoidance of naturalistic fear stimuli

3.1.1. Highly fearful and non-fearful individuals

Highly fearful participants chose the spider/high reward option in 60.6% of the trials ($SD = 26.1\%$); non-fearful participants chose this option in 94.5% of the trials ($SD = 8.8\%$). Within highly fearful individuals, the frequency of spider/high reward choices strongly declined with increasing probability of a spider presentation (see Fig. 2). In contrast, non-fearful participants rarely selected the no spider/low reward option irrespective of the indicated spider probability. Accordingly, we found a significant interaction of the predictors *Group* and *Spider Probability*, $\chi^2(1) = 27.94, p < .001$. A follow-up analysis revealed a stronger effect of spider probabilities in highly fearful participants: The estimated trend for *Spider Probability* was steeper and more negative in highly fearful individuals (slope = -2.19 ; $CI_{95} = -2.90$ to -1.47) compared to non-fearful individuals (slope = 0.88 ; $CI_{95} = 0.15$ to 1.60). Bonferroni corrected follow-up comparisons of estimated marginal

means (EMMs) yielded no significant difference between groups for the three lowest spider probabilities (0%, 10%, 25%), $|z\text{-ratio}|s \leq 2.44, ps \geq .089$. Importantly, however, highly fearful participants compared to non-fearful participants more frequently avoided the spider/high reward option when it was linked to higher spider probabilities (45%, 70%, 100%), $|z\text{-ratio}|s \geq 4.11, ps < .001$. The maximum estimated difference between groups according to EMMs was 94.1% and occurred at the spider probability of 100%. The minimum estimated difference between groups was 4.8% at the spider probability of 0%.

In addition, highly fearful individuals showed an increasing frequency of spider/high reward choices with increasing reward magnitudes (see Fig. 2). Decisions of non-fearful participants were less strongly affected by the varying reward magnitudes. This effect was indicated by a significant interaction of the predictors *Group* and *Reward Magnitude*, $\chi^2(1) = 6.80, p = .009$. A follow-up analysis revealed a stronger effect of the varying rewards in highly fearful individuals: The estimated trend for *Reward Magnitude* was more positive in highly fearful participants (slope = 0.92 ; $CI_{95} = 0.71$ to 1.12) compared to non-fearful individuals (slope = 0.45 ; $CI_{95} = 0.21$ to 0.70). Bonferroni corrected follow-up

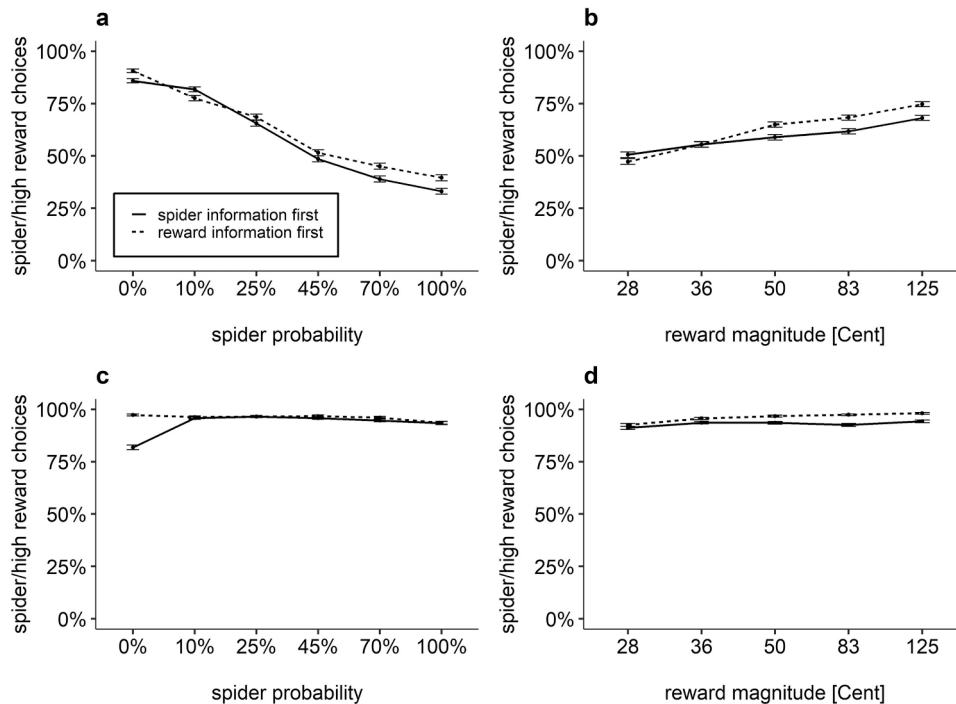


Fig. 3. Mean percentage of spider/high reward choices (with standard error) in highly fearful individuals in relation to (a) spider probability and (b) reward magnitude and in non-fearful individuals in relation to (c) spider probability and (d) reward magnitude of the spider/high reward option, separately for the “spider information first” block and the “reward information first” block.

comparisons of EMMs indicated more frequent avoidance of the spider/high reward option in highly fearful individuals compared to non-fearful individuals for all reward magnitudes (28, 36, 50, 83, 125 Cents), $|z\text{-ratio}|s \geq 4.07$, $ps < .001$. The maximum estimated difference between groups according to EMMs was 52.9% and occurred at the reward magnitude of 28 Cents. The minimum estimated difference between groups was 24.5% at the reward magnitude of 125 Cents. There was no significant interaction of the predictors *Spider Probability* and *Reward Magnitude*, $\chi^2(1) = 1.55$, $p = .213$.

Taken together, highly fearful participants showed increased avoidance with increasing spider probability. Importantly, such an increase in avoidance was not observed in non-fearful individuals. Thus, intense fear led to significant costly avoidance. However, avoidance decreased in highly fearful participants as rewards for approach increased.

3.1.2. Order of fear vs. reward information

The effect of presentation order was small in non-fearful individuals. In contrast, decisions of highly fearful individuals responded more strongly to the varying reward magnitudes, spider probabilities, the order of fear vs. reward information, as well as their interactions (see Fig. 3). These different patterns of results between groups resulted in a significant four-way interaction of *Group*, *Block*, *Spider Probability*, and *Reward Magnitude*, $\chi^2(1) = 4.90$, $p = .027$. To follow up on this effect, a separate follow-up model for each group was computed.

In the “spider information first” block, highly fearful participants chose the spider/high reward option in 59.0% of the trials ($SD = 26.9\%$); in the “reward information first” block, they chose the spider/high reward option in 62.2% of the trials ($SD = 26.4\%$). In both blocks, the frequency of spider/high reward choices in highly fearful individuals decreased with increasing spider probability. Importantly, this decrease was steeper in the “spider information first” compared to the “reward information first” block (see Fig. 3). This effect was indicated by a significant interaction of the predictors *Block* and *Spider Probability*, $\chi^2(1) = 28.02$, $p < .001$. The estimated trend for *Spider Probability* was more negative in the “spider information first” block (slope = -2.57 ; $CI_{95} = -3.57$ to -1.57) compared to the “reward information first” block (slope = -2.17 ; $CI_{95} = -3.17$ to -1.17). Bonferroni corrected follow-up comparisons of EMMs indicated no significant difference between blocks for most spider probabilities (0%, 10%, 25%, 45%, 100%), $|z\text{-ratio}|s \leq 2.21$, $ps \geq .165$. However, less frequent spider/high reward choices in the “spider information first” compared to the “reward information first” block were found for the spider probability of 70%, $|z\text{-ratio}| = 3.52$, $p = .003$. The maximum estimated difference between blocks in EMMs was 14.6% and occurred accordingly at the spider probability of 70%, indicating a small effect.

In both blocks, the frequency of spider/high reward choices in highly fearful individuals increased with increasing reward magnitude. But importantly, this increase was steeper in the “reward information first” compared to the “spider information first” block (see Fig. 3). Hence, we found a significant interaction of the predictors *Block* and *Reward Magnitude*, $\chi^2(1) = 33.80$, $p < .001$. The estimated trend for *Reward Magnitude* was more positive in the “reward information first” block (slope = 1.19; $CI_{95} = 0.94$ to 1.44) compared to the “spider information first” block (slope = 0.82; $CI_{95} = 0.57$ to 1.06). Bonferroni corrected follow-up comparisons of EMMs indicated no significant difference between blocks for the three lowest reward magnitudes (28, 36, 50 Cents), $|z\text{-ratio}|s \leq 1.50$, $ps \geq .672$. Importantly, however, the spider/high reward option was more frequently selected in the “reward information first” compared to the “spider information first” block when it was linked to higher reward magnitudes (83, 125 Cents), $|z\text{-ratio}|s \geq 3.05$, $ps \leq .011$. The maximum estimated difference between blocks in EMMs was 12.8% and occurred at the reward magnitude of 125 Cents, indicating a small effect. Again, there was no significant interaction of the predictors *Spider Probability* and *Reward Magnitude*, $\chi^2(1) = 0.19$, $p = .665$.

A different pattern of results was found in non-fearful individuals (see Fig. 3). In the “spider information first” block, non-fearful participants chose the spider/high reward option in 93.0% of the trials ($SD = 10.3\%$); in the “reward information first” block, they chose the spider/high reward option in 96.1% of the trials ($SD = 8.4\%$). Because of this high frequency of approach and low variance in final decisions, the follow-up model for non-fearful participants only is considered to be of limited informative value (i.e., since variance in the dependent variable is needed to obtain meaningful statistical models). This is also reflected in the merely small statistical effects of the predictors included in the model.

Only for the spider probability of 0%, the frequency of spider/high reward choices was lower in the “spider information first” compared to the “reward information first” block (see Fig. 3). This effect was reflected in a significant interaction of the predictors *Block* and *Spider Probability*, $\chi^2(1) = 41.24$, $p < .001$. The estimated trend for *Spider Probability* was steeper in the “spider information first” block (slope = 0.91; $CI_{95} = 0.44$ to 1.38) compared to the “reward information first” block (slope = 0.20; $CI_{95} = -0.29$ to 0.68). Bonferroni corrected follow-up comparisons of EMMs indicated no significant differences between blocks for any of the individual spider probabilities, $|z\text{-ratio}|s \leq 2.18$, $ps \geq .175$. Descriptively, the maximum estimated difference between blocks in EMMs was 2.0% and occurred at the spider probability of 0%.

In non-fearful participants, the slight increase in spider/higher reward choices with increasing reward magnitude was a bit steeper in the “reward information first” compared to the “spider information first” block (see Fig. 3). This was evident in a significant interaction of the predictors *Block* and *Reward Magnitude*, $\chi^2(1) = 26.66$, $p < .001$. The estimated trend for *Reward Magnitude* was more positive in the “reward information first” block (slope = 0.82; $CI_{95} = 0.57$ to 1.06) compared to the “spider information first” block (slope = 0.24; $CI_{95} = 0.05$ to 0.42). Bonferroni corrected follow-up comparisons of EMMs indicated no significant differences between blocks for any of the individual reward magnitudes, $|z\text{-ratio}|s \leq 2.20$, $ps \geq .139$. Descriptively, the maximum estimated difference between blocks in EMMs was 0.9% and occurred at the reward magnitude of 83 Cents. Again, there was no significant interaction of the predictors *Spider Probability* and *Reward Magnitude*, $\chi^2(1) = 1.13$, $p = .289$.

In sum, final decisions of highly fearful individuals were more strongly affected by fear information when this information was presented before reward information. Likewise, reward information had an increased influence on final decisions if it was presented before fear information. This suggests that presenting a piece of information first may enhance its impact on fearful approach-avoidance decisions. However, descriptively, these effects tended to be small (see also Fig. 3). In contrast, final decisions of non-fearful individuals were barely affected by presentation order. Most notably, the order of presentation was effective when a spider probability of 0% was presented (see Fig. 3), presumably because non-fearful participants could not identify the high reward option when spider information were presented first. However, the corresponding follow-up comparison was non-significant.

3.2. Temporal impact of reward and fear information

3.2.1. Highly fearful and non-fearful individuals

Results of the TCMR for highly fearful participants are shown in Fig. 4 and Table 2. Throughout the decision process, both *Spider Probability* and *Reward Magnitude* showed a continuously significant impact: Higher spider probabilities predicted avoidance movements, i.e., movement tendencies towards the no spider/low reward option; higher competing rewards predicted approach movements, i.e., tendencies towards the spider/high reward option. The impact of *Spider Probability* was considerably stronger compared to the impact of *Reward Magnitude* (see Fig. 4 and Table 2).

Results of the TCMR for non-fearful participants are shown in Fig. 4. In these individuals, there was little variance in movement tendencies.

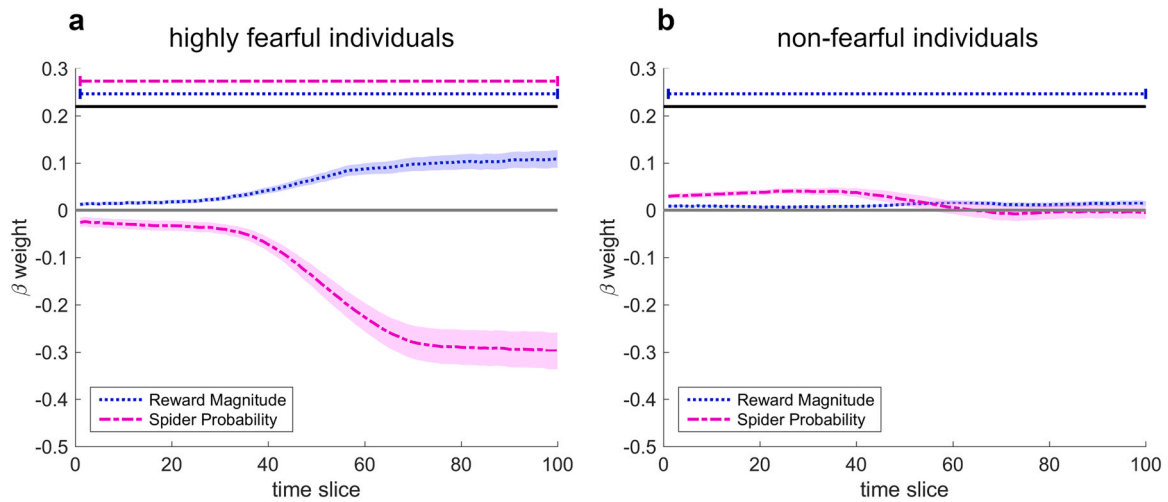


Fig. 4. Time-continuous beta weights from TCMR analysis in (a) highly fearful participants and (b) non-fearful individuals for the predictors Reward Magnitude and Spider Probability. Positive β weights indicate tendencies towards the spider/high reward option, negative β weights indicate tendencies towards the no spider/low reward option. Horizontal lines at the top indicate segments of significant impact. Shaded areas represent standard error of the mean. Only segments of more than 10 successive significant one-sided t -tests were accepted as meaningful.

Table 2
Segments of significant beta weights for Reward Magnitude and Spider Probability in highly fearful individuals.

Beta for	Highly fearful individuals			
	Start	End	Duration	Peak strength
Reward Magnitude	1	100	99 (\approx 801.9 ms)	0.108
Spider Probability	1	100	99 (\approx 801.9 ms)	0.298

Note. In highly fearful individuals, a time slice corresponds on average to 8.1 ms. Only segments of more than 10 significant one-sided t -tests were accepted as meaningful.

This is also reflected in the small impact of both Spider Probability and Reward Magnitude throughout the decision process (see Fig. 4), reflecting many pre-planned decisions.

In sum, the TCMR analysis for highly fearful individuals provides evidence for a stronger weighting of fear information towards avoidance

compared to reward information, which was weighted towards approach. This temporal pattern was not observed in non-fearful individuals: the temporal impact of both information remained small throughout decision-making, which indicates many pre-planned approach decisions irrespective of fear and reward information.

3.2.2. Order of fear vs. reward information

Results of the blockwise TCMR analysis in highly fearful individuals are displayed in Fig. 5 and Table 3. In the “spider information first” block, a continuously significant impact of Spider Probability emerged right from the beginning of the decision process, while the impact of Reward Magnitude appeared later. In the “reward information first” block, the impact of Reward Magnitude was continuously significant from the start of the decision process, while the impact of Spider Probability emerged later. Accordingly, in the early phase of the decision process, a significantly stronger impact of Spider Probability was found in the “spider information first” compared to the “reward information first” block. Likewise, a significantly stronger impact of Reward

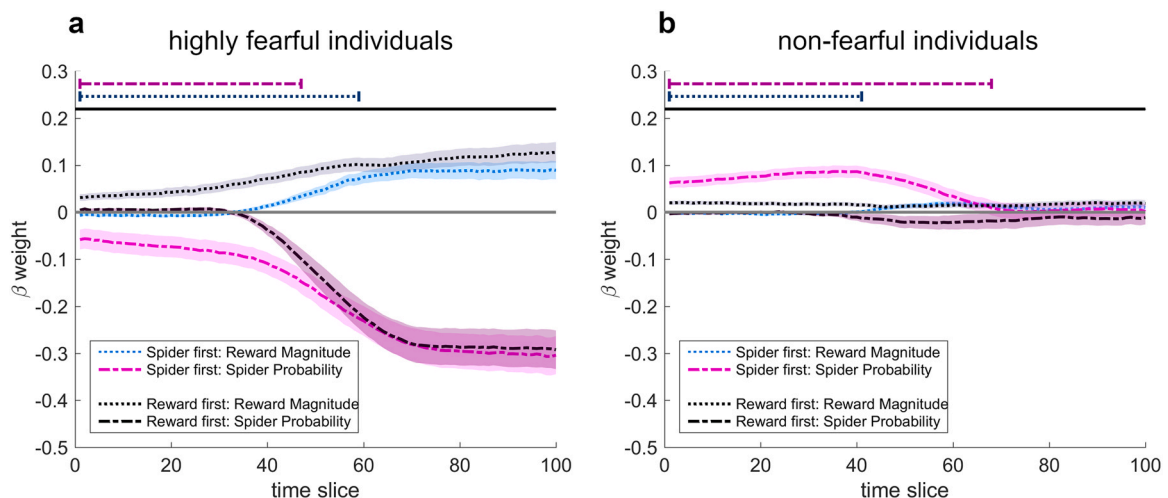


Fig. 5. Time-continuous beta weights from TCMR analysis for the predictors Reward Magnitude and Spider Probability for the “spider information first” block (light-colored) and the “reward information first” block (dark-colored) in (a) highly fearful participants and (b) non-fearful individuals. Positive β weights indicate tendencies towards the spider/high reward option, negative β weights indicate tendencies towards the no spider/low reward option. Horizontal lines at the top indicate segments of significant difference between blocks for a specific predictor. Shaded areas represent standard error of the mean. Only segments of more than 10 successive significant t -tests were accepted as meaningful.

Table 3

Segments of significant beta weights for Reward Magnitude and Spider Probability separately for the “spider information first” block and the “reward information first” block in highly fearful individuals.

Beta for	Spider information first				Reward information first				Spider vs. reward information first		
	Start	End	Duration	Peak strength	Start	End	Duration	Peak strength	Start	End	Duration
Reward Magnitude	37	100	63 (\approx 510.3 ms)	0.090	1	100	99 (\approx 801.9 ms)	0.127	1	59	58 (\approx 469.8 ms)
Spider Probability	1	100	99 (\approx 801.9 ms)	0.307	37	100	63 (\approx 510.3 ms)	0.293	1	47	46 (\approx 372.6 ms)

Note. Only segments of more than 10 significant *t*-tests were accepted as meaningful. In highly fearful individuals, a time slice corresponds on average to 8.1 ms.

Magnitude was found at the beginning of the decision process in the “reward information first” compared to the “spider information first” block. Importantly, in the late phase of the decision process no significant difference between blocks was found for any of the predictors (i.e., there was no late decrease in impact of spider information when this information was presented first; see Fig. 5). In both blocks, the peak impact of Spider Probability was stronger than the peak impact of Reward Magnitude (see Table 3).

Results of the blockwise TCMR analysis for non-fearful individuals are also displayed in Fig. 5. In the “reward information first” block, the impact of both Reward Magnitude and Spider Probability remained very small throughout the decision process, reflecting pre-planned decisions. In the “spider information first” block, the impact of Reward Magnitude was also very small during the entire decision process. However, interestingly, in the “spider information first” compared to the “reward information first” block, Spider Probability showed a significantly stronger impact in the early phase of the decision process towards the spider/high reward option (i.e., higher spider probabilities predicted approach movements). Further, a significantly stronger impact of Reward Magnitude was found at the beginning of the decision process in the “reward information first” compared to the “spider information first” block (see Fig. 5).

In summary, for highly fearful individuals, the impact of fear-relevant information occurred earlier during decision-making if that information was presented first. Likewise, rewards had an earlier impact if they were shown first. This suggests that the information presented first already guides the decision-making process even if the other information (fear or reward) is not yet available (i.e., highly fearful participants do not withhold decision-making until all relevant information is present). But importantly, no late decrease in impact of fear-relevant information was found when this information was presented first. In non-fearful individuals, in contrast, both fear and reward information barely affected decision-making. The only notable exception was the early but not lasting impact of fear information when this information was presented first.

4. Discussion

This study investigated approach-avoidance decisions and their temporal dynamics when avoiding naturalistic fear stimuli conflicts with competing rewards. By continuously recording mouse cursor movements needed for selecting an option, insights into the distinct temporal decision processes in highly fearful individuals were gained. To distinguish between *cognitive control* and *sequential-sampling models*, fear and reward information were presented in varying order (fear vs. reward information first) while final decisions and mouse movements were assessed. Main findings show (a) significant costly avoidance in highly fearful participants, which decreased as rewards for approach increased. (b) Temporal dynamics analyses uncovered a stronger impact of fear compared to reward information during the decision process. (c) Presenting either information first (fear or reward) enhanced its impact during the early decision process and on final approach-avoidance decisions of highly fearful individuals. However, no significant effect of presentation order was found during the late decision process. Taken together, we replicated the stronger weighting of fear compared to rewards during approach-avoidance decisions found in our previous study

(Boschet et al., 2022) in face of naturalistic fear stimuli. Importantly, the finding of an increased impact of information presented first during early decision-making while no effect of presentation order was found during late decision-making is not in line with *cognitive control accounts* and rather matches the predictions of *sequential-sampling models*. These findings provide important insights into approach-avoidance decision processes with significant clinical implications.

Final decisions of highly fearful participants were systematically influenced by both the probability of a spider presentation and the varying reward magnitudes. In particular, costly avoidance increased substantially with increasing spider probability, which parallels previous findings on US-avoidance (Pittig & Scherbaum, 2020; Sierra-Mercado et al., 2015; Zorowitz et al., 2019) and fear CS-avoidance (Boschet et al., 2022). This highlights that, as expected, naturalistic fear stimuli effectively motivate avoidance despite costs. Remarkably, avoidance in the highly fearful sample decreased with increasing rewards for approach. Thus, competing rewards can help to counter not only US- and CS-avoidance (Boschet et al., 2022; Pittig & Scherbaum, 2020; Sierra-Mercado et al., 2015), but also avoidance of naturalistic fear stimuli in highly fearful individuals (in line with Pittig et al., 2018). This strengthens the notion that competing rewards and goals may support the reduction of maladaptive avoidance in clinical populations (see also Pittig et al., 2020). Non-fearful participants, in contrast, rarely avoided, irrespective of the varying reward magnitudes and spider probabilities. Notably, the merely small impact of the varying rewards in non-fearful participants was due to the extremely high proportion of approach even in presence of small competing rewards. In sum, intense fear was specifically linked to pronounced costly avoidance.

Moreover, temporal dynamics analyses revealed how fear and competing rewards guide the underlying approach-avoidance decision process. Specifically, we found a strong impact of fear information during the decision process in highly fearful individuals, while the temporal impact of reward information was less pronounced (i.e., the beta weight of Spider Probability reached a maximum of \sim 0.30, while the peak beta of Reward Magnitude was \sim 0.11). Thus, in highly fearful individuals, fear information was the main driving factor during decision-making. In non-fearful participants, in contrast, temporal dynamics analyses were less informative, since there was little variance in movement tendencies. This reflects many pre-planned approach decisions irrespective of fear and reward information. This finding is not surprising, as non-fearful participants were not afraid of the fear stimuli and thus were not assumed to experience approach-avoidance conflict. In summary, temporal dynamics analyses of mouse movements replicated the stronger weighting of fear and threat information in approach-avoidance decisions found in our earlier studies (Boschet et al., 2022; Pittig & Scherbaum, 2020), but using naturalistic fear stimuli in intense fear of spiders.

Further, the order of presenting fear and reward information had a systematic effect on decisions of highly fearful participants and their temporal dynamics. Presenting an information first significantly enhanced its impact on final decisions, which was true for fear and reward information, although these effects tended to be small. Moreover, temporal dynamics analyses revealed an earlier temporal impact of the information presented first. Importantly, in the later phase of the decision process, the impact of both fear and reward information was

not significantly affected by presentation order. These findings fit well with *sequential-sampling models*, according to which fear and reward information dynamically drive evidence accumulation towards either an approach or an avoidance decision boundary (cf. Pedersen et al., 2021; Rolle et al., 2022). From this perspective, presenting a piece of information earlier allows prolonged time for evidence accumulation, as reflected in the earlier and thus prolonged temporal impact during the decision process. In line with this view, prolonged evidence accumulation was associated with an enhanced impact on final decisions. *Cognitive control accounts*, in contrast, would have predicted that presenting fear information first facilitates inhibitory control, which should have been reflected in a reduced impact of fear information towards the end of the decision process and a diminished effect on final decisions. In non-fearful participants, final decisions and temporal dynamics were less strongly affected by the order of presentation. Interestingly, approach was less frequent for a spider probability of 0% when fear information was presented first. For this specific combination, participants were not able to identify the spider/high reward option before the start of each trial (i.e., for both options “0%” was indicated on screen). This likely hindered the execution of pre-planned approach decisions, resulting in a somewhat lower proportion of approach. Accordingly, this effect once again highlights the strong reliance of non-fearful participants on pre-planned decisions. Interestingly, temporal dynamics in non-fearful individuals revealed a significant impact of fear information towards approach (not avoidance) when fear information were presented first. In the paradigm, fear information above 0% were always associated with higher rewards. When fear information was presented first, the high reward option could thus be identified by a probability greater than 0%. Non-fearful individuals therefore not only refrained from avoiding, but in fact used fear information to identify and approach the high rewards. Taken together, highly fearful participants’ decisions and movement trajectories did not yield evidence for inhibitory control during approach-avoidance decisions. Hence, maladaptive fearful avoidance may be characterized by biased evidence accumulation rather than altered cognitive control.

Clinical implications may be tentatively derived from the present findings. First, our results provide further evidence that competing rewards can support the reduction of maladaptive avoidance (see also Pittig et al., 2018; Pittig et al., 2020). This strategy is already used in clinical practice, when patients are encouraged to work out individual values, goals, and rewards to motivate fear-opposite approach. Second, our findings suggest that fear and reward information dynamically drive approach-avoidance decisions and that fear information outweighs reward information. Therefore, not only working out competing positive outcomes may be beneficial, but also therapeutic strategies that strengthen their dynamic impact during the decision process. According to *sequential-sampling models*, selective attention may mediate decision-making by decreasing the contribution of less relevant information to evidence accumulation while enhancing relevant information (e.g., Rangelov & Mattingley, 2020). It may thus be beneficial for patients with clinical anxiety to focus their attention on competing positive outcomes whenever they are confronted with a fear-related approach-avoidance decision (e.g., by mentally rehearsing or visualizing positive outcomes). However, attention away from feared stimuli may itself be an avoidance response. Focusing attention on feared stimuli is even considered essential during exposure (e.g., Craske et al., 2022). Further research is thus needed to test if such strategies are effective in promoting evidence accumulation towards approach and do not interfere with subsequent extinction learning.

In the current study, the use of a rather new experimental approach provided novel insights into fearful approach-avoidance decision-making. However, it is also subject to some limitations. First, the current study aimed to distinguish whether decisions are dynamically driven by both fear and reward information (*sequential-sampling*) or whether cognitive control is involved by inhibiting fear information (*cognitive control*). It may be possible that both processes are not completely

independent and show intertwined effects on the decision process, which would not be recognizable when analyzing final decisions only. Importantly, participants’ mouse movements did not support this assumption. Specifically, there was no evidence for a temporal pattern that includes both an enhanced impact of fear information during the early phase of the decision process (in line with *sequential-sampling*) as well as an attenuated effect of fear information during the late phase of the decision process (in line with *cognitive control accounts*) when this information was presented first. However, it cannot be ruled out that an overlap or combination of both processes occurred in individual trials or in single participants, or that such intertwined effects may be evident in different experimental paradigms. Thus, further research is warranted.

Second, the order of presenting fear and reward information was manipulated blockwise to distinguish between the two accounts. This manipulation is considered effective since it creates a situation in which the predictions of the two accounts diverge substantially while keeping the paradigm simple. However, as a shortcoming of this manipulation, the timing of each information was not varied independently. Future studies may keep the timing of one piece of information fixed while varying the other to test the models’ predictions independently. In sum, additional manipulations may be used in future research to provide further evidence for disentangling *sequential sampling* and *cognitive control accounts*.

Third, to ensure continuous movements required for temporal dynamics analyses, response time limits were implemented in the current study. These time limits caused moderate time pressure, which might have influenced the decision process. For instance, it cannot be ruled out that signs of inhibitory control may have occurred with longer decision times. Thus, further research may test whether *sequential-sampling models* better describe fearful approach-avoidance conflict decisions in all or only some contexts (e.g., with or without time pressure). Fourth, questionnaire scores suggest that most participants in the fearful sample may have fulfilled the diagnostic criteria for spider phobia. However, participants were not formally diagnosed by a clinician, which might present a limitation for generalizing our findings to patient populations in clinical settings. Fifth, the current approach-avoidance paradigm and the temporal dynamics analyses are not yet widely used in avoidance research. Accordingly, our findings on the temporal dynamics of approach-avoidance decisions have not yet been independently replicated, which should be addressed in future research.

In conclusion, the current study adds to a better understanding of costly avoidance in naturalistic fears and its underlying decision process. First, our results highlight a stronger weighting of fear compared to rewards during approach-avoidance decisions in face of naturalistic fear stimuli. Second, the increased impact of information presented first during early approach-avoidance decision-making while no effect of presentation order was found during late decision-making is not in line with *cognitive control accounts* and rather matches the predictions of *sequential-sampling models*. In line with these findings, future research may examine (a) whether results that match the predictions of *sequential-sampling models* can be found even in clinical populations and across different conditions and varying approach-avoidance paradigms, and (b) how we can strengthen the effect of positive outcomes during decision-making.

Funding

This work was supported by the overhead funding of the Faculty of Human Sciences of the University of Würzburg to J.B.

CRediT authorship contribution statement

Andre Pittig: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. **Stefan Scherbaum:** Conceptualization, Formal analysis, Software, Writing – review & editing. **Juliane M.**

Boschet-Lange: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – original draft.

Declaration of Competing Interest

The authors report no conflict of interest.

Acknowledgements

The authors would like to thank Talisa Höning and Julian-Lennart Faße for their help with data collection.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.janxdis.2024.102844](https://doi.org/10.1016/j.janxdis.2024.102844).

References

- American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders: DSM-5* (Fifth ed.). Washington, DC: American Psychiatric Association.
- Arnaudova, I., Kindt, M., Fanselow, M., & Beckers, T. (2017). Pathways towards the proliferation of avoidance in anxiety and implications for treatment. *Behaviour Research and Therapy*, 96, 3–13. <https://doi.org/10.1016/j.brat.2017.04.004>
- Aupperle, R. L., & Paulus, M. P. (2010). Neural systems underlying approach and avoidance in anxiety disorders. *Dialogues in Clinical Neuroscience*, 12(4), 517–531. <https://doi.org/10.31887/dens.2010.12.4/raupperle>
- Bari, A., & Robbins, T. W. (2013). Inhibition and impulsivity: behavioral and neural basis of response control. *Progress in Neurobiology*, 108, 44–79. <https://doi.org/10.1016/j.neurobio.2013.06.005>
- Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, 67(1). <https://doi.org/10.18637/jss.v067.i01>
- Becker, E., & Rinck, M. (2004). Sensitivity and response bias in fear of spiders. *Cognition and Emotion*, 18(7), 961–976. <https://doi.org/10.1080/02699930341000329>
- Beierlein, C., Kovaleva, A., Kemper, C. J., & Rammstedt, B. (2014). *Eine Single-Item-Skala zur Erfassung von Risikobereitschaft: Die Kurzskala Risikobereitschaft-1 (R-1) (GESIS-Working Papers, 2014/34)*. Mannheim: GESIS - Leibniz-Institut für Sozialwissenschaften.
- Bond, F. W., Hayes, S. C., Baer, R. A., Carpenter, K. M., Guenole, N., Orcutt, H. K., & Zettle, R. D. (2011). Preliminary psychometric properties of the Acceptance and Action Questionnaire-II: a revised measure of psychological inflexibility and experiential avoidance. *Behavior Therapy*, 42(4), 676–688. <https://doi.org/10.1016/j.beth.2011.03.007>
- Boschet, J. M., Scherbaum, S., & Pittig, A. (2022). Costly avoidance of Pavlovian fear stimuli and the temporal dynamics of its decision process. *Scientific Reports*, 12(1), 6576. <https://doi.org/10.1038/s41598-022-09931-1>
- Corr, P. J. (2013). Approach and avoidance behaviour: Multiple systems and their interactions. *Emotion Review*, 5(3), 285–290. <https://doi.org/10.1177/2F1754073913477507>
- Craske, M. G., Hermans, D., & Vervliet, B. (2018). State-of-the-art and future directions for extinction as a translational model for fear and anxiety. *Philosophical Transactions of the Royal Society B*, 373(1742). <https://doi.org/10.1098/rstb.2017.0025>
- Craske, M. G., Stein, M. B., Eley, T. C., Milad, M. R., Holmes, A., Rapee, R. M., & Wittchen, H. U. (2017). Anxiety disorders. *Nature Reviews Disease Primers*, 3, Article 17024. <https://doi.org/10.1038/nrdp.2017.24>
- Craske, M. G., Treanor, M., Zbozinek, T. D., & Vervliet, B. (2022). Optimizing exposure therapy with an inhibitory retrieval approach and the OptEx Nexus. *Behaviour Research and Therapy*, 152, Article 104069. <https://doi.org/10.1016/j.brat.2022.104069>
- Dale, R., Kehoe, C., & Spivey, M. J. (2007). Graded motor responses in the time course of categorizing atypical exemplars. *Memory & Cognition*, 35(1), 15–28. <https://doi.org/10.3758/BF03195938>
- Dshemuchadse, M., Grage, T., & Scherbaum, S. (2015). Action dynamics reveal two types of cognitive flexibility in a homonym relatedness judgment task. *Frontiers in Psychology*, 6, 1244. <https://doi.org/10.3389/fpsyg.2015.01244>
- Dshemuchadse, M., Scherbaum, S., & Goschke, T. (2013). How decisions emerge: Action dynamics in intertemporal decision making. *Journal of Experimental Psychology*, 142(1), 93–100. <https://doi.org/10.1037/a0028499>
- Forstmann, B. U., Ratcliff, R., & Wagenmakers, E. J. (2016). Sequential sampling models in cognitive neuroscience: Advantages, applications, and extensions. *Annual Review of Psychology*, 67, 641–666. <https://doi.org/10.1146/annurev-psych-122414-033645>
- Friston, K. J., Ashburner, J. T., Kiebel, S. J., Nichols, T. E., & Penny, W. D. (2007). *Statistical parametric mapping: the analysis of functional brain images*. Elsevier. <https://doi.org/10.1016/B978-0-12-372560-8.X5000-1>
- García-Guerrero, S., O'Hora, D., Zgonnikov, A., & Scherbaum, S. (2023). The action dynamics of approach-avoidance conflict during decision-making. *Quarterly Journal of Experimental Psychology*, 76(1), 160–179. <https://doi.org/10.1177/17470218221087625>
- Glogan, E., Meulders, M., Pfeiffer, L., Vlaeyen, J. W. S., & Meulders, A. (2022). Alike, but not quite: Comparing the generalization of pain-related fear and pain-related avoidance. *Journal of Pain*, 23(9), 1616–1628. <https://doi.org/10.1016/j.jpain.2022.04.010>
- Goschke, T. (2014). Dysfunctions of decision-making and cognitive control as transdiagnostic mechanisms of mental disorders: advances, gaps, and needs in current research. *International Journal of Methods in Psychiatric Research*, 23(Suppl 1), 41–57. <https://doi.org/10.1002/mpr.1410>
- Helman, E., Stolier, R. M., & Freeman, J. B. (2015). Advanced mouse-tracking analytic techniques for enhancing psychological science. *Group Processes & Intergroup Relations*, 18(3), 384–401. <https://doi.org/10.1177/2F1368430214538325>
- Hulsman, A. M., Kaldewaij, R., Hashemi, M. M., Zhang, W., Koch, S. B. J., Figner, B., & Klumpers, F. (2021). Individual differences in costly fearful avoidance and the relation to psychophysiology. *Behaviour Research and Therapy*, 137, Article 103788. <https://doi.org/10.1016/j.brat.2020.103788>
- Kieslich, P. J., Henninger, F., Wulff, D. U., Haslbeck, J. M. B., & Schulte-Mecklenbeck, M. (2019). Mouse-tracking: A practical guide to implementation and analysis. In M. Schulte-Mecklenbeck, A. Kühberger, & J. G. Johnson (Eds.), *A Handbook of Process Tracing Methods* (pp. 111–130). New York, NY: Routledge.
- Krypotos, A. M., Vervliet, B., & Engelhard, I. M. (2018). The validity of human avoidance paradigms. *Behaviour Research and Therapy*, 111, 99–105. <https://doi.org/10.1016/j.brat.2018.10.011>
- LeBeau, R. T., Glenn, D., Liao, B., Wittchen, H. U., Beesdo-Baum, K., Ollendick, T., & Craske, M. G. (2010). Specific phobia: a review of DSM-IV specific phobia and preliminary recommendations for DSM-V. *Depress Anxiety*, 27(2), 148–167. <https://doi.org/10.1002/da.20655>
- Lenth, R. V. (2022). emmeans: Estimated Marginal Means, aka Least-Squares Means (Version 1.7.2) [R package]. Retrieved from <https://CRAN.R-project.org/package=emmeans>.
- Lovibond, S. H., & Lovibond, P. F. (1995). *Manual for the Depression Anxiety Stress Scales* (2nd ed.). Sydney: Psychology Foundation.
- Pedersen, M. L., Ironside, M., Amemori, K. I., McGrath, C. L., Kang, M. S., Graybiel, A. M., & Frank, M. J. (2021). Computational phenotyping of brain-behavior dynamics underlying approach-avoidance conflict in major depressive disorder. *PLoS Comput Biol*, 17(5), Article e1008955. <https://doi.org/10.1371/journal.pcbi.1008955>
- Pittig, A., Boschet, J. M., Glück, V. M., & Schneider, K. (2021). Elevated costly avoidance in anxiety disorders: Patients show little downregulation of acquired avoidance in face of competing rewards for approach. *Depress Anxiety*, 38, 361–371. <https://doi.org/10.1002/da.23119>
- Pittig, A., Hengen, K., Bublatzky, F., & Alpers, G. W. (2018). Social and monetary incentives counteract fear-driven avoidance: Evidence from approach-avoidance decisions. *Journal of Behavior Therapy and Experimental Psychiatry*, 60, 69–77. <https://doi.org/10.1016/j.jbtep.2018.04.002>
- Pittig, A., & Scherbaum, S. (2020). Costly avoidance in anxious individuals: Elevated threat avoidance in anxious individuals under high, but not low competing rewards. *Journal of Behavior Therapy and Experimental Psychiatry*, 66, Article 101524. <https://doi.org/10.1016/j.jbtep.2019.101524>
- Pittig, A., Treanor, M., LeBeau, R. T., & Craske, M. G. (2018). The role of associative fear and avoidance learning in anxiety disorders: Gaps and directions for future research. *Neuroscience & Biobehavioral Reviews*, 88, 117–140. <https://doi.org/10.1016/j.neubiorev.2018.03.015>
- Pittig, A., Wong, A. H. K., Glück, V. M., & Boschet, J. M. (2020). Avoidance and its bidirectional relationship with conditioned fear: Mechanisms, moderators, and clinical implications. *Behaviour Research and Therapy*, 126, Article 103550. <https://doi.org/10.1016/j.brat.2020.103550>
- R Core Team. (2020). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.
- Rangelov, D., & Mattingley, J. B. (2020). Evidence accumulation during perceptual decision-making is sensitive to the dynamics of attentional selection. *NeuroImage*, 220, Article 117093. <https://doi.org/10.1016/j.neuroimage.2020.117093>
- Rinck, M., Bundschuh, S., Engler, S., Müller, A., Wissmann, J., Ellwart, T., & Becker, E. S. (2002). Reliabilität und Validität dreier Instrumente zur Messung von Angst vor Spinnen. *Diagnostica*, 48(3), 141–149. <https://doi.org/10.1026//0012-1924.48.3.141>
- Rinck, M., Reinecke, A., Ellwart, T., Heuer, K., & Becker, E. S. (2005). Speeded detection and increased distraction in fear of spiders: evidence from eye movements. *Journal of Abnormal Psychology*, 114(2), 235–248. <https://doi.org/10.1037/0021-843X.114.2.235>
- Rolle, C. E., Pedersen, M. L., Johnson, N., Amemori, K. I., Ironside, M., Graybiel, A. M., & Etkin, A. (2022). The role of the dorsal-lateral prefrontal cortex in reward sensitivity during approach-avoidance conflict. *Cerebral Cortex*, 32(6), 1269–1285. <https://doi.org/10.1093/cercor/bhab292>
- Scherbaum, S. (2020). *TCMR: Time continuous multiple regression toolbox for mouse tracking*.
- Scherbaum, S., & Dshemuchadse, M. (2020). Psychometrics of the continuous mind: Measuring cognitive sub-processes via mouse tracking. *Memory & Cognition*, 48, 436–454. <https://doi.org/10.3758/s13421-019-00981-x>
- Scherbaum, S., Frisch, S., & Dshemuchadse, M. (2018). A bird in the hand isn't good for long. *Experimental Psychology*, 65(1), 23–31. <https://doi.org/10.1027/1618-3169/a000385>
- Scherbaum, S., Gottschalk, C., Dshemuchadse, M., & Fischer, R. (2015). Action dynamics in multitasking: the impact of additional task factors on the execution of the prioritized motor movement. *Frontiers in Psychology*, 6, 934. <https://doi.org/10.3389/fpsyg.2015.00934>

- Schlund, M. W., Brewer, A. T., Magee, S. K., Richman, D. M., Solomon, S., Ludlum, M., & Dymond, S. (2016). The tipping point: Value differences and parallel dorsal-ventral frontal circuits gating human approach-avoidance behavior. *NeuroImage*, *136*, 94–105. <https://doi.org/10.1016/j.neuroimage.2016.04.070>
- Schoemann, M., O'Hara, D., Dale, R., & Scherbaum, S. (2021). Using mouse cursor tracking to investigate online cognition: Preserving methodological ingenuity while moving toward reproducible science. *Psychonomic Bulletin and Review*, *28*, 766–787. <https://doi.org/10.3758/s13423-020-01851-3>
- Sierra-Mercado, D., Deckersbach, T., Arulpragasam, A. R., Chou, T., Rodman, A. M., Duffy, A., & Dougherty, D. D. (2015). Decision making in avoidance-reward conflict: a paradigm for non-human primates and humans. *Brain Structure and Function*, *220* (5), 2509–2517. <https://doi.org/10.1007/s00429-014-0796-7>
- Singmann, H., Bolker, B., Westfall, J., Aust, F., & Ben-Shachar, M.S. (2021). afex: Analysis of Factorial Experiments (Version 1.0–1) [R package]. <https://CRAN.R-project.org/package=afex>.
- Spielberger, C. D., Gorsuch, R. L., Lushene, R., Vagg, P. R., & Jacobs, G. A. (1983). *Manual for the State-Trait Anxiety Inventory*. Palo Alto, CA: Consulting Psychologist Press.
- Stillman, P. E., Shen, X., & Ferguson, M. J. (2018). How mouse-tracking can advance social cognitive theory. *Trends in Cognitive Sciences*, *22*(6), 531–543. <https://doi.org/10.1016/j.tics.2018.03.012>
- Sullivan, N., Hutcherson, C., Harris, A., & Rangel, A. (2015). Dietary self-control is related to the speed with which attributes of healthfulness and tastiness are processed. *Psychological Science*, *26*(2), 122–134. <https://doi.org/10.1177/0956797614559543>
- Szymanski, J., & O'Donohue, W. (1995). Fear of Spiders Questionnaire. *Journal of Behavior Therapy and Experimental Psychiatry*, *26*(1), 31–34. [https://doi.org/10.1016/0005-7916\(94\)00072-t](https://doi.org/10.1016/0005-7916(94)00072-t)
- Treanor, M., & Barry, T. J. (2017). Treatment of avoidance behavior as an adjunct to exposure therapy: Insights from modern learning theory. *Behaviour Research and Therapy*, *96*, 30–36. <https://doi.org/10.1016/j.brat.2017.04.009>
- Zorowitz, S., Rockhill, A. P., Ellard, K. K., Link, K. E., Herrington, T., Pizzagalli, D. A., & Dougherty, D. D. (2019). The neural basis of approach-avoidance conflict: A model based analysis. *eNeuro*, *6*(4), 1–12. <https://doi.org/10.1523/ENEURO.0115-19.2019>