Depression symptoms enhance goal-directed behavior under uncertainty

Authors: Shiyi Liang[1,2], Evan Russek [3], Robb B. Rutledge[4,5], G. Elliott Wimmer[1,2,*]

Affiliations:

[1]Max Planck University College London Centre for Computational Psychiatry and Ageing Research, University College London, London, UK.

[2]Department of Imaging Neuroscience, UCL Queen Square Institute of Neurology, University College London, London, UK

[3]Department of Computer Science, Princeton University, Princeton, NJ, USA

[4]Departments of Psychology and Psychiatry, Yale University, New Haven, CT, USA

[5]Wu Tsai Institute, Yale University, New Haven, CT, USA

Preprint server: bioRxiv. CC-BY 4.0 International license.

Abstract

Achieving goals in uncertain environments requires integrating expected benefits, costs, and the likelihood of outcomes – processes that may be disrupted in depression. Although depression is characterized by affective and motivational biases, the computational mechanisms by which these symptoms shape goal-directed decision-making remain poorly understood. We investigated these mechanisms using a novel goal-directed decision task. After learning the structure of the environments, participants (n = 384) chose between certain rewards and risky goals varying in both reward magnitude and distance, where greater goal distance led to higher compounded risk of failure. Using transdiagnostic symptom factors derived from clinical questionnaires, we found that individuals with higher apathy–anhedonia symptoms reported lower expectations of goal success yet showed enhanced performance across multiple aspects of goal-directed behavior. These results reveal a dissociation between perceived risk and its influence on choice in individuals with motivational symptoms, and uncover a novel positive link between these symptoms and adaptive behavior.

Introduction

Goal-directed decisions, fundamental to everyday life, require integrating expected benefits, costs, and the likelihood of outcomes. Such decisions frequently depend on memory and involve weighing uncertainty, often across multiple steps. Psychiatric symptoms – particularly those associated with depression – may alter the computations underlying these choices. For example, depression symptoms are linked to pessimistic expectations about future rewards (Strunk and Adler, 2009), while apathy and anhedonia – characterized by diminished motivation and reduced pleasure – are associated with reduced effort allocation toward rewards (Bustamante et al., 2024; Treadway et al., 2012). Understanding how depression symptoms affect goal-directed behavior is essential for developing comprehensive models of human decision-making and designing targeted interventions.

Recent transdiagnostic studies have characterized impairments in goal-directed behavior in relation to compulsivity and intrusive thoughts (Donegan et al., 2023; Gillan et al., 2016; Patzelt et al., 2019). However, large-scale investigations have found no association between depression symptoms and deficits in goal-directed behavior (Donegan et al., 2023; Gillan et al., 2016; Patzelt et al., 2019), while smaller studies have reported mixed evidence (Gillan et al., 2020; Heller et al., 2018; Heo et al., 2021). One potential limitation of prior large-scale studies is that the transdiagnostic factors combined anxiety and depression, potentially obscuring more specific effects.

Task design is another important consideration. Most research employs efficient yet relatively simple paradigms, such as the widely adopted two-step task (Daw et al., 2011). While this task has significantly advanced our understanding of the cognitive and neural mechanisms underlying goal-directed behavior (Daw et al., 2011; Doll et al., 2015; Gillan et al., 2016; Liu et al., 2021; Miller et al., 2017; Vikbladh et al., 2019; Wimmer et al., 2023), it may not capture key characteristics of real-world behavior, such as reliance on rich mental models and episodic memory. These additional demands may differentially challenge individuals with elevated depression symptoms. Moreover,

real-world goal pursuit is inherently risky, with risk often compounding as the number of steps to a goal increases. Given that depression symptoms are associated with pessimistic expectations (Strunk and Adler, 2009), such contexts could lead to impairments in goal-directed behavior. More representative paradigms may therefore be necessary to fully capture the influence of psychiatric symptoms on behavior (Dhami et al., 2004).

To address these gaps, we developed a novel multi-step decision-making task that embeds goal pursuit within a learned, uncertain environment. Non-clinical participants (n = 384) learned the structure and associated risks of two semi-circular mazes over two days (**Figure 1**). After the learning phase, participants chose between a certain reward and a risky goal that varied in reward magnitude and distance, with greater distance entailing higher compounded risk of failure. We also collected participants' subjective estimates of goal success, enabling direct comparison between beliefs (often the focus in clinical contexts) and objective performance (typically emphasized in behavioral research). Transdiagnostic symptom factors were derived from clinical questionnaires (Gillan et al., 2016), with a particular focus on depression and anxiety symptoms. Complementary tasks assessed risk-taking for described options, delay discounting, effort-based decision-making, and reward learning.

We found a dissociation between subjective beliefs and actual behavior in individuals with higher apathy-anhedonia scores. Despite reporting lower expectations of goal success, these individuals did not avoid risky goals; instead, they showed enhanced goal-directed performance, including a stronger influence of goal values on choice. This reveals a novel and seemingly paradoxical relationship in which apathy and anhedonia are linked to enhanced performance in goal-directed decision-making under uncertainty.

Results

Risky goal task.

We studied goal-directed decision-making under conditions of learned uncertainty and examined its relationship with transdiagnostic measures of mental health. The study was preregistered (https://osf.io/x3z5f); below we use the term 'hypothesized' to refer to preregistered hypotheses. In the risky goal task, participants learned about and navigated to goals in two different loop-shaped 'mazes' (**Figure 1c**). Each maze location was represented by a unique image. The experiment was conducted over two days to allow for sufficient learning of the environments and the risk of failure, aligning with conditions outside the lab where such knowledge is often acquired over time. Initially, participants freely explored the mazes in short episodes. In the subsequent learning phase, participants completed goal pursuit trials, during which they navigated from a designated start location to a goal location, where the primary decision was whether to move clockwise or counter-clockwise (**Figure 1b**). Goal success was uncertain, because each step carried a small random, independent risk of failure that would terminate the trial. So that participants learned this risk The small step failure probability (~10%) was learned through experience and was never described. The risk compounded across distance (steps). As a result, the expected value of pursuing a goal decreased with goal distance. Thus, higher goal rewards should be required to justify pursuing longer, or riskier, paths (**Figure S3**).

To quantify participants' valuation of risky goals, participants completed a choice phase following the learning phase. On each choice-phase trial, participants decided between a certain alternative and a goal option that comprised a start item, a goal item, and a goal reward value (**Figure 1a**). If participants chose the goal option, they proceeded to navigate toward the goal by selecting the first direction to move, followed by subsequent direction selections at each step. If they chose the certain alternative, the outcome was displayed, followed by a delay. Goal distance varied from 1-7 steps (defined by the shorter path), with offered goal reward values generally increasing with distance. In the task, all start-goal combinations were unique, except for a small set that was excluded

from primary analyses. To estimate individual indifference points – the reward value at which participants switched between preferring the goal and the certain option – goal reward values for each distance were titrated during the choice phase (**Methods**). To further probe the use of a cognitive map, the choice phase included occasional 'roadblock' trials, where a signaled location would be blocked (indicated by an object picture appended to the left of the example in **Figure 2b**; **Figure S2**). Finally, participants completed several post-test ratings and memory assessments. On day two, the experiment proceeded as described above, with the exploration and learning phases reduced and twice the number of choice phase trials. On a subsequent day ('day three'), participants completed a follow-up session that included a memory assessment.

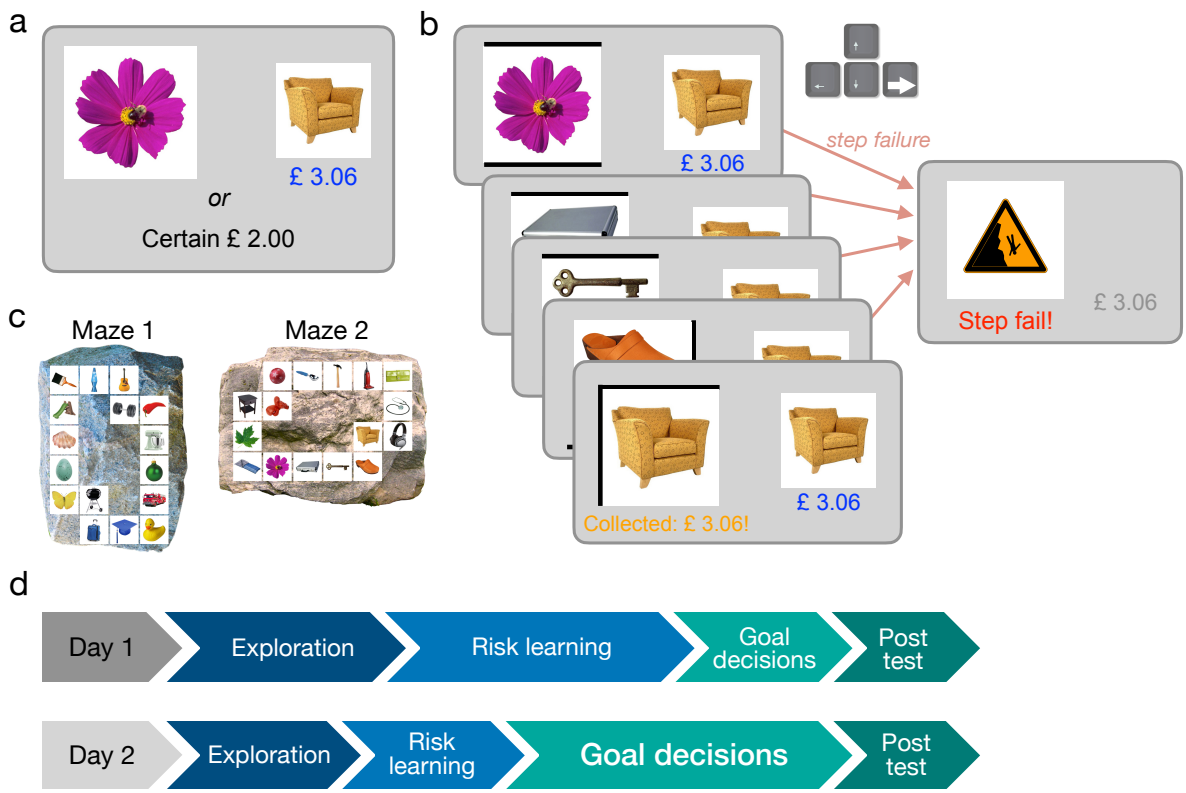

Figure 1. Risky goal task. a) Choice trial screen. Participants could choose between the offered goal or a fixed certain alternative. In this example, the start location is the flower and the goal location is the chair, which is four steps away and would yield £3.06 if reached (see bottom row of Maze 2 in panel c for location). b) Goal pursuit screen. This display is shown following a goal choice (as in panel a) or at the start of learning trials. At this and every subsequent step, participants selected a direction of navigation using the arrow keys. If the selected direction led to a location, the next location was shown, and the next direction could be selected. If a wall was hit (represented by the black lines), participants would select the direction again. At each step, there was an undisclosed 10% probability of a "step failure" (here indicated by the pink arrows), which occurred independently of participants' behavior. If a failure event occurred, the screen on the right would appear. See also **Figure S1**. c) Maze examples. Each maze contained 16 different locations, with each marked by a unique object. This overhead view was shown briefly in between task phases but not during trials. d) Timeline of the two-day experiment. Our primary analyses focus on the goal decisions (choice phase) in Day 2, as depicted in panel a. Memory location and success probability ratings were collected in the post-test sections, while additional memory location tests were also presented early in each session.

Transdiagnostic factor analysis.

To identify potential dimensions of psychiatric symptoms that cut across traditional diagnostic categories, we utilized a transdiagnostic approach to examine relationships with behavior in the risky goal pursuit task (Gillan et al., 2016; Wise et al., 2023). We conducted a factor analysis over data from a large set of standard clinical questionnaires. To better differentiate depression from anxiety symptoms, we included additional depression- and anxiety-focused scales beyond those utilized by Gillan et al. (2016; Wise et al., 2023). The computational factor analysis identified three factors, which we labeled 'Apathy-Anhedonia', 'Worry', and 'Impulsivity' based on item loadings (**Figure 2**; **Supp. Results**). In addition to and separate from the scales included in factor analysis, we included two general scales focused on the propensity for risk-taking behavior to examine relationships with risky goal pursuit (Frey et al., 2017)(**Supp. Methods**). Findings regarding the risk questionnaires can be found in the **Supplemental Results**.

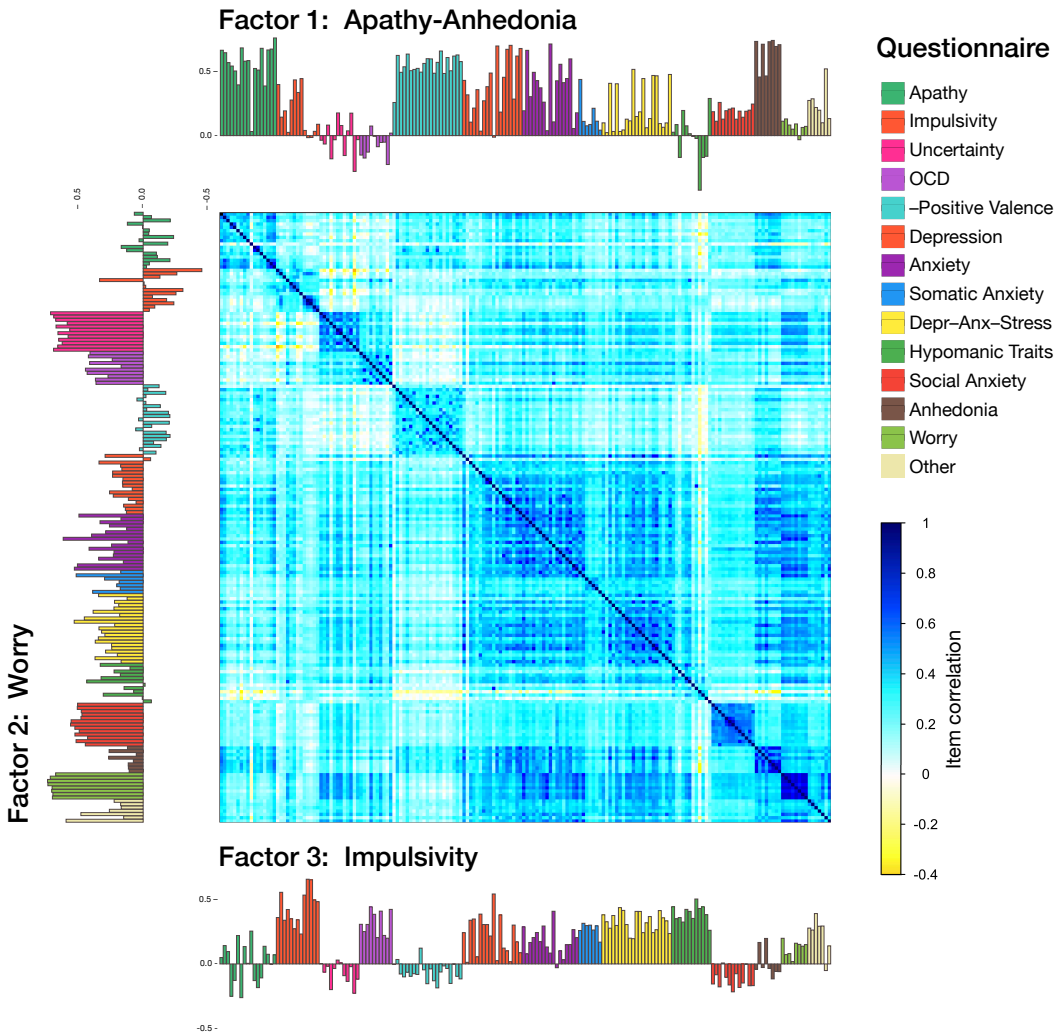

Figure 2. Transdiagnostic factors. The correlation matrix of 184 items used in the factor analysis is shown in the center. Factors were labeled 'Apathy-Anhedonia', 'Worry', and 'Impulsivity'. Item loadings for each factor are presented on the top, left and bottom sides of the correlation matrix. Loading colors reflect the questionnaire from which each item was drawn. Please refer to the **Methods** section to align the questionnaire descriptor with its full name. For visualization only, the positive valence scale was inverted. The 'Other' items at the end reflect additional depression-targeted items selected from other scales (see **Supp. Methods** for full information).

Learning and memory.

To assess maze learning and memory, participants completed an item location replacement memory phase ('location memory') early and late on each day. Location memory was assessed by presenting single items that participants were required to replace on an empty maze grid (**Figure S1b**). Location replacement memory

performance was already quite high on the first day, following the initial free exploration phase (83.89 ± 0.70% (SEM); **Figure 3a**), indicating that participants were successfully building an internal model of the two environments. First-move direction accuracy during goal pursuit, defined as pursuing the shortest path to the goal, was 91.21 ± 0.43% on day one, indicating a strong model-based component to behavior. Note that in order to study decision-making in successful learners, poor location memory and first-move accuracy were used as exclusion criteria (**Supp. Methods**).

Based on suggestions from previous research (Seow et al., 2021; Sharp et al., 2023; Sookud et al., 2024), we hypothesized that a factor related to compulsivity and intrusive thoughts (CIT) would be negatively associated with the acquisition of model-based knowledge of the maze. Our 'Impulsivity' factor, which also heavily weighted items related to intrusive thoughts, most closely aligned with the prior CIT factor. Regression analyses revealed that this factor was negatively associated with location memory in both measures from the primary day 2 session (early $r_s(380) = -0.141$, $p = 0.0060$; late $r_s(380) = -0.111$, $p = 0.0304$), as well as the early test on day one (early $r_s(381) = -0.158$, $p = 0.0020$; late $r_s(380) = -0.080$, $p = 0.114$; partial rank correlation including three factors; **Figure 3b**), and the follow-up test on day three ($r_s(368) = -0.120$, $p = 0.0206$). The same relationships were observed in bivariate analyses (**Figure S8**). We found no relationship between memory measures and 'Worry' or 'Apathy-Anhedonia' factor scores (p-values > 0.161; **Figure 3**), despite our hypothesis that memory may also be negatively related to depression symptoms (Dillon and Pizzagalli, 2018). In exploratory analyses, we examined a derived compulsivity and intrusive thought (CIT) factor (Gillan et al., 2016; Hopkins et al., 2022) which was strongly related to 'Impulsivity' factor scores ($r(382) = 0.820$). However, derived CIT factor scores were not significantly related to memory performance (**Supp. Results**).

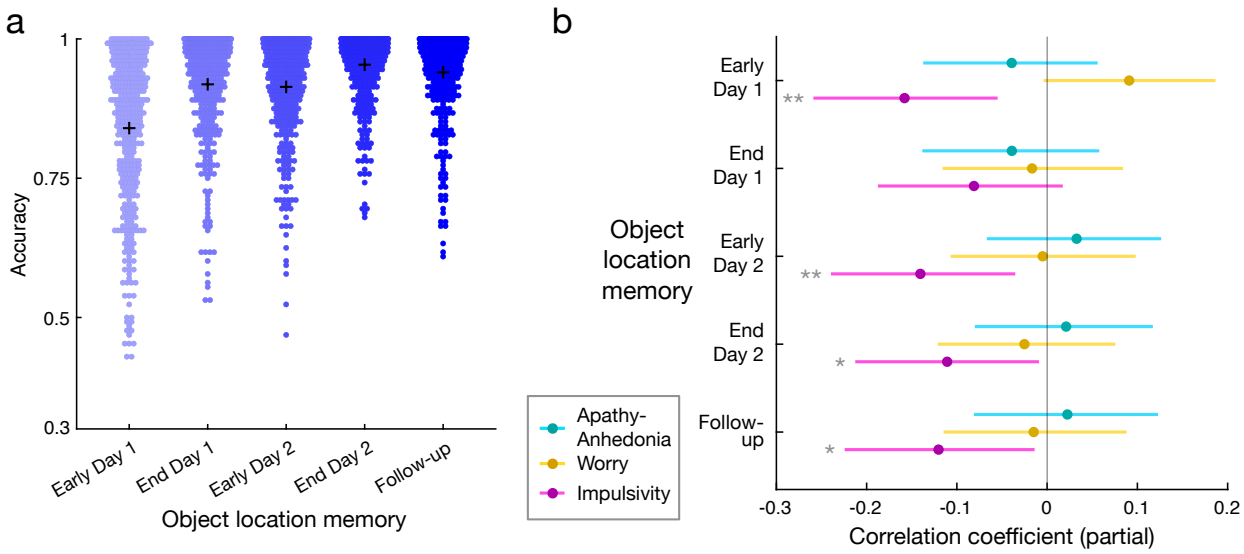

Figure 3. a) Performance in object location replacement memory tests. Points represent individual participants, with black crosses indicating the mean. b) Location memory performance correlation with factor scores. Analyses control for all three factors. Confidence intervals (lines) were estimated by bootstrapping. * $p < 0.05$; ** $p < 0.01$.

Risky goal preference and goal success ratings.

Our primary hypotheses focused on participants' behavior during the day two choice phase, where they decided whether to pursue risky goals or accept a certain alternative. To better estimate risky goal valuation, we titrated goal values for each distance for each participant across both days (**Figure 4**). Below, we first describe general choice behavior and risk-taking, followed by an examination of relationships with symptoms.

As expected, participants' decisions to pursue risky goals were influenced by both the potential goal value and the distance to the goal. We found that participants were significantly more likely to choose the goal option as its value increased ($z = 14.76$, $p < 0.001$, multilevel model with fixed effects of participant and distance). Importantly, as the distance to the goal increased, participants required a higher goal reward to elicit a goal choice (indifference point increasing with distance: $t = 20.496$, $p < 0.001$, multilevel model; **Figure 4**). This effect indicates that participants utilized cognitive map-like knowledge of the mazes combined with a learned estimate of risk to inform their choices.

Previous work shows that risk attitudes depend on both how uncertainty is conveyed and the probability of the risky outcome (Hertwig and Erev, 2009; Kahneman and Tversky, 1979). Specific studies that have used similar ranges of probabilities to those used here have demonstrated that humans tend to be risk-averse in experimental tasks where risk is visually described but tend to be risk-seeking after learning from brief experience (Garcia et al., 2021). Our task involved extensive experience-based learning of risk. To test overall risk-taking, we examined choice rates for those goals where the risk-neutral expected goal value was approximately equal to the certain alternative. We found that participants were risk-seeking, choosing the risky option 64.86% (± 1.35%) of the time ($t_{(403)} = 10.985$, $p < 0.001$, versus a chance level of 50%).

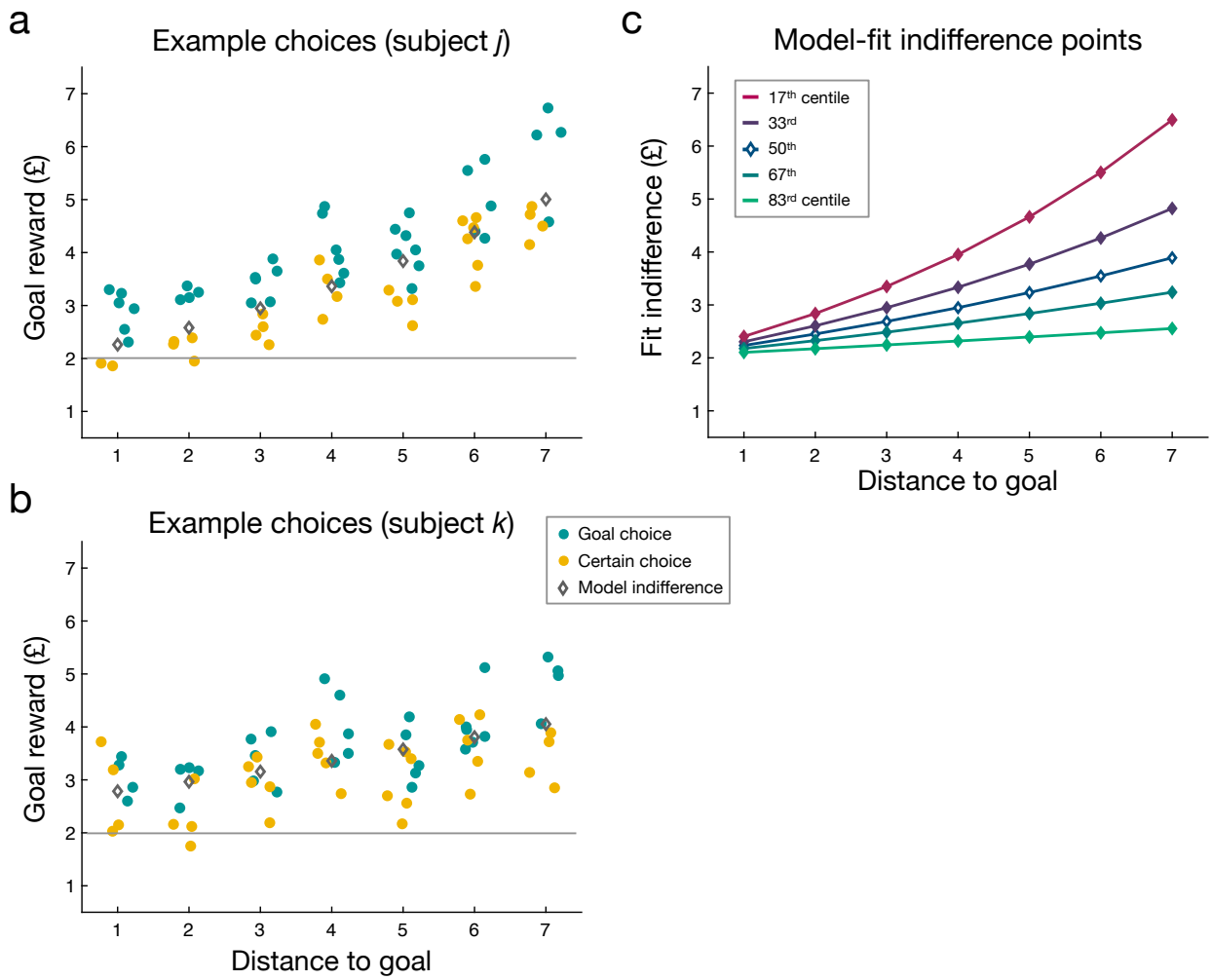

Figure 4. a-b) Example participant risky goal choice data and model-fit indifference points. Each dot represents an offered choice between a goal at the indicated value and the certain option. Participant choices of the goal are colored teal, while selections of the certain option are colored yellow. Grey diamonds represent model-fit indifference points. As the distance to the goal increases, on average, the goal reward required for a participant to choose the goal increased. Participants differed in their degree of risk-taking for goals: participant *j* (panel a) was more risk-averse than participant *k* (panel b). Participants also differed in how well their choices were guided by the offered goal values: participant *j* showed less noisy choices than participant *k*. For a schematic of behavioral effects of compounding risk, see **Figure S3**. c) Distribution of model-fit indifference points by distance, stratified by different centiles of model-fit step failure probability. White-filled diamonds represent the mean. For display purposes, the intercept, representing the goal engagement cost, was set to the group median value.

We then fit a computational model to participants' choice behavior in which goal values were discounted by the cumulative risk associated with distance to a goal. The discounting parameter in the model represents the subjective step success probability

(the inverse of step failure probability). This model provided a better fit to behavior than several alternatives (**Table S1**). Further supporting the fit of the model, the success probability parameter exhibited a high correlation with an independent measure of risk-taking based on estimation of distance-specific indifference points ($r(360) = 0.868$; **Supp. Results**). The mean value of the step success probability parameter was 90.68 ± 5.98% (SD), which was close to but higher than the experienced step success rate on day two (89.29 ± 1.91% (SD); difference $t_{(403)} = 4.57$, $p < 0.001$). We refer to the step success parameter as risk-taking for goals, as higher values reflect greater acceptance of lower-value rewards for distant goals.

Turning to relationships with transdiagnostic factors, we hypothesized that depression symptoms, reflected in the 'Apathy-Anhedonia' factor, would negatively correlate with risk-taking for goals. However, we found that 'Apathy-Anhedonia' factor scores were not related to risk-taking for goals ($t_{(403)} = -0.553$, $p = 0.581$; regression including three factors). We can further rule out a small effect of size $d = \pm 0.15$ or larger (TOST against equivalence bounds $d = \pm 0.15$; **Supp. Results**). No significant associations were found between the other two transdiagnostic factors and risk-taking for goals (p-values > 0.36). The computational model included a second free parameter, goal engagement cost, which captured any general bias toward or away from goal choices that was independent of distance. Exploratory analyses revealed no significant relationships between goal engagement cost and any of the three transdiagnostic factors (p-values > 0.29) and we could also rule out even a small effect for 'Apathy-Anhedonia' (**Supp. Results**).

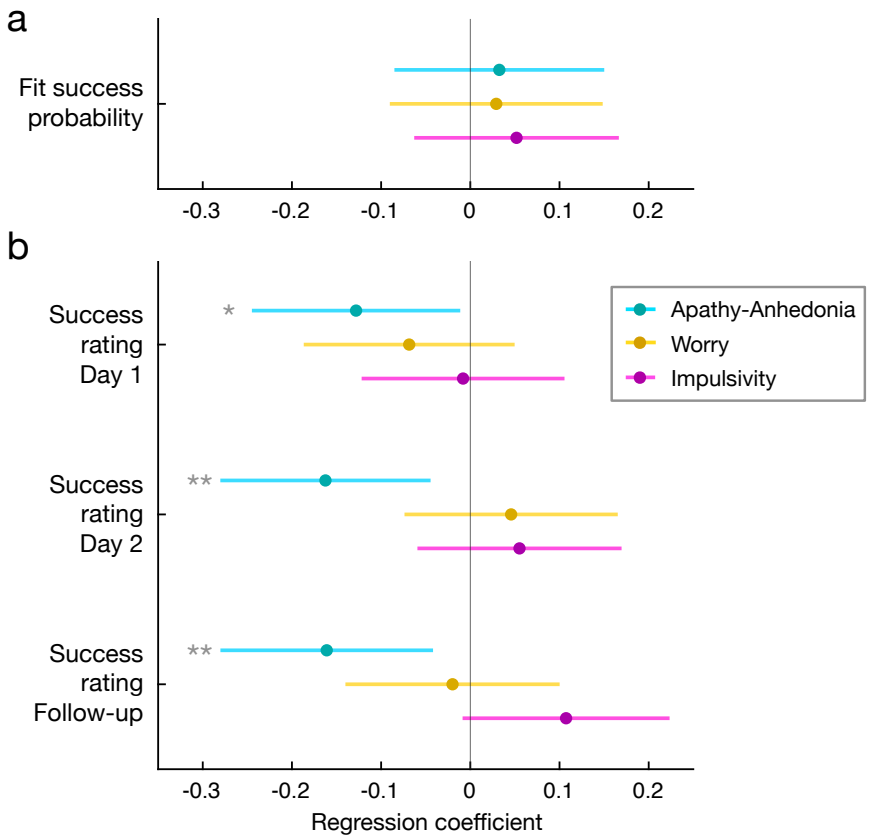

Figure 5. Relationship between model-fit success probability (reflecting risk-taking for goals), subjective goal success probability ratings, and factor scores. 'Apathy-Anhedonia' factor scores were negatively related to goal success probability ratings. Analyses control for all three factors. * $p < 0.05$; ** $p < 0.01$.

To further understand risk-taking and risk estimation, participants provided subjective predictions of goal success probability after the main task, based on specific start-goal combinations with varied distances to the goal (**Figure S7**; note that distance information was not provided). As expected, success ratings decreased with distance to the goal ($t = -31.619$, $p < 0.001$, multilevel model; **Figure S7**). On average, success ratings were close to but more pessimistic than the extrapolated experienced success rates (mean rating across distances: 63.58 ± 0.60%; experienced step success rate extrapolated across distances: 65.65 ± 0.24%; $t_{(389)} = -3.0389$, $p = 0.0025$). Goal success ratings were positively related to actual behavior in the choice phase, quantified by the risk-taking for goals measure (fit success probability; $r(388) = 0.196$, $p < 0.001$). Notably, subjective success probability ratings were stable across delays of at

least one day (correlation of day two mean and follow-up mean: $r(371) = 0.810$, $p < 0.001$).

Mirroring our hypothesis about goal decisions, we hypothesized that depression symptoms would be related to lower expectations of goal success. Supporting this hypothesis, we found that people with higher 'Apathy-Anhedonia' factor scores reported lower goal success ratings ($t_{(369)} = -2.756$, $p = 0.006$; regression including all three factor scores; **Figure 4**). Similar effects were observed earlier in learning, on day one ($t_{(377)} = -2.082$, $p = 0.0380$) and persisted in a follow-up session (day three; $t_{(365)} = -2.633$; $p = 0.009$). No significant associations were found between goal success ratings and the other two transdiagnostic factors (p-values > 0.33, uncorrected; **Figure 4**). The 'Apathy-Anhedonia' relationship with goal success ratings remained when controlling for memory performance, memory confidence, or experienced step success rate. Further, the relationship remained when controlling for baseline mood rating, which itself was strongly negatively correlated with 'Apathy-Anhedonia' factor scores (**Figure S12**). These results indicate that depression symptoms, as captured by 'Apathy-Anhedonia' factor scores, negatively influence subjective predictions of goal success, yet show no relationship to risky goal decisions.

Goal-directed behavior and factor scores.

In addition to overall risk-taking for goals, our paradigm provides multiple measures of goal-directed behavior. While participants overall were strongly goal-directed, as expected, individual variability allows us to examine how such behavior may relate to variability in 'Apathy-Anhedonia' and other factor scores. We first assessed the relationship between 'Apathy-Anhedonia' and how strongly goal values influenced decisions. We then examined relationships with complementary behavioral indicators, including model-based roadblock avoidance and goal navigation reaction times, as well as an independent measure assessing the influence of episodic memory.

Our behavioral model of risk-taking included a softmax inverse temperature parameter, which indexed how strongly goal values shaped decision-making. Notably, we found a

significant positive correlation between ‘Apathy-Anhedonia’ factor scores and softmax inverse temperature ($t_{(380)}$ = 3.0023, p = 0.0023; **Figure 5**), indicating that individuals with higher scores were more sensitive to differences in goal value during decision-making.

Previous research has associated a compulsivity and intrusive thought factor (CIT) with reduced model-based behavior (Gillan et al., 2016). Subsequent studies suggested that this relationship may be driven by impairments in learning a model of the underlying structure (Seow et al., 2021; Sharp et al., 2023; Sookud et al., 2024), and as we found (**Figure 3**), our ‘Impulsivity’ factor, which was most closely related to CIT, was indeed negatively related to memory. For softmax inverse temperature, we also found a negative correlation with ‘Impulsivity’ factor scores ($t_{(380)}$ = -2.533, p = 0.0117; **Figure 5**). However, this relationship was no longer significant when including location memory performance from day 2 in the regression model (early or late test; p-values > 0.0802), suggesting that weaker structure memory may be underlying effects on goal-directed behavior. No significant associations were found for the ‘Worry’ factor score (p > 0.521).

To complement this behavioral model, we also calculated a model-agnostic measure of overall ‘choice quality’ that did not rely on formal assumptions about risk- and distance-related discounting (**Supp. Methods**). This metric, which compared chosen versus non-chosen goal values within and then across each distance, was preregistered as a criterion for identifying inattentive participants. Note that exclusions based on this criterion were minimal (n = 6) and did not affect the results. Supporting a common source of variance, choice quality was highly correlated with model-fit softmax inverse temperature (r(382) = 0.863, p < 0.001). Further, we found a significant positive relationship between ‘Apathy-Anhedonia’ factor scores and choice quality ($t_{(380)}$ = 3.0072, p = 0.0028), supporting the above relationship with softmax inverse temperature. The ‘Worry’ and ‘Impulsivity’ factor scores showed no significant relationships (p-values > 0.14).

The positive relationship between ‘Apathy-Anhedonia’ scores and the influence of goal value on choice – using either softmax or choice quality – was not attributable to differences in memory performance, as the effect was unchanged when controlling for memory performance. Also, we confirmed that the relationship was not driven by emotional responsivity to feedback, which was negatively associated with ‘Apathy-Anhedonia’ factor scores (**Supp. Results**), or baseline emotion ratings, as it remained significant when including these variables in the regression model. Additional analyses confirmed that the relationship with the softmax or choice quality parameter also remained when controlling for simple trial-to-trial behavioral patterns, including goal or certain choice perseveration and win-stay / lose-switch tendencies. Finally, we examined reward earnings in the choice phase, which was correlated with both softmax and choice quality (r-values > 0.55). ‘Apathy-Anhedonia’ factor scores positively correlated with reward earnings ($t_{(380)} = 3.9084$, $p = 0.0028$), an effect that remained when including softmax or choice quality in the regression model (**Supp Results**).

We next focused on variability in goal-based behavior on trials involving roadblocks, which probed model-based flexibility by introducing temporary changes in task structure (Tolman, 1948). In these trials, an additional image and the word “roadblock” signaled that a specific location was blocked (**Figure S2**). Roadblocks were placed on the shorter (relevant) or the longer (irrelevant) route to the goal, with relevant roadblocks significantly reducing the expected success probability. As expected, participants chose the goal option on relevant roadblock trials at a significantly lower rate than for irrelevant roadblock trials (18.4% versus 65.0%; $t_{(402)} = 19.815$, $p < 0.001$) and standard trials without roadblocks (54.7%; $t_{(403)} = 24.014$, $p < 0.001$). We defined model-based roadblock avoidance as the difference in goal choice rate between irrelevant and relevant roadblock conditions.

We observed a significant positive relationship between ‘Apathy-Anhedonia’ factor scores and model-based roadblock avoidance ($t_{(379)} = 3.355$, $p = 0.0009$; **Figure 5**). This effect aligns with the association between factor scores and a stronger influence of goal value on choice. The effect was unchanged when controlling for memory

performance, baseline mood, or emotional responses to outcomes in the regression model. In contrast, 'Impulsivity' factor scores were not significantly associated with model-based roadblock avoidance ($t_{(379)} = -1.381$, $p = 0.168$), nor were 'Worry' scores ($p > 0.135$).

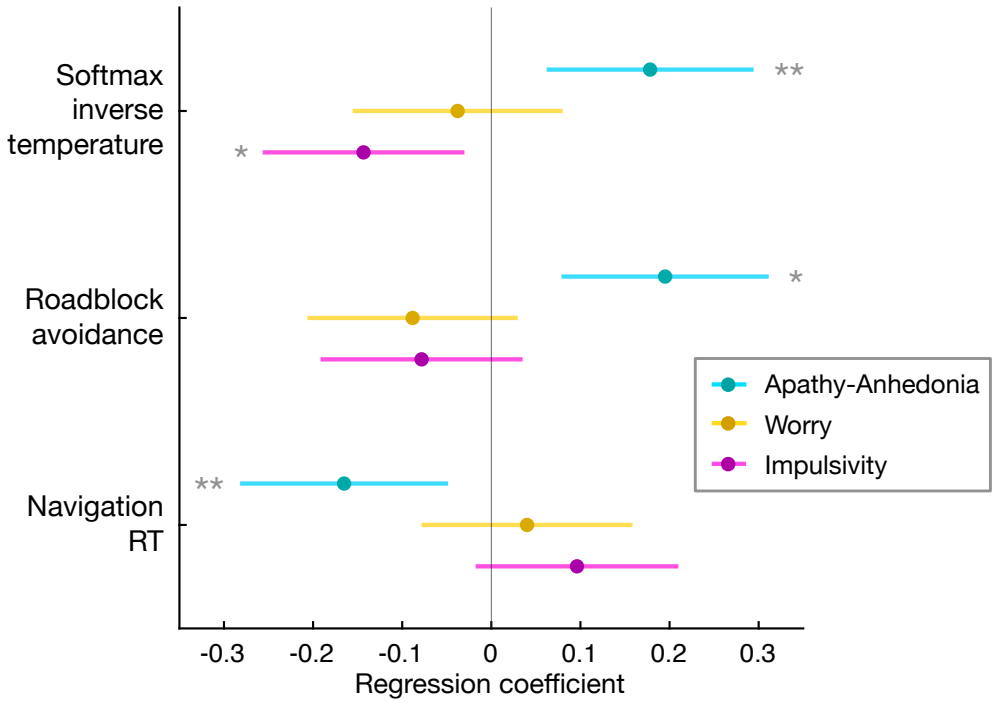

Figure 6. Relationship between 'Apathy-Anhedonia' factor scores and three measures of goal-directed behavior: softmax inverse temperature (an index of how strongly choices are guided by goal values), roadblock avoidance, and goal navigation direction reaction time. All analyses control for the three factors. * $p < 0.05$; ** $p < 0.01$; The correlation between softmax and 'Impulsivity' factor scores was not significant after controlling for location memory performance.

Third, to further investigate a relationship between 'Apathy-Anhedonia' factor scores and goal-directed behavior, we analyzed reaction times (RTs) during goal-directed navigation. Following a decision to pursue a goal, the start and goal images reappeared at the center of the screen, and participants initiated navigation by using the arrow keys to indicate the direction of the first move. Because this initial direction typically determined the entire path to the goal, reaction time for this first step likely reflects advance planning or rapid decision-making. Alternatively, we hypothesized that

participants with higher depression symptoms might show slower navigation RTs, consistent with prior findings linking depressive symptoms to reduced motivation (Treadway et al., 2012). First looking across all goal navigation RTs within a trial, we found that higher 'Apathy-Anhedonia' factor scores were associated with faster navigation reaction times ($t_{(380)} = -2.831$, $p = 0.005$). The effect was primarily driven by the first step RT ($t_{(380)} = -3.192$, $p = 0.0030$, corrected for two comparisons), with the mean RT across subsequent navigation steps showing no significantly relationship ($t_{(380)} = -1.236$, $p = 0.434$, corrected). The relationship between 'Apathy–Anhedonia' scores and faster initial navigation remained significant when controlling for first move accuracy, which itself was unrelated to factor scores ($p > 0.91$), indicating that speed was not achieved at the expense of accuracy. We found no significant between 'Impulsivity' factor scores and goal navigation RT ($t_{(380)} = -1.689$, $p = 0.092$, uncorrected) and no significant relationship with the 'Worry' factor ($p > 0.498$, uncorrected).

The 'Apathy-Anhedonia' relationship with direction RT was unchanged when controlling for memory performance, baseline mood, or emotional responses to outcomes in the regression model. Furthermore, no relationship was found between 'Apathy-Anhedonia' scores and RTs in other task components, including the initial goal versus certain decision ($t_{(380)} = -0.866$, $p = 0.387$) or the series of three spacebar presses following each navigation direction selection ($t_{(380)} = -1.086$, $p = 0.278$). These findings suggest that individuals with higher 'Apathy-Anhedonia' scores may exhibit greater advance preparation for goal-directed navigation or faster decision-making. While unexpected, this result is consistent with the above findings of enhanced goal-directed behavior in individuals with higher 'Apathy-Anhedonia' scores.

Fourth, we examined the relationship between 'Apathy-Anhedonia' factor scores and the influence of learning and memory on goal-directed behavior. We focus on repeated start-goal combinations that were encountered during both the day one learning phase and the day two decision phase. On day one, after the choice phase participants completed a brief set of non-choice learning trials. These start-goal combinations were

later offered as goal options in the choice phase on day two. (All other start-goal combinations in the experiment were unique.) We hypothesized that higher depression symptoms would be associated with increased avoidance of specific prior failure episodes. Supporting this, we found that 'Apathy-Anhedonia' factor scores were associated with greater avoidance of previously failed goals, relative to non-repeated goals ($t_{(372)} = 2.04$, $p = 0.042$). No effect was found for previously successful goals ($p > 0.89$, corrected for two comparisons). This result suggests that goal-directed decisions in individuals with higher 'Apathy-Anhedonia' factor scores are more influenced by specific negative events. We found no significant evidence for a relationship between 'Impulsivity' factor scores and avoidance of previously failed goals ($t_{(372)} = 1.247$, $p = 0.213$, uncorrected) and no significant evidence for the 'Worry' factor ($p > 0.542$, uncorrected).

The 'Apathy-Anhedonia' relationship with previously experienced goals was unchanged when controlling for memory performance, baseline mood, or emotional responses to feedback in the regression model. Together with the above results linking 'Apathy–Anhedonia' scores to greater value sensitivity, model-based flexibility, and faster goal navigation, these findings converge to support a positive association between motivational symptoms and the effective use of memory in guiding goal-directed behavior.

Goal-directed behavior on day 1.

Finally, we analyzed choice behavior from day one to assess whether the same three measures of goal-directed behavior that were related to 'Apathy-Anhedonia' factor scores on day two also emerged earlier in the task. Our preregistered hypotheses focused on day two, as on day one, learning and task adjustment was still ongoing and the choice phase contained only half as many choice trials. Owing to the limited data, to examine the relationship between factor scores and the influence of goal value on choice, we used the model-agnostic choice quality measure in place of softmax inverse temperature, which could not be reliably estimated.

We found a positive relationship between 'Apathy-Anhedonia' factor scores and choice quality on day one ($t_{(379)} = 1.983$, $p = 0.0481$; **Figure S11**), consistent with the day two findings. Second, the association between 'Apathy-Anhedonia' factor scores and model-based roadblock avoidance on day one was in the same positive direction but did but reach significance ($t_{(378)} = 1.592$, $p = 0.112$; **Figure S11**). Third, we replicated the significant positive relationship between Apathy-Anhedonia factor scores and faster navigation direction reaction times ($t_{(379)} = -3.645$, $p = 0.003$; **Figure S11**). This effect was observed for both first navigation step RT and subsequent step RTs, unlike on day two (first step RT, $t_{(378)} = -3.114$, $p = 0.0063$, corrected for two comparisons; mean of other step RTs, $t_{(379)} = -3.0485$, $p = 0.0050$, corrected). Together, these findings show that two of the three day two effects – positive relationships with choice quality and faster navigation reaction times – were already present on day one, despite fewer trials and reduced task familiarity. This consistency supports the robustness of our main results and suggests that the observed associations between 'Apathy–Anhedonia' factor scores and goal-directed behavior are not driven solely by post-learning consolidation processes, such as sleep.

Discussion

In this study, we investigated goal-directed decision-making in multi-step environments involving learned, compounding risk, using a transdiagnostic approach to examine how motivational symptoms shape the evaluation and pursuit of uncertain goals. Participants with higher scores on an 'Apathy-Anhedonia' factor reported lower expectations of goal success but paradoxically did not reduce goal pursuit. Instead, higher scores were associated with enhanced goal-directed behavior, including greater sensitivity to goal values in decision-making. These effects were specific to goal-directed behavior and were not explained by memory performance for the goal environments. Together, our findings challenge the notion that motivational symptoms uniformly impair goal-directed behavior and provide new insights into the computational mechanisms underlying such behavior.

Consistent with prior research on a pessimistic probability bias in depression (Mukherjee et al., 2020; Strunk and Adler, 2009), individuals with higher 'Apathy-Anhedonia' scores rated their likelihood of success lower in a post-choice assessment. This effect was specific to motivational symptoms, as anxiety-related 'Worry' factor scores showed no relationship with beliefs. Our findings demonstrate that pessimism can emerge from uncertainty learned through direct experience, rather than abstract self-report or hypothetical scenarios often used in previous research (Mukherjee et al., 2020; Strunk and Adler, 2009). Notably, pessimism did not reduce goal pursuit, highlighting a dissociation between the effects of motivational symptoms on belief and behavior. These findings underscore the importance of assessing both beliefs and actions in mental health research.

While apathy and anhedonia are associated with reduced motivation in real-world contexts (Le Heron et al., 2019), our choice behavior results suggest a more nuanced relationship. Individuals with higher 'Apathy-Anhedonia' scores displayed stronger integration of goal values into decision-making. This enhancement, reflected in higher softmax inverse temperatures and a complementary choice quality metric, reflects the effective integration of model-based knowledge into goal valuation. Further supporting this relationship, a supplementary drift-diffusion model incorporating decision reaction times revealed that 'Apathy-Anhedonia' factor scores were associated with a stronger influence of goal value on drift rate (**Supp. Results**). Individuals with elevated scores also demonstrated better avoidance of blocked paths and faster initial movement toward goals, suggesting more efficient planning or action preparation. Finally, elevated 'Apathy-Anhedonia' scores were associated with higher reward earnings. Exploratory analyses of individual scales indicated that the apathy scale had the strongest associations with goal-directed behavior, whereas general depression measures were not significantly related (**Figure S10**). Importantly, we found no significant relationships between 'Apathy-Anhedonia' scores and behavior in additional control tasks (**Table S3**), suggesting that the observed effects are selective to goal-directed behavior rather than a general decision-making ability (Moutoussis et al., 2021). Overall, our paradigm

appears sensitive to individual differences in goal-directed behavior, making it a valuable tool for future research.

Prior large-scale transdiagnostic studies have not reported associations between depression or anxiety symptoms and goal-directed (model-based) behavior (Donegan et al., 2023; Gillan et al., 2016; Patzelt et al., 2019). However, a smaller clinical study reported an association between a combined depression-anxiety factor and impaired model-based behavior (Gillan et al., 2020; see also Heller et al., 2018; Heo et al., 2021). Our set of clinical questionnaires, which allowed for the isolation of motivational symptoms from other depression and anxiety symptoms, may have increased sensitivity to these effects. A potentially more important factor contributing to our findings is the inclusion of additional representative features in our task design (Dhami et al., 2004; Shamay-Tsoory and Mendelsohn, 2019), relative to the well-studied two-step task. Our paradigm, based on an extensive multi-step environment with learned, compounding risk, may more closely mirror the demands of everyday goal pursuit, which often requires integrating episodic memory, mental models, and uncertainty across multiple steps. Our design also specifically targeted goal-directed (model-based) behavior in a well-learned environment, whereas in the two-step task, the degree of model-based relative to model-free behavior is strongly influenced by instructions (Feher da Silva and Hare, 2020). The emphasis on representative features, as well as other task differences discussed below, may have increased our sensitivity to symptom-related individual differences in decision-making.

Why might individuals with higher ‘Apathy-Anhedonia’ scores exhibit enhanced goal-directed behavior? One possibility is that reduced reward motivation and hedonic experience encourages more analytical or systematic decision strategies, consistent with studies on the effects of negative mood on cognition (Schwarz and Clore, 2003). While the vast majority of clinical research has emphasized cognitive impairments in depression (Dillon and Pizzagalli, 2018; Rock et al., 2014), including perseveration in default behavior with higher apathy symptoms (Scholl et al., 2022), a few studies have reported enhanced performance among depressed individuals in inference or multi-step

reasoning tasks (Albiński et al., 2012; von Helversen et al., 2011). Importantly, negative mood is distinct from motivational symptoms, and in our study, mood ratings were not related to goal-directed behavior.

An alternative interpretation focuses on a contrast between everyday experience and the goal-directed task. For individuals with high 'Apathy-Anhedonia' scores, who may perceive daily rewards as sparse or inaccessible, the structured and attainable goals of the task may create a salient positive contrast. This contrast could enhance attention and motivation, similar to effects documented in animal research (Crespi, 1942). Likewise, the novelty of goal achievement – relative to daily experience – may increase engagement and task performance (Schomaker and Meeter, 2015).

Specific design features may have also contributed to the enhanced performance in individuals with higher 'Apathy-Anhedonia' scores. Guided learning across two days may have mitigated some performance deficits, consistent with findings that structured support can ameliorate memory deficits in depression (Hertel, 2000; Hertel and Rude, 1991; Keller et al., 2019). Second, external provision of goals may have reduced the impact of deficits in goal generation and initiation, commonly reported in motivational disorders (Dickson and MacLeod, 2004; Molinaro and Collins, 2023). These features parallel therapeutic approaches: goal setting is a core component of cognitive behavioral therapy (CBT), the most widely implemented evidence-based psychotherapy treatment for depression (Cuijpers et al., 2023; David et al., 2018). Thus, our goal-directed paradigm could serve as a novel experimental tool to investigate mechanisms underlying behavioral improvement in therapeutic contexts.

A secondary aim was to characterize goal-directed behavior under learned, compounding risk. This context more closely mirrors many real-world situations, yet remains underexplored (Olschewski et al., 2024). Participants' overall choices were risk-seeking, in contrast to risk aversion typically observed in described-risk paradigms (Hertwig and Erev, 2009). However, this pattern aligns with prior work demonstrating increased risk-seeking when probabilities are learned from experience rather than

provided explicitly (Hertwig and Erev, 2009). Crucially, whereas previous studies often used brief learning periods spanning only seconds (Hertwig and Erev, 2009), our extended two-day design relied on long-term rather than short-term or working memory (Wimmer et al., 2018), as shown in stable goal success ratings in a follow-up session (**Figure S7**). This extended paradigm also aligns with animal models of learned risk-taking (Garcia et al., 2021). Nevertheless, the association between task-based risk-taking and self-reported risk propensity remained modest, in line with prior studies (Frey et al., 2017; Steiner and Frey, 2021) (see **Supp. Results**).

Several limitations should be considered. Our transdiagnostic design did not rely on clinical diagnoses, although 26% of participants scored above the clinical threshold for depression on the SDS scale, suggesting that the sample included a significant portion of individuals meeting criteria for major depressive disorder. Our approach focused instead on capturing dimensional variation in psychopathology within a general population sample, and we used no inclusion or exclusion criteria with respect to psychiatric symptoms. This approach allows for the examination of symptom-behavior relationships across a broad continuum and also allows for a reflection of normal rates of comorbidity. Future work should examine these effects in clinically diagnosed populations and in patient groups with elevated apathy or anhedonia due to brain injury or neurodegenerative disorders such as Parkinson's disease. Additionally, the apparent discrepancy between enhanced task performance and reduced motivation in everyday life (Le Heron et al., 2019) underscores the need to investigate how task-based goal pursuit translates to real-world contexts.

In summary, our study offers a detailed examination of goal-directed decision-making in environments involving learned, compounding risk. Our findings reveal a paradoxical relationship between motivational symptoms and goal-directed behavior: individuals with higher 'Apathy-Anhedonia' scores had lower expectations of goal success yet showed enhanced goal-directed performance. These findings challenge prevailing assumptions about motivational impairments in depression, highlighting a more nuanced and context-dependent relationship between motivational symptoms and goal

pursuit. This work opens up new avenues for experimental investigations of goal setting and structured interventions aimed at ameliorating real-world motivational deficits.

Methods

Participants were recruited from the online platform Prolific. Eligibility criteria included residing in the United Kingdom, being between 18–38 years old, and fluency in the English language. No mental health-related screening was used. Informed consent was obtained in a manner approved by the University College London Research Ethics Committee (Approval ID No. 3451/001). Participants accessed the experiment via a web browser on a computer (excluding phones and tablets). Participants were compensated at a rate of £8.21 per hour, plus bonus earnings based on different phases of the tasks. The study was preregistered prior to the collection of data (https://osf.io/x3z5f).

A total of 486 participants completed both days of the risky goal task and the self-report scales. 384 participants (52.2% female; mean age 29.9 years, range 18-38) with complete data remained after the application of task and self-report scale exclusion criteria. Participants were screened for both task performance and performance on (in)frequency catch questions embedded within the self-report questionnaires (Zorowitz et al., 2023); see **Supplemental Methods** for details.

Experimental task

All experiments were programmed in JavaScript using the JsPsych library (de Leeuw, 2015). In the risky goal task, on the first day an initial instruction and practice phase involved a simple non-loop maze where participants explored the maze, tried to reach goals, and learned about the risk of move failure. Participants were instructed that the best strategy was to learn the location of items to facilitate successful navigation to goals. After practice, participants were presented with an overhead view of maps of the two mazes they would learn about. This overhead view was presented briefly during breaks between blocks but shown not during individual trials of the task.

The day one session continued with the main experiment phases. First, participants engaged in free exploration of the mazes (with each trial ending after 16 moves), with goal pursuit trials interleaved throughout the second half of the exploration phase. Second, to measure initial learning of the mazes, participants completed an item

location replacement memory test for half of the items in each maze. Third, participants completed a risk learning and goal pursuit phase. In this phase, participants were instructed that the risk of move failure would be introduced from this point onwards, such that at each step in the maze, they had a small chance of failure which would end the trial. Note that participants were not instructed on the specific probability of failure but instead learned this via experience. On each trial, participants were presented with a start item and goal item. A trial ended after the goal was successfully reached or if a failure occurred (with a target rate of 10%), or, rarely, if the movement response time limit was reached.

To measure participants' valuation of and preferences for different risky goals, participants then completed a choice phase. On each trial, they were presented with a goal option, comprising a start item, a goal item, and a goal reward value, and a certain option of £2.00. If the goal was chosen, the trial would begin navigation to the goal. If the certain option was chosen, this reward was displayed, followed by a delay approximating the expected duration of the goal option alternative. Goals varied in distance from 1-7 steps (but distance was not shown to participants) and goal reward values increased with distance with some jitter around a mean. To best estimate individual indifference points where participants switch between choosing the goal versus certain option, goal reward values for each goal distance were individually titrated during the choice phase (**Supp. Methods**). The choice phase included occasional 'roadblock' trials. On these trials, an additional image was displayed to the left of the start item with the word 'roadblock' below in red, indicating that the path through the roadblock object would be blocked. Without providing this information to participants, half of roadblocks were on the short path to the goal ('relevant') and half on the long path ('irrelevant').

After the choice phase on day one, participants completed an additional short goal pursuit phase where new start item-goal item pairs were presented in the absence of choice. These start item-goal item pairs were presented again on choice trials during day two to measure the effect of previous success or failure episodes on later decisions.

Beside these specific ten trials, all start item-goal item pairs across the full experiment were unique.

At the end of each session, participants completed several post-test ratings and memory measures. The first phase presented different start and goal combinations and asked participants to rate on a continuous 0-100% scale how likely they would be to succeed in reaching the goal given the starting point, taking into account the chance of move failure. The second measure assessed first-move direction accuracy. Participants were given a start and goal combination and asked to enter the first direction movement that would reach the goal via the shortest path. Then, participants completed an item location replacement memory measure as in the one collected earlier in the session, but over a different half of the maze locations. Last, participants completed two general success ratings trials, where instead of a specific start and goal item, only colored squares were presented alongside text indicating a goal 1 step away.

On day two, the experiment proceeded as above, with a shorter exploration and learning phase, a longer choice phase, and no second learning phase. Further, a location memory test was administered at the start of the session, prior to any task re-exposure. Participants were also invited to an additional session ("day three") including additional post-test phases, with the invite sent the day following day two.

Additional tasks

On each of the two main days of the study as well as a follow-up session, data from additional tasks were collected. For details, see **Supplementary Methods**. At the end of day one, participants completed a working memory measure (symmetry span). At the end of day two, participants completed a described risk task followed by the first half of the self-report questionnaires. Participants then completed a delay discounting task, followed by the second half of the self-report questionnaires. Participants were invited to a follow-up session the next day, where participants completed a test of location memory and a goal success rating phase for the risky goal task. Next, participants completed a reward learning task followed by an effort-reward decision-making task.

Self-report measures

Participants completed a battery of mental health questionnaires, based on those used in Gillan et al. (2016). To further focus the factor analysis on depression symptoms and to minimize participant fatigue, we selectively reduced or eliminated scales not targeting depression or anxiety symptoms based on findings from Hopkins et al. (2022), resulting in a total of 191 items. To conservatively ensure a sufficient sample for the computational factor analysis, additional survey data were collected from a separate group of participants (additional n = 568; factor analysis total n = 1026; **Supp. Methods**).

The scales included the: Apathy Evaluation Scale (AES), Mini Mood and Anxiety Symptoms Questionnaire – anhedonic depression (MASQ-AD), Positive Valence Systems Scale (PVSS), Zung Depression Scale (SDS), State-Trait Anxiety Inventory (STAI), Depression Anxiety Stress Scale-21 (DASS-21), Intolerance of Uncertainty Scale – Short (IUS), Penn State Worry Questionnaire (PSWQ), and State Trait Inventory of Cognitive & Somatic Anxiety – somatic anxiety (STICSA-S), Liebowitz Social Anxiety Scale (LSAS), Barratt Impulsivity Scale (BIS), Obsessive Compulsive Inventory – Revised (OCIR), Hypomanic Personality Scale – Short (HPS). We added the MASQ-AD, PVSS, DASS, IUS, PSWQ, STICSA-S, and HPS to the set scales used by Gillan et al. (2016). To further target depression and anxiety, 7 items were also added from different scales. See **Supplemental Methods** for references and details, **Table S2** for questionnaire descriptive statistics, **Figure S4** for covariance across summed scores, and **Figure S5** for histograms of scores.

Analysis

Analyses were conducted in MATLAB 2024b, R (4.4.2), julia (1.11.5), and python. Please see **Supp. Methods** for full analysis details. Primary results derive from the following analyses: Pearson correlations, Spearman rank correlations, linear regressions, and paired t-tests. A computational model of risky goal pursuit was developed and fit using hierarchical model fitting. Alternative models of hyperbolic

discounting and models without goal engagement cost were compared using summed AIC across participants. Factor analysis was conducted using maximum likelihood estimation and oblimin rotation. Factor number was selected based on the CNG test and Parallel Analysis.

Acknowledgments: This research was funded in whole, or in part, by the Medical Research Council [MR/V032429/1]. For the purpose of Open Access, the author has applied a CC BY public copyright license to any Author Accepted Manuscript version arising from this submission.

Author contributions: S.L., G.E.W., E.R, and R.R. designed the experiment. S.L. and G.E.W. collected and analyzed the data. S.L. and G.E.W wrote the analysis code. S.L., E.R., R.R. and G.E.W. contributed to data interpretation. S.L. and G.E.W. wrote the paper with E.R. and R.R.

Competing interests: The authors declare no competing interests.

References

Albiński, R., Kliegel, M., Sędek, G., and Kleszczewska-Albińska, A. (2012). Positive effects of subclinical depression in prospective memory and ongoing tasks in young and old adults. Aging, Neuropsychology, and Cognition 19, 35-57.

Bustamante, L.A., Barch, D.M., Solis, J., Oshinowo, T., Grahek, I., Konova, A.B., Daw, N.D., and Cohen, J.D. (2024). Major depression symptom severity associations with willingness to exert effort and patch foraging strategy. Psychological medicine 54, 4396-4407.

Crespi, L.P. (1942). Quantitative variation of incentive and performance in the white rat (Princeton University).

Cuijpers, P., Miguel, C., Harrer, M., Plessen, C.Y., Ciharova, M., Ebert, D., and Karyotaki, E. (2023). Cognitive behavior therapy vs. control conditions, other psychotherapies, pharmacotherapies and combined treatment for depression: A comprehensive meta-analysis including 409 trials with 52,702 patients. World Psychiatry 22, 105-115.

David, D., Cristea, I., and Hofmann, S.G. (2018). Why cognitive behavioral therapy is the current gold standard of psychotherapy. Frontiers in psychiatry 9, 4.

Daw, N.D., Gershman, S.J., Seymour, B., Dayan, P., and Dolan, R.J. (2011). Model-based influences on humans' choices and striatal prediction errors. Neuron 69, 1204-1215.

de Leeuw, J.R. (2015). jsPsych: a JavaScript library for creating behavioral experiments in a Web browser. Behav Res Methods 47, 1-12.

Dhami, M.K., Hertwig, R., and Hoffrage, U. (2004). The role of representative design in an ecological approach to cognition. Psychol Bull 130, 959-988.

Dickson, J.M., and MacLeod, A.K. (2004). Approach and avoidance goals and plans: Their relationship to anxiety and depression. Cognitive Therapy and Research 28, 415-432.

Dillon, D.G., and Pizzagalli, D.A. (2018). Mechanisms of Memory Disruption in Depression. Trends Neurosci 41, 137-149.

Doll, B.B., Duncan, K.D., Simon, D.A., Shohamy, D., and Daw, N.D. (2015). Model-based choices involve prospective neural activity. Nat Neurosci 18, 767-772.

Donegan, K.R., Brown, V.M., Price, R.B., Gallagher, E., Pringle, A., Hanlon, A.K., and Gillan, C.M. (2023). Using smartphones to optimise and scale-up the assessment of model-based planning. Commun Psychol 1, 31.

Feher da Silva, C., and Hare, T.A. (2020). Humans primarily use model-based inference in the two-stage task. Nat Hum Behav.

Frey, R., Pedroni, A., Mata, R., Rieskamp, J., and Hertwig, R. (2017). Risk preference shares the psychometric structure of major psychological traits. Sci Adv 3, e1701381.

Garcia, B., Cerrotti, F., and Palminteri, S. (2021). The description-experience gap: a challenge for the neuroeconomics of decision-making under uncertainty. Philos Trans R Soc Lond B Biol Sci 376, 20190665.

Gillan, C.M., Kalanthroff, E., Evans, M., Weingarden, H.M., Jacoby, R.J., Gershkovich, M., Snorrason, I., Campeas, R., Cervoni, C., and Crimarco, N.C. (2020). Comparison of the association between goal-directed planning and self-reported compulsivity vs obsessive-compulsive disorder diagnosis. JAMA psychiatry 77, 77-85.

Gillan, C.M., Kosinski, M., Whelan, R., Phelps, E.A., and Daw, N.D. (2016). Characterizing a psychiatric symptom dimension related to deficits in goal-directed control. Elife 5.

Heller, A.S., Ezie, C.C., Otto, A.R., and Timpano, K.R. (2018). Model-based learning and individual differences in depression: The moderating role of stress. Behaviour research and therapy 111, 19-26.

Heo, S., Sung, Y., and Lee, S.W. (2021). Effects of subclinical depression on prefrontal–striatal model-based and model-free learning. PLoS computational biology 17, e1009003.

Hertel, P.T. (2000). The cognitive-initiative account of depression-related impairments in memory. Psychology of learning and motivation 39, 47-71.

Hertel, P.T., and Rude, S.S. (1991). Depressive deficits in memory: focusing attention improves subsequent recall. Journal of Experimental Psychology: General 120, 301.

Hertwig, R., and Erev, I. (2009). The description-experience gap in risky choice. Trends Cogn Sci 13, 517-523.

Hopkins, A.K., Gillan, C., Roiser, J.P., Wise, T., and Sidarus, N. (2022). Optimising the measurement of anxious-depressive, compulsivity and intrusive thought and social withdrawal transdiagnostic symptom dimensions. PsyArXiv.

Kahneman, D., and Tversky, A. (1979). Prospect theory: An analysis of decision under risk. Econometrica 47, 363-391.

Keller, A.S., Leikauf, J.E., Holt-Gosselin, B., Staveland, B.R., and Williams, L.M. (2019). Paying attention to attention in depression. Translational psychiatry 9, 279.

Le Heron, C., Holroyd, C.B., Salamone, J., and Husain, M. (2019). Brain mechanisms underlying apathy. Journal of Neurology, Neurosurgery & Psychiatry 90, 302-312.

Liu, Y., Mattar, M.G., Behrens, T.E.J., Daw, N.D., and Dolan, R.J. (2021). Experience replay is associated with efficient nonlocal learning. Science 372.

Miller, K.J., Botvinick, M.M., and Brody, C.D. (2017). Dorsal hippocampus contributes to model-based planning. Nat Neurosci 20, 1269-1276.

Molinaro, G., and Collins, A.G. (2023). A goal-centric outlook on learning. Trends in Cognitive Sciences 27, 1150-1164.

Moutoussis, M., Garzon, B., Neufeld, S., Bach, D.R., Rigoli, F., Goodyer, I., Bullmore, E., Consortium, N., Guitart-Masip, M., and Dolan, R.J. (2021). Decision-making ability, psychopathology, and brain connectivity. Neuron 109, 2025-2040 e2027.

Mukherjee, D., Lee, S., Kazinka, R., T, D.S., and Kable, J.W. (2020). Multiple Facets of Value-Based Decision Making in Major Depressive Disorder. Sci Rep 10, 3415.

Olschewski, S., Luckman, A., Mason, A., Ludvig, E.A., and Konstantinidis, E. (2024). The Future of Decisions From Experience: Connecting Real-World Decision Problems to Cognitive Processes. Perspect Psychol Sci 19, 82-102.

Patzelt, E.H., Kool, W., Millner, A.J., and Gershman, S.J. (2019). Incentives Boost Model-Based Control Across a Range of Severity on Several Psychiatric Constructs. Biol Psychiatry 85, 425-433.

Rock, P.L., Roiser, J.P., Riedel, W.J., and Blackwell, A. (2014). Cognitive impairment in depression: a systematic review and meta-analysis. Psychological medicine 44, 2029-2040.

Scholl, J., Trier, H.A., Rushworth, M.F., and Kolling, N. (2022). The effect of apathy and compulsivity on planning and stopping in sequential decision-making. PLoS biology 20, e3001566.

Schomaker, J., and Meeter, M. (2015). Short-and long-lasting consequences of novelty, deviance and surprise on brain and cognition. Neuroscience & Biobehavioral Reviews 55, 268-279.

Schwarz, N., and Clore, G.L. (2003). Mood as information: 20 years later. Psychological inquiry 14, 296-303.

Seow, T.X.F., Benoit, E., Dempsey, C., Jennings, M., Maxwell, A., O'Connell, R., and Gillan, C.M. (2021). Model-Based Planning Deficits in Compulsivity Are Linked to Faulty Neural Representations of Task Structure. J Neurosci 41, 6539-6550.

Shamay-Tsoory, S.G., and Mendelsohn, A. (2019). Real-life neuroscience: an ecological approach to brain and behavior research. Perspectives on Psychological Science 14, 841-859.

Sharp, P.B., Dolan, R.J., and Eldar, E. (2023). Disrupted state transition learning as a computational marker of compulsivity. Psychol Med 53, 2095-2105.

Sookud, S., Martin, I., Gillan, C., and Wise, T. (2024). Impaired goal-directed planning in transdiagnostic compulsivity is explained by uncertainty about learned task structure. In PsyArXiv.

Steiner, M.D., and Frey, R. (2021). Representative design in psychological assessment: A case study using the Balloon Analogue Risk Task (BART). J Exp Psychol Gen 150, 2117-2136.

Strunk, D.R., and Adler, A.D. (2009). Cognitive biases in three prediction tasks: a test of the cognitive model of depression. Behav Res Ther 47, 34-40.

Tolman, E.C. (1948). Cognitive maps in rats and men. Psychol Rev 55, 189-208.

Treadway, M.T., Bossaller, N.A., Shelton, R.C., and Zald, D.H. (2012). Effort-based decision-making in major depressive disorder: a translational model of motivational anhedonia. J Abnorm Psychol 121, 553-558.

Vikbladh, O.M., Meager, M.R., King, J., Blackmon, K., Devinsky, O., Shohamy, D., Burgess, N., and Daw, N.D. (2019). Hippocampal contributions to model-based planning and spatial memory. Neuron 102, 683-693 e684.

von Helversen, B., Wilke, A., Johnson, T., Schmid, G., and Klapp, B. (2011). Performance benefits of depression: sequential decision making in a healthy sample and a clinically depressed sample. Journal of abnormal psychology 120, 962.

Wimmer, G.E., Li, J.K., Gorgolewski, K.J., and Poldrack, R.A. (2018). Reward learning over weeks versus minutes increases the neural representation of value in the human brain. J Neurosci 38, 7649-7666.

Wimmer, G.E., Liu, Y., McNamee, D.C., and Dolan, R.J. (2023). Distinct replay signatures for prospective decision-making and memory preservation. Proc Natl Acad Sci U S A 120, e2205211120.

Wise, T., Robinson, O.J., and Gillan, C.M. (2023). Identifying Transdiagnostic Mechanisms in Mental Health Using Computational Factor Modeling. Biol Psychiatry 93, 690-703.

Zorowitz, S., Solis, J., Niv, Y., and Bennett, D. (2023). Inattentive responding can induce spurious associations between task behaviour and symptom measures. Nat Hum Behav 7, 1667-1681.