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Effects of reward anticipation on memory encoding and cognitive control outcomes: A meta-analysis

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ABSTRACT

Extensive evidence suggests that cognitive performance is typically enhanced under increased motivation, often in the form of reward anticipation. While monetary incentive delay (MID)-style paradigms have been widely used to elicit and examine effects of reward anticipation on cognition, the extent to which such effects are comparable across cognitive domains and varying task designs is unclear. This meta-analysis synthesizes the literature, examining how reward anticipation modulates memory encoding accuracy (58 effect sizes from 43 publications, N = 2072), cognitive control accuracy (70 effect sizes from 53 publications, N = 2615), and cognitive control reaction time (RT; 74 effect sizes from 56 publications, N = 2554). Reward effect magnitudes differed across outcomes, with the largest effect for cognitive control RT (Cohen's d = 0.807), followed by memory accuracy (Cohen's d = 0.537), and cognitive control accuracy (Cohen's d = 0.286). Moderators related to reward manipulations and task design were tested. For memory accuracy, significant moderators included reward incentive type, presence of a false alarm penalty at recognition, encoding intentionality, memoranda type, and retrieval format. For cognitive control accuracy and RT, reward type and task type moderated the effect. Task timing was not a significant moderator for any domain. Overall, reward effects on cognitive performance appear highly sensitive to contextual parameters, with study-level variability in experimental designs accounting for notable heterogeneity, particularly for memory encoding. Considering such heterogeneity within and across cognitive domains is crucial for developing a comprehensive understanding of reward anticipation effects and advancing the field of motivated cognition.

1. Introduction

We live in a complex world. The sheer volume of sensory input offered by our surrounding environments, along with the number of possible behavioral responses to this input, present a capacity problem for the limitations of the cognitive system. Motivational significance may act as a critical signal triggering adaptive cognitive prioritization and behavioral selectivity. Motivational processes, operationalized as those guiding behavior towards desired goal outcomes and away from potential threats, are often learned through reinforcement processes, have been long recognized as critical for survival, and are extensively studied in terms of their underlying neurobiology. This work, largely conducted in rodents and other animal models, includes seminal work illustrating that processes of reward and reinforcement can be elicited through brain activity (Olds and Milner, 1954), specifically in association with dopaminergic system functioning (Salamone and Correa, 2002; Wise and Rompre, 1989), and that such processes can be linked to a range of biological motives including homeostasis, approach and avoidance, and responses to incentives (as reviewed in (Berridge, 2004; Dickinson and Balleine, 1994). More recently, empirical evidence from studies largely conducted in humans indicates that motivational influences can further modulate cognition and information processing, in addition to behavioral responses, across a broad range of domains, including perception, attention, cognitive control, and memory (Braver et al., 2014; Hughes and Zaki, 2015; Lang et al., 2013).

With growing empirical evidence indicating its importance to understanding adaptive human behavior, motivated cognition has become a central topic in cognitive psychology and neuroscience in recent years.

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0149-7634/© 2026 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

Despite this large and flourishing literature, a comprehensive understanding of how, and under what conditions, motivation adaptively modulates cognition is not fully characterized. Variations in experimental context and task design have made it challenging to fully parse this relationship. Motivational influences have been investigated across multiple domains of cognition, with memory encoding and cognitive control as two of the most well-studied domains in this now-extensive literature. *Memory encoding* refers to the ability to learn and retain information long-term (Tulving, 1993), while *cognitive control* is a broad umbrella term that refers to executive functions supporting flexible representation, maintenance, and updating of internal goals (Miller, 2000). Memory encoding and cognitive control are critical to adaptive, goal-directed behavior over time, with motivational context identified as a modulator of task performance in both domains (as reviewed in cognitive control: (Botvinick and Braver, 2015); in memory: (Miendlarzewska et al., 2016). While memory processes and cognitive control can work in concert with one another (Badre and Wagner, 2007; Dudukovic and Kuhl, 2017), their modulation by motivation has typically been studied in separate research programs focusing on distinct performance outcomes. As such, the extent to which a given motivation manipulation might comparably modulate cognitive performance, and the similarities and differences across domains, remains an open and important question. Additionally, observed effects of reward on cognition may differ across studies, given variability in several parameters of study designs used, including those relating to reward type, amounts, and contingency, as well as task rules, timing, and stimulus format. Prior meta-analyses of reward effects on cognition (i.e., Burton et al., 2021; Swirsky et al., 2023) have identified heterogeneity in the magnitude of reward effects, suggesting the presence of potential moderators. However, those prior studies have been limited in accounting for such heterogeneity, suggesting that a more comprehensive evaluation of potential moderators is warranted. Thus, the goal of the present meta-analysis is to synthesize the literature and advance our understanding of the extent to which a broad range of experimental parameters moderate reward motivation effects on cognition in two separate domains of memory encoding and cognitive control. Specifically, our meta-analysis seeks to address the following unresolved key questions: (1) To what extent are reward anticipation effects on cognitive performance comparable versus dissimilar for cognitive control and memory outcomes? (2) What factors, particularly those relating to study design, moderate the magnitude of such reward effects? Across both domains, our meta-analysis focused on studies employing Monetary-Incentive-Delay (MID)-style paradigms to elicit reward anticipation and examine its effects on cognitive performance. The MID paradigm and this approach are described in more detail below.

2. Monetary-incentive-delay (MID) paradigms for assessing motivated cognition

Across both memory and cognitive control domains, the MID paradigm and related adaptations have become well-established tools for characterizing the effects of reward motivation on brain activity and behavioral task performance. The MID paradigm was originally adapted from instrumental conditioning paradigms used in animal models for use with humans during fMRI scans, with the goal of examining discrete anticipatory and consummatory stages of reward processing and their associated neural substrates. On each trial of the original MID paradigm (Knutson et al., 2000), a reward (or non-reward) cue was presented, creating an anticipatory period, followed by a target to be responded to and reward receipt. This simple cue-probe paradigm allows for the investigation of brain activity during reward anticipation and subsequent receipt or reward feedback. Dovetailing with animal studies of reward anticipation and motivated behavior, fMRI evidence using the MID paradigm has demonstrated that activity in the mesolimbic dopamine pathway, originating in the midbrain and projecting dopamine to multiple cortical and subcortical regions crucial to cognition, including prefrontal cortex, striatum, and hippocampus, is implicated in human reward anticipation and receipt (Braver et al., 2014; Knutson et al., 2001). In particular, mesolimbic dopaminergic input to the prefrontal cortex has been of interest as an anatomical basis for reward modulation of cognitive control (Botvinick and Braver, 2015), while mesolimbic dopaminergic input to the hippocampus has been of interest as an anatomical basis for reward modulation of memory encoding (Shohamy and Adcock, 2010). More recent research posits that anticipatory activity in the mesolimbic dopamine pathway might specifically enable neural preparation for approach behavior and memory encoding (e.g., by inducing a potential “convergence state” for adaptive cognition; (Poh et al., 2022).

The MID paradigm has now been adapted into many variations to investigate effects of reward anticipation on cognitive performance, but the basic cue-target trial structure of the paradigm has generally been retained across these adaptations. This makes the MID-style paradigm an ideal “case study” for examining the influence of motivation (and related putative mesolimbic dopamine pathway engagement) on cognitive task performance across different domains and experimental contexts. While other task designs have also been used to examine the influences of reward on cognitive performance (i.e., blocked designs where tasks are performed in a sustained reward context, paradigms where rewards are presented concurrently with processed target stimuli or received as feedback; reviewed in (Bowen, 2020). We elected to constrain the present literature search and meta-analysis to studies using MID-style experimental paradigms, where each trial follows a cue-probe/target structure. Such paradigms are widely used in the study of motivated cognition and extensive evidence exists regarding their elicitation of motivation-related brain activity in humans. As such, focusing on effects elicited using MID-style paradigms in the present investigation might allow for a certain degree of consistency in putative brain activity during the reward anticipation period and facilitation of cross-study, as well as cross-domain (memory encoding versus cognitive control), examinations of motivational effects on cognitive performance.

MID-style paradigms assessing effects of reward anticipation on cognitive control typically manipulate reward on a within-subjects basis, using trial structures where a high reward or non-/low-reward cue is initially presented. Such a cue is followed by a target to be responded to, and the timing interval between processing of motivational information, the presentation of the target stimulus, and the participant behavioral response is typically brief (i.e., on the order of seconds). Both accuracy and reaction time are often examined as outcome measures of interest. In the memory domain, a variant of the MID paradigm known as the Monetary-Incentive-Encoding (MIE) paradigm has been used to examine effects of reward anticipation on memory encoding (Adcock et al., 2006). In the MIE task, the basic trial structure of a high reward or non-/low-reward cue, followed by a target stimulus, is also employed. Participants are typically either instructed to encode the stimuli, with rewards tied to successful memory performance, or incidentally encode stimuli (i.e., where rewards are not memory performance contingent, but received incidentally to task performance or earned via engagement in an unrelated task) without instruction that their memory will be later tested. Motivated memory in the MIE paradigm is measured at retrieval; by design, participant behavioral responses are collected following a retention interval, using retrieval tests of different formats including recognition, free recall, paired-associations, and alternative forced-choice tasks. Performance accuracy is typically used as the primary outcome of interest.

While theoretical and empirical accounts support the idea that both memory encoding and cognitive control should be adaptively modulated by modulation, it remains an open question whether MID-style reward anticipation cues influence memory and cognitive control outcomes with comparable effect amplitude, given differences in how the studies are conducted between these domains. Specifically, the temporal proximity of the motivational cue (and associated putative dopamine activity) to assessed behavioral output differs across domains. Memory is typically assessed with accuracy-related metrics at retrieval, following an encoding block and retention interval, whereas cognitive control is typically assessed with both accuracy- and speed-related metrics derived from an immediate motor response on each trial. These differences in performance characteristics across memory and cognitive control domains might have important implications for how they are modulated by reward anticipation. Extensive evidence indicates that dopaminergic activity might underlie motivation-related benefits to cognitive performance, but may also be implicated in enhanced or accelerated motor responding (sometimes characterized as "vigor"; Beierholm et al., 2013), and that such enhancements to both cognitive and motor activity might have evolved together to maximize reward harvesting in resource-rich environments (Düzel et al., 2010). At the same time, motor activity has been identified as engaging the noradrenergic system of the brain, a catecholamine pathway closely related to and interacting with dopamine, to support motivated cognition and behavior (Yebra et al., 2019). It is possible that the effect of reward anticipation on cognitive performance in MID-style paradigms might be amplified for cognitive control versus MIE-style memory encoding outcomes, given the closer temporal proximity between elicitation of reward anticipation and execution of behavioral output used to assess cognitive control, compared to examining memory retrieval at a delay. Further, such amplification of reward effects on cognitive control might specifically manifest in terms of increased speed, reflecting dopamine effects on motoric vigor. However, to our knowledge, no systematic comparison of reward anticipation effects in MID-style paradigms, across memory encoding and cognitive control outcomes, has been conducted. Such a comparison might be important for advancing understanding of common versus distinct mechanisms driving motivated cognition across cognitive domains.

3. Experimental design differences in memory encoding and cognitive control paradigms

While MID-style paradigms have been prevalent within the motivated cognition literature across both memory and cognitive control domains, variability in task design within this paradigm structure has proliferated. Experimental paradigms to assess the

effects of reward anticipation on memory encoding, cognitive control, and other cognitive outcomes have differed on a number of parameters. These include the types and amounts of motivators employed to elicit reward anticipation, incentive contingency (i.e., whether motivational incentives are performance-contingent or incidental), task rules, event structure and timing, and for memory paradigms, parameters of the retrieval test and retention interval. Differences in these and other elements of study design may further moderate how motivational and cognitive mechanisms are engaged across studies, potentially underlying heterogeneity in the reward effects observed. Testing for potential moderators is important both for advancing a basic scientific knowledge of motivated cognition as well as effective application of this knowledge in myriad settings including educational, occupational and health contexts.

While monetary gains/losses and points are the most commonly observed incentives in the motivated cognition literature, other types of incentives have also been used, including foods and consumable liquids, threat of electric shock, and social incentives (Krug and Braver, 2014). Limited comparisons of the motivational effects of different types of incentives on cognition have been conducted, but past studies have suggested both diverging and comparable modulatory effects (Beck et al., 2010; Crawford et al., 2020). Further, task-based incentives are often offered as performance-based bonuses in the motivated cognition literature, but such bonuses can interact with compensation to participate in the research study (e.g., course credit or monetary payment) to influence task performance (Bowen and Kensinger, 2017).[1] Incentives can also vary in valence, with reward-approach and punishment-avoidance designs utilizing both monetary and alternative forms of incentives, and with some studies combining positively- and negatively-valenced incentives (i.e., simultaneously implementing rewards for good performance and penalties for poor performance). The extent to which differing valences and types of incentives might moderate cognitive outcomes is an emerging topic for the field, with both commonalities and differences in their effects identified across both cognitive control (Cubillo et al., 2019; Yee and Braver, 2018) and memory domains (Murty and Adcock, 2017; Shigemune et al., 2014). With the use of parametrically varying incentives such as money or points, it is also possible that the amplitude of motivational effects on performance might correspond to the relative difference between high- and low/no-incentive conditions. Prior studies have yielded mixed effects; some evidence suggests that reward influences on memory can be adaptively scaled, with larger reward amounts associated with greater benefits (Bunzeck et al., 2010), but other evidence has suggested nonlinear relationships or decrements in performance at higher reward levels ("choking under pressure"; Beilock and Carr, 2001; Mason et al., 2017; Yu, 2015). To our knowledge, it remains an open question whether study-level variability in the relative amount of incentives across high and low/no-reward conditions might relate to the amplitude of relative effects on performance.

Incentive contingency might be a second important moderator of motivational influences on cognitive performance. Both performance-contingent (i.e., rewards earned for cognitive task performance) and incidental incentives (i.e., rewards received independently of task performance or earned via engagement in an unrelated task) have been used to examine effects of motivation on memory encoding and cognitive control. In the memory domain, evidence suggests that both contingent and incidental rewards can enhance performance (Adcock et al., 2006; Chiew and Bowen, 2022; Wittmann et al., 2005). However, we might speculate that the amplitude of the reward effect on memory encoding might be larger when rewards are performance-contingent, as such contingency might promote more attention to presented memoranda or engagement in effective encoding strategies such as semantic elaboration. We can also consider potential effects of intentional versus incidental encoding independent of reward – in other words, whether participants know their memory will be tested later, separately of rewards associated with that memory performance. Evidence suggests that memory performance is generally enhanced under intentional versus incidental encoding (Craig et al., 2016), but it is unclear whether the

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[4] Specifically, Bowen and Kensinger (Bowen and Kensinger, 2017) demonstrated that participants in a motivated memory experiment compensated by monetary payment showed a larger selectivity effect for high-value information, but their global memory performance did not significantly differ from participants receiving course credit for compensation. It was suggested that these diverging results might reflect varying degrees of extrinsic versus intrinsic motivation, which might have been stronger drivers of performance in the monetary and credit compensation conditions respectively. These findings reflect the broader principle that extrinsic incentives might interact with intrinsic motivation (Ryan and Deci, 2000) and may, in some circumstances, undermine it (Murayama et al., 2010) to impact task performance. While the interplay between extrinsic and intrinsic motivation is an important issue in the study of motivated cognition, experimental studies of cognitive performance using MID-style paradigms have generally manipulated motivation via extrinsic rewards and incentives, with limited investigation of the role of intrinsic motivation. As such, our meta-analysis is limited in the extent to which the role of intrinsic motivation can be characterized.

benefit of intentionality might interact with incidental rewards. In the cognitive control domain, effects of reward on task performance have been observed to vary with incentive contingency. In contrast to the memory literature, where both contingent and incidental rewards have generally been found to enhance memory performance, rewards have been associated with opposite effects on cognitive control depending on contingency: for example, increases in cognitive control have been observed with performance-contingent rewards (Chiew et al., 2018; Braem et al., 2012; Chiew and Braver, 2013), while decreases in cognitive control have been observed with non-contingent rewards (van Steenbergen et al., 2009). However, to our knowledge, such diverging effects with reward contingency have not been systematically studied in cognitive control. Further, the effects of performance-contingent reward on cognitive control might also depend on specifics of the contingency structure – for example, whether incentives are awarded on the basis of accuracy, speed, or a combination of both (Dambacher et al., 2011).

Third, variation in task rules, trial event content, and timing is common across studies in the motivated cognition literature, but the extent to which this variation might moderate effects of motivation on cognitive outcomes is not well-characterized. In the cognitive control domain, a wide variety of tasks have been used to examine effects of reward anticipation on performance within MID-style paradigms (i.e., Stroop, Flanker, AX-CPT, task switching, etc.), but such differing tasks are argued to involve distinct cues, rules, and responses (Freitas et al., 2007) and different sources of conflict (i.e., stimulus-stimulus versus stimulus-response conflict; Kornblum et al., 1990), the processing of which might be differentially modulated by motivation. While some initial evidence suggests that incentive valence might interact with cognitive control demands (i.e., evidence suggests that rewards might benefit active responses more than passive withdrawal, while punishments might benefit inhibitory responses more than active; Guitart-Masip et al., 2012), the extent to which effects of reward motivation on cognitive performance might vary as a function of cognitive control task is largely unknown. In the memory domain, a variety of memoranda have been used, including word and picture stimuli, which might vary in memorability (Oates and Reder, 2011) and potential modulation by motivational manipulation. For example, neuroimaging evidence suggests that value-directed modulation of memory encoding for word stimuli is specifically associated with enhanced activity in the semantic network (Cohen et al., 2016); such modulation might be reduced with image stimuli if they engage regions related to semantic processing differently or to a lesser extent than word stimuli (Chee et al., 2000; Devereux et al., 2013). Temporal variability in trial events, particularly in reward cue, target, and cue-target interval durations, might be important given evidence that neural responses to reward anticipation cues unfold over time (Fiorillo et al., 2003; Schultz, 2007) and that cues to certain versus uncertain reward have been found to impact memory formation differently as a function of cue-target interval duration (Stanek et al., 2019). Specific to motivated memory encoding, the importance of retention interval length (i.e., timing between encoding and retrieval) has been the subject of debate. Some studies suggest that motivated memory might depend on dopaminergic modulation of hippocampally-based consolidation processes that take time to unfold (Gruber et al., 2016; Spaniol et al., 2014), while other studies have identified comparable or even enhanced reward benefits to memory without an overnight consolidation period (Castel et al., 2002; Gholston et al., 2023).

Finally, in the memory domain, emerging evidence suggests that motivational effects might vary with the format of the retrieval test. Memory performance can be assessed using methods such as recall, recognition, and paired-associates tests. Prior research suggests that successful memory recall might depend on recollective memory, while memory recognition might depend on either recollective- or familiarity-based memory (Mandler, 1980; Yonelinas, 2002). Given that reward motivation has been associated with enhanced hippocampal activity, arguably promoting recollection, it is possible that reward-related benefits to memory might be amplified when a recall memory test is used, compared to a recognition memory test. Additionally, our recent work suggests that reward motivation might modulate decision biases at retrieval as well as memory encoding processes, shaping recognition memory performance differently as a function of both rewards for correct responses as well as penalties for false alarms (Bowen et al., 2020). Taken together, a meta-analysis is an ideal opportunity to characterize the effects of these potential moderators of motivational effects on cognitive outcomes, across memory and cognitive control domains, and across a broad and heterogeneous research literature.

4. Past reviews and meta-analyses

While some prior syntheses of motivated cognition research that consider potential moderators of and sources of variability in motivation effects have emerged, they remain relatively limited in number. In one such study, Burton, Knibb, and Jones (Burton et al., 2021) conducted a meta-analytic investigation of reward effects specifically on inhibitory control to address prior observations of inconsistent outcomes across studies. Burton et al. tested a limited number of moderators (clinical status, reward type, task type, and age) and, while observing high heterogeneity in reward effect sizes, found that their tested moderators did not account well for this heterogeneity, leaving open questions about the factors that might contribute to reward benefits to cognition. As a pre-cursor to the present meta-analysis, we recently published a narrative review of popular experimental paradigms that have been used to study motivated memory (Chiew and Bowen, 2022), highlighting how differing aspects of task paradigms, including incentive type, participant compensation, and retention interval, might contribute to observed results. We also theorized where strategic control versus automatic processes might underlie motivated memory performance (i.e., suggesting that strategic control might be mobilized more at encoding when participants intentionally encoded information, knowing there would be a subsequent memory test, versus incidental encoding followed by a surprise memory test) and emphasized where controlled and automatic reward-related processes might work in tandem to modulate memory. Writing that review helped us consider potential sources of variability in motivated cognition and identify what moderators might be important to investigate empirically in the present meta-analysis.

In parallel with our review, Knowlton and Castel (Knowlton and Castel, 2022) published a comprehensive review of evidence that motivated memory (or *value-directed remembering*; i.e., the prioritization of higher-value or more motivationally significant information in memory) might depend on both strategic and automatic cognitive processes associated with distinct neural substrates and differentially engaged across different contexts. They further postulate that reliance on strategic versus automatic mechanisms to support value-directed remembering may vary across the lifespan in relation to age-related neurocognitive changes, with reduced reliance on automatic processes in older age. Notably, this review did not quantify the extent of these potential differences through meta-analytic approaches. To test this more directly, Murphy et al. (Murphy et al., 2025) developed a novel paradigm investigating age-related differences in the automatic processing of value during memory encoding and its influence on subsequent remembering, and reported evidence that automatic effects of value might have a greater effect on subsequent memory in younger versus older adults.

Finally, in a similar vein, Swirsky et al. conducted a systematic review (Swirsky and Spaniol, 2019) followed by a meta-analysis (Swirsky et al., 2023) focusing on motivated cognition across the lifespan. Specifically, Swirsky and Spaniol (Swirsky and Spaniol, 2019) reviewed empirical findings of both declines and maintenance of motivational selectivity in older age, proposing a new framework comprising multiple mechanisms of selectivity to reconcile disparate results in the cognitive aging literature. In the follow-up meta-analysis (Swirsky et al., 2023), the authors quantitatively tested for significant age differences in motivated cognition (examining Motivation × Age interaction terms from the literature), specifically in terms of memory and cognitive control outcomes. Their meta-analytic results did not yield the hypothesized significant Motivation × Age interaction, nor did most of the tested moderators reach significance, with the exception of incentive type on memory outcomes. Similar to Burton et al. (Burton et al., 2021), Swirsky et al. observed a high degree of heterogeneity in reward effect sizes, suggesting the presence of important but unexplored moderator variables.

Taken together, these prior studies have advanced the field of motivated cognition by identifying potential variability in neurocognitive mechanisms and examining associated participant- and study-level factors that may have contributed to inconsistent effects of reward on cognitive performance. However, prior meta-analyses (Burton et al., 2021; Swirsky et al., 2023) have revealed high levels of heterogeneity in reward effect magnitude that have yet to be fully accounted for by potential moderating variables. Notably, Swirsky et al. (Swirsky et al., 2023) focused specifically on age-related differences in motivation effects (i.e., the Motivation × Age interaction), used a very broad set of "motivation" search terms, and collapsed across varied task designs, while Burton et al.'s results suggested that reward effects on cognitive performance may vary with task type, but their investigation was limited to the topic of inhibitory control. Additionally, to our knowledge, no prior meta-analysis has systematically compared reward main effects on cognitive performance and significant moderators of such effects across domain (memory versus cognitive control) and performance outcome (for cognitive control, accuracy versus response times). In the present study, we examined a larger and more comprehensive array of potential moderators than prior identified meta-analyses, including several task design parameters, paradigm type, and event timing, across both cognitive control and memory outcomes. We further focused our investigation on studies employing MID-style cue probe designs to induce reward anticipation. Given extensive neuroimaging research employing the MID to characterize neural activity related to reward, this approach allowed us to compare cognitive performance across domains and characterize the role of potential moderators in the context of putative, but well-studied, brain activity related to reward anticipation with some consistency across included datasets. Finally, while a substantial portion of this prior work suggests that age-related differences may be an important dimension of motivated cognition, the primary focus of our study was to characterize the magnitude of reward anticipation effects on cognition and how they may differ with varying task parameters and by the performance outcome examined. Given this, we elected to focus on young adult samples rather than incorporate a lifespan approach.

5. Current study

The goal of this pre-registered meta-analysis is to examine the effect of motivated anticipation (induced through the use of trial-level reward cues) on cognitive performance. We specifically focused on studies using cue-target MID-style task designs to examine the influence of reward anticipation on memory encoding and cognitive control outcomes. We had two main research questions:

1) To what extent does reward anticipation modulate memory encoding and cognitive control performance, and how comparable are the effects across these two cognitive domains?
2) What specific elements of task design moderate reward anticipation influences on memory encoding and cognitive control?

The present study extends prior work on motivated cognition in several important ways. First, by focusing on widely-used, cue-target task designs, we can meaningfully compare effects of reward cues on performance outcomes across the domains of memory encoding and cognitive control. Second, we build on the work of Swirsky et al. (Swirsky et al., 2023), but elected to examine main effects of motivation on cognition broadly, as opposed to focusing on the potential interaction of motivation with age. Finally, we test for potential moderation by varying aspects of task design – largely under-characterized in the cognitive psychology literature, but potentially altering the mechanisms underlying motivation-cognition interaction – which could significantly influence study outcomes and contribute to variability in observed results across the motivated cognition literature.

6. Methods

6.1. Transparency and openness

This project was preregistered on the Open Science Framework (OSF) on April 20, 2020: https://osf.io/vc2ht. We developed a protocol for objectives, search criteria, and strategy for data extraction prior to conducting the meta-analysis, in line with guidelines for systematic reviews (Centre for Review and Dissemination, 2008) and we adhered to the PRISMA 2020 guidelines for systematic reviews (Page et al., 2021). The literature search and selection process is presented in a PRISMA flow diagram in Fig. 1 top panel (Moher et al., 2009). Data were modeled using Comprehensive Meta-Analysis Version 4.0 (Biostat Inc; Borenstein et al., 2022). All data and research materials including our coding scheme are available at the OSF project page https://osf.io/h295a/files/osfstorage.

6.2. Search strategy

In February 2020, the following electronic databases were searched: PubMed (https://pubmed.ncbi.nlm.nih.gov/), APA PsycINFO (https://www.apa.org/pubs/databases/psycinfo), and Web of Science (https://www.webofscience.com/wos/woscc/basic-search). To be as inclusive as possible and reduce potential bias, limits were not placed on the years searched or the resource type, and unpublished studies (e.g., dissertations) were included. Given our interests in investigating the effects of reward motivation on cognition in two domains – memory encoding and cognitive control– we developed two families of search terms for studies investigating memory encoding and cognitive control as follows:

1) Memory Encoding: ("memory encoding" OR "subsequent memory" OR "recognition") + ("reward" OR "reward anticipation" OR "motivation" OR "incentive" OR "motivational incentive")
2) *Cognitive Control:* ("cognitive control" OR "executive function" OR "executive control") + ("reward" OR "reward anticipation" OR "motivation" OR "incentive" OR "motivational incentive")

Bibliographic information for each record was exported into a spreadsheet for the article screening process.

A second search was conducted on October 17, 2025, with the same search terms and procedure except the search was limited to the date range of February 1, 2020 to present. The results of this search are reported in Fig. 1 bottom panel. The results reported below include papers from both searches combined.

6.3. Screening process

Once exported, bibliographic information for each citation was inspected across reference databases and duplicate citations were removed. Then, search results were inspected to determine whether they met the inclusion criteria for the meta-analysis. These criteria were as follows:

1) Studies had to be empirical (i.e., refereed, peer-reviewed journal articles, dissertations, theses), quantitatively examining the association between reward motivation and memory or cognitive control using cue-target designs. Qualitative studies (i.e., focus groups, case

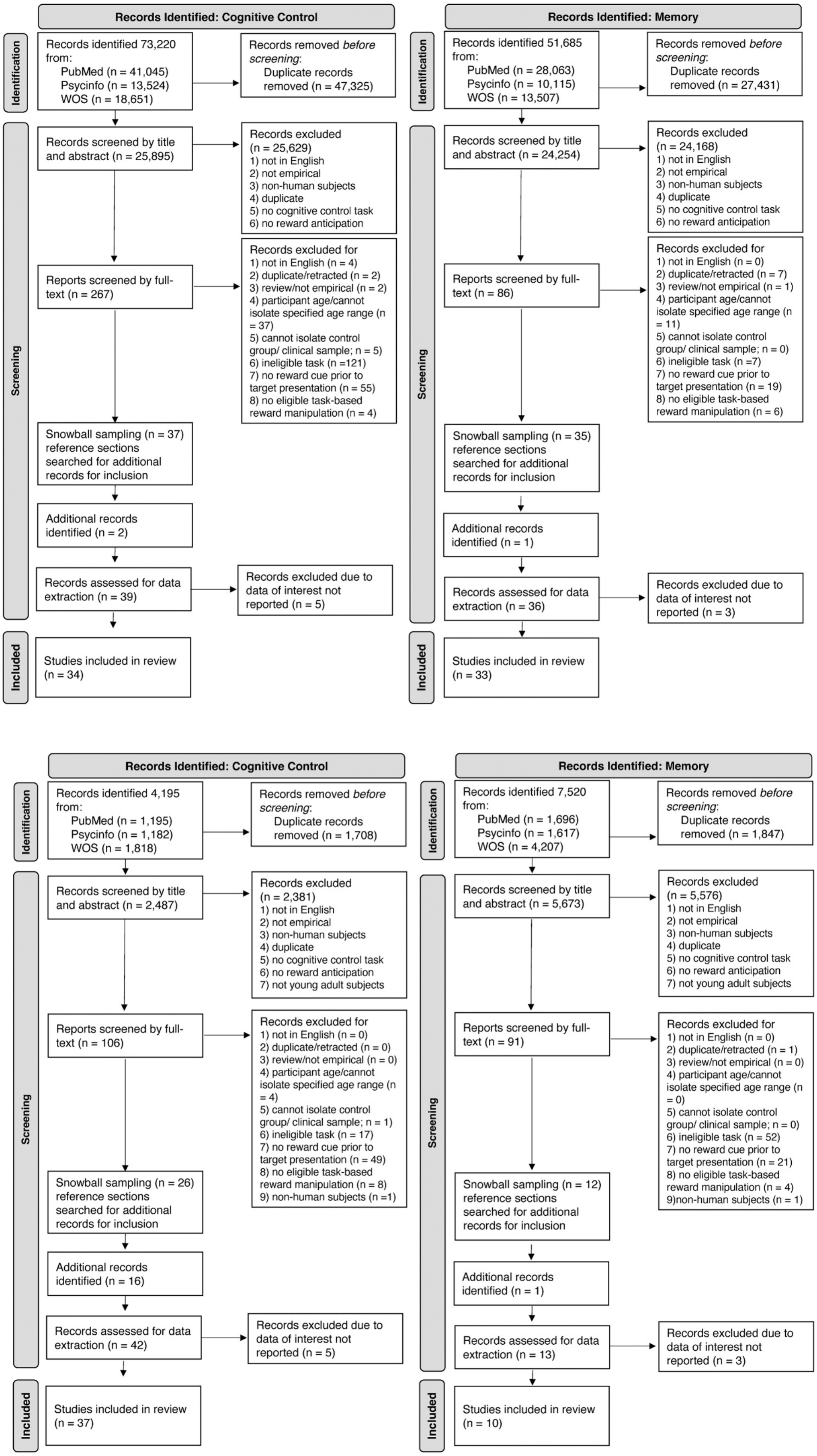

Fig. 1. *Prisma Diagram of the Search Strategy and Selection Process. Note*. The two top diagrams are from the original February 2020 search and the bottom diagrams are from the October 2025 search.

studies), systematic narrative reviews, and opinion pieces were excluded.

2) Studies had to include healthy young adult participants ages 18–35 years, where healthy was specified as: a) no recent head or brain injuries; b) no current diagnosis of neurological or psychological disorder; c) no history of stroke, epilepsy, or learning disability; d) no current use of psychotropic medications. Control groups of healthy individuals from clinical studies or young adult groups from developmental studies were considered eligible for meta-analysis inclusion if data from eligible individuals was available separate from ineligible individuals.
3) Studies had to include reported outcomes for memory performance (in terms of memory accuracy, as measured at retrieval) or cognitive control performance (in terms of error rates, reaction times, or both).
4) Studies had to employ random assignment to reward conditions during the task and include at least two within-subject reward anticipation conditions (i.e., low or no-reward versus high reward).
5) Studies were required to be published in English, with no geographic limitations on data collection or samples.

Studies were screened for inclusion in separate steps. After the removal of duplicates, we inspected studies first by titles and abstracts, and second via the full text. Studies identified as ambiguous regarding eligibility in the first step (i.e., in their use of reward manipulations, cognitive performance outcomes, or populations sampled) were included for full-text screening to reduce potential coding errors and bias. To further reduce potential coding errors and bias, each article was screened for inclusion by two independent raters. There was 95.4% inter-rater agreement on study inclusion and discrepancies were handled by discussion. After identifying citations for inclusion, the reference sections of included papers were also manually searched for additional papers that were missed in our initial search. This “snowball sampling” approach yielded 1 additional memory publication and 2 additional cognitive control publications included in the meta-analysis. These additional studies were also coded by two independent raters. The final meta-analysis included 43 publications (58 studies) for memory accuracy, 65 publications (82 studies) for cognitive control. Within cognitive control, 53 publications (70 studies) reported reward effects on accuracy, and 56 publications (74 studies) reported reward effects on RT. Of these cognitive control studies, 10 were included for cognitive control RT but not accuracy, and 6 were included for cognitive control accuracy but not RT. Finally, in 3 cognitive control studies, we were able to obtain effect sizes for inverse efficiency scores, a composite measure combining accuracy and RT, but not for accuracy and RT alone; for these 3 studies, we used the same effect size for both accuracy and RT. Separate reference lists for the studies included in the cognitive control and in the memory meta-analyses are available in the Supplement.

6.4. Data extraction

Data coding and extraction were conducted by the research team members and included publication title, year, author(s), journal, publication type, country of origin, population of interest, sample size, percentage of women, race/ethnicity distribution, mean age, age range, employment information, type and amount of reward, performance-contingent status of reward, durations of cue, target, and cue-target interval, and summary statistics needed for calculation of effect sizes of interest. Additionally, for memory studies only, we coded for intentional versus incidental memory, type of retrieval test, retention interval between study and test, punishment of errors at encoding, false alarm penalties at retrieval, and types of target stimuli encoded. For cognitive control studies only, we coded the type of cognitive control task, punishment of errors, and presence of RT deadline.

The effects of interest in the present study were accuracy differences in high versus low/no-reward conditions for memory studies, and accuracy and RT differences in high versus low/no-reward conditions for cognitive control studies. Where effect sizes were reported, these values were extracted; otherwise, outcome means and standard deviations for memory and cognitive control as a function of high versus low/no-reward conditions, along with *t*-test or *F*-test statistics and sample sizes, were extracted and used to estimate effect sizes (following Lakens, 2013, described in more detail below).

Where studies met eligibility criteria for inclusion but statistical information to calculate effect size was not reported, the corresponding author was contacted with a request for this information. Across domains, 56 authors were contacted, and of these, 17 provided missing data. An additional 15 authors did not respond to email, but 14 of their studies were included due to determining effect size upon second glance. Effect sizes were directionally signed such that positive effect sizes indicated better performance (in terms of higher accuracy and faster RTs) in the high (versus low/no) reward condition and negative effect sizes indicated better performance in the low/no versus high reward condition.

As outlined in the pre-registration, we coded for multiple potential moderators of the effect of reward anticipation (high versus low/no reward) on memory encoding and cognitive control outcomes. Departing from the pre-registration, we focused on trial-by-trial manipulations and did not examine block versus event-related reward manipulation as a moderator, as we discovered that fMRI studies using the MID and related task paradigms to characterize mesolimbic dopamine activity primarily used event-related designs where reward was manipulated trial by trial. Across both memory and cognitive control outcomes, we first tested reward-related moderators including 1) reward type (primary versus secondary), 2) type of secondary reward (money or points), 3) the difference in amounts between the high and low/no reward condition, 4) the presence versus absence of a false alarm penalty (memory studies only), 5) the compensation format (receiving compensation for participation time, bonus, both, or course credit compensation plus monetary bonus), 5) incentive contingency (reward performance-contingent versus incidental), and 6) the presence of penalty incentives (in addition to reward incentives or not) including a punishment at the time of memory encoding, or a punishment for errors in the case of cognitive control tasks. Next, we coded moderators related to task conditions. For memory outcomes only, we also examined the following moderators 1) intentional versus incidental memory encoding (i.e., whether the subsequent retrieval test was anticipated or surprise), 2) target stimulus type (words, pictures, faces, or multiple types of stimuli), and 3) retrieval test type (recall, recognition, or paired associates). For cognitive control outcomes only, we also examined the following moderators 1) task type (coded as Auditory, AX-CPT, Discrimination, Flanker, Simon, Stroop, Switch, Working Memory), and 2) the presence of RT deadline (receiving reward based on accuracy versus accuracy and speed). Third, for both memory and cognitive control domains, we coded moderators related to task timing including 1) reward cue length (in milliseconds), 2) target stimulus length (in milliseconds), and 3) cue-target interval length (in milliseconds). For memory studies with recognition paradigms, we also coded for the length of the retention interval (categorically grouped into studies with immediate memory test, same day but different session test, and next day test). Finally, we tested for general moderators of country of origin, year of publication, and percentage of female participants across both memory and cognitive control studies. Results for these three last moderators are presented in the Supplemental Material.

6.5. Study quality

Two independent raters evaluated the quality of each study using a modified version of the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (NIH, 2020). This tool allows for the evaluation of selection, information, or measurement bias, as well as confounding variables, where higher quality scores indicate lower risk of bias. Ten items of the original fourteen in the Quality Assessment Tool were used in the current study. Given the present focus on studies employing experimental repeated-measures designs, the remaining four criteria were not applicable: Criteria 6 (exposures of interest were measured prior to the outcome) was not used because it necessarily applied to all included studies. Criteria 12 (outcome assessors blinded to exposure status of participants), Criteria 13 (percentage of attrition from baseline to follow-up), and Criteria 14 (potential confounding variables controlled in analyses) did not apply to any studies included in the current meta-analysis. Each study was rated on the eleven criteria (as 0 = *no* or 1 = *yes*) and the ratings were summed to generate a total quality score.

6.6. *Analysis plan*

For each study included in the analyses, when possible, we used the effect size reported in the paper and, if necessary, converted the effect size to Cohen's d using code from https://haiyangjin.github.io/2020/05/eta2d/. For studies that did not directly report the effect size but reported the necessary statistical information to calculate it, we used a spreadsheet-based tool (Lakens, 2013) to estimate Cohen's d and the standard error (SE), assuming a correlation between within-subjects measures of.70. Many cognitive control studies included both accuracy and RT outcomes (see *Screening Process* section above), but analyses on these two outcomes were carried out separately. Within the memory studies, we did not have multiple effects within the same study, so independence was assumed.

All analyses were implemented with Comprehensive Meta-Analysis (CMA) software (Version 4.0, Biostat Inc; Borenstein et al., 2022). The random-effects model was employed (Borenstein et al., 2010), using sub-group analyses for categorical moderator variables, and meta-regressions for continuous moderator variables.

We first calculated the overall effect size of reward on memory, cognitive control accuracy, and cognitive control RT. Next, the moderators described above were examined individually for each outcome type. Finally, to compare reward anticipation effects on cognitive performance across memory and control domains, we conducted meta-analyses examining reward effect size across both memory and cognitive control studies, with outcome type as a moderator. To be included in a categorical moderator analysis, we required at least 3 studies per category.

7. Results

7.1. *Description of the participants*

For each memory study, we coded country of origin, sample size ($M = 35.72$, $SD = 19.92$), age ($M = 21.86$, $SD = 2.36$, range min = 18, range max = 35), percent female participants ($M = 57.34\%$, $SD = 17.30$). For cognitive control studies, we coded country of origin, sample size ($M = 35.46$, $SD = 20.95$), age ($M = 22.20$, $SD = 1.65$ range min = 18, range max = 43), percent female participants ($M = 63\%$, $SD = .13$). Only a small number of studies reported race and ethnicity information, which is summarized in Supplementary Table 1. No studies reported employment information apart from a subset indicating that participants were recruited from a student population; such populations are indicated as part of the demographic information included in Tables 1 and 2.

7.2. *Study quality assessment*

Using the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies NIH, 2020 (NIH, 2020), study quality was assessed by two independent coders. Given the types of studies included in this meta-analysis, only 10 out of 14 criteria were appropriate to apply. In line with previous work (Gower et al., 2022; Schuman et al., 2019), but adjusted for the current study with only 10 criteria, studies in the current review were placed in three categories, based on their total quality scores: 'good' (8−10), 'fair' (4−7), or 'poor' (0−3). Quality assessment scores indicated that the quality of included studies was good (cognitive control quality scores: $M = 9.11$, $SD = 0.42$, inter-relater reliability, $k = .75$, $p < .001$; memory quality scores: $M = 9.01$, $SD = 0.55$, inter-relater reliability, $k = .79$, $p < .001$). The results of the study quality assessment revealed that all studies fell into the 'good' category by both raters, so the current meta-analysis can be interpreted with some confidence.

8. Memory accuracy outcomes

8.1. *Relation between reward anticipation and memory accuracy*

This analysis is based on 43 publications (58 studies), with Cohen's d used as the measure of effect size. The overall mean effect size is d = 0.537 (see Fig. 2, forest plot diamond), a medium effect, with 95% confidence interval (95% CI) = [0.43 – 0.65]. This mean effect size is significantly greater than zero, $Z = 9.79$, $p < .001$. There was significant between-study heterogeneity in the relation between reward and memory, $Q(57) = 479.54$, $p < .001$; a substantial proportion of variance in these 58 studies reflects variance in true effects $I^2 = 88\%$, as opposed to sampling error (12%). The prediction interval of how much the true effect size varies, in 95% of comparable studies, ranges from −0.24–1.31 (see forest plot bottom line), $Tau^2 = 0.15$.

8.2. *Sensitivity analyses*

To ensure that the effect size was not driven by one particular study and that the results were robust, we first examined the relative weight that each study was assigned in the random effects model. Study weights ranged from 1.01 to 1.96, indicating that no study was overweighted in the analysis and each contributed fairly. Second, to ensure the results were not skewed by one study's particular effect size, we ran an iterative "one study removed" version of the model. Across these iterations, there were no significant changes to the overall mean effect size and all studies continued to have a p-value of < .001. This verified that the pattern of results was not driven by a single study's effect size and ensured the results were robust.

8.3. *Publication bias*

We used a funnel plot to visualize the effect sizes of the 58 included memory studies against standard errors as an indication of precision (see Fig. 3). Visual inspection of this funnel plot revealed asymmetry, signaling the possibility of publication bias. This asymmetry was particularly apparent for effect sizes from studies with smaller samples – the funnel plot indicates an unequal number of studies to the right of the mean compared to the left, and the effect size tended to be larger for studies with smaller sample sizes. The average sample size was N = 35.72 (median N = 29, range: 12–89 participants). This asymmetry was confirmed using a trim and fill procedure. As noted, under the random effects model, the point estimate for the combined studies is 0.537 (95% CI = [0.43 – 0.65]; indicated by the white diamond in Fig. 3. The white circles represent the effect size for each individual study included in the meta-analysis. The trim and fill procedure imputed 19 possible missing effect sizes to the left of the mean (see Fig. 1 in Supplemental Materials). With the addition of the imputed studies, the point estimate was 0.278 (95% CI = [0.15 – 0.40]. Egger's regression test of bias was significant $b = 4.99$, $SE = 1.04$, $t(56) = 4.78$, $p < .001$.

9. Moderator effects on the relation between reward anticipation and memory accuracy

There was significant heterogeneity in the effect size between studies, indicating that there might be important moderators influencing study effect sizes. We first describe the analyses testing for moderators

Table 1
Demographic Characteristics of Memory Studies Included in the Analysis.

First Author and Publication Year	Country	Source	Experiment	Sample Size	Sample Type	Gender % F	Age M (SD)	Age Range
Adcock et al., 2006	USA	P		12	U	25%	NR	18–35
Anderson, 2016	USA	D	3.1	60	U	43%	21.00 (2.18)	18–31
Anquillare and Selmeczy, 2023	USA	P		89	U	79.77%	20.62 (.38)	18–33
Bennion et al., 2016	USA	P		74	N	NR	20.3 (NR)	18–27
Bialleck et al., 2011	Germany	P		20	U	53%	23.87 (1.92)	NR
Bowen and Kensinger, 2017	USA	P	1	23	S	NR	20.04 (1.74)	18–26
			2	23	S	NR	19.04 (1.15)	18–21
Bowen, 2020	USA	P		16	SC	56.25%	25.44 (3.79)	20–33
Bowen et al., 2023	USA	P		62	C	40.32%	28.53 (3.63)	18–35
Bunzeck et al., 2010	UK	P	2	16	N	56.25%	23.63 (4.22)	19–33
Callan and Schweighofer, 2008	Japan	P		15	U	100%	26.00 (3.90)	23–34
Cohen, 2015	USA	D	2	20	N	55%	21.65 (3.66)	18–30
			4.2	43	S	NR	NR	NR*
			4.3	46	S	NR	NR	NR*
			4.4	64	S	NR	NR	NR*
			4.5	48	S	NR	NR	NR*
			4.6	64	S	NR	NR	NR*
da Silva Castanheira et al., 2022	Canada	P		44	U	81.81%	20.2 (1.31)	18–25
Ding et al., 2022	China	P		27	U	51.85%	20.9 (NR)	NR
Elliott and Brewer, 2019	USA	P	1	40	S	NR	18.81 (NR)	18–22
			2	40	S	NR	19.49 (NR)	18–29
			3	40	S	NR	19.82 (NR)	18–28
Elliott et al., 2020	USA	P		33	S	NR	18.82 (NR)	18–23
Eysenck and Eysenck, 1980	UK	P		15	S	NR	NR	18–30
Eysenck and Eysenck, 1982	UK	P	1	20	S	NR	NR	18–30
		P	2	13	S	NR	NR	18–30
Feld et al., 2014	Germany	P		16	N	0%	24.50 (NR)	19–30
First Author and Publication Year	Country	Source	Experiment	Sample Size	Sample Type	Gender % F	Age M (SD)	Age Range
Gholston et al., 2023	USA	P	1	27	S	74.07%	20.7 (.63)	NR
	USA	P	2 A	31	S	58.06%	19.18 (.47)	NR
	USA	P	2B	24	S	54.17%	19.12 (1.12)	NR
	USA	P	3	30	S	76.67%	19.44 (.30)	NR
Gruber and Otten, 2010	UK	P		24	N	65.22%	23.00 (NR)	19–33
Gruber et al., 2013	UK	P		24	N	70%	24.00 (NR)	19–33
Halsband et al., 2012	Germany	P	1	19	U	47.36%	24.00 (NR)	18–31
Han et al., 2023	USA	P		22	S	NR	20.6 (3.27)	NR
Hennessee, 2018	USA	D	1	33	S	66.67%	20.68 (2.30)	18–28
Hennessee et al., 2019	USA	P	2	80	S	73.75%	20.20 (1.64)	18–27
Loh et al., 2016	UK	P		27	N	66.67%	22.85 (3.08)	19–31
Mason et al., 2017	UK	P		40	N	70%	21.30 (3.23)	18–32
Mather and Schoeke, 2011	USA	P		42	U/C	71.4%	21.60 (3.40)	18–33
Murty and Adcock, 2017	USA	P		20	U/C	60%	23.00 (NR)	18–34
Oyarzún et al., 2016	Spain	P	1a	20	S	80%	23.00 (3.10)	NR
			1b	36	S	100%	20.21 (3.07)	NR
Reggente, 2018	USA	P		19	U	52.63%	21.80 (3.70)	NR
Richter et al., 2017	Germany	P		62	U	NR	24.58 (2.75)	NR
Spaniol et al., 2014	Canada	P	1	36	S	50%	23.06 (3.33)	18–33
			2	32	S	75%	21.25 (4.41)	18–33
Stanek et al., 2019	USA	P	1	20	U	60%	27.45 (3.82)	NR
Studte et al., 2017	Germany	P		21	U	66.67%	21.70 (2.60)	NR
Swirsky et al., 2020	Canada	P		50	C	66%	NR	18–35
Tucker et al., 2011	USA	P		152^{+}	S	59%	20.00 (1.70)	NR
Villaseñor et al., 2021	USA	P		75	S	49.33%	19.70 (1.94)	18–35
Wittmann et al., 2008	UK	P		25	N	48%	24.00 (2.00)	NR
Wittmann et al., 2013	UK	P		24	N	66.67%	25.30 (3.90)	NR
Wolosin et al., 2012	USA	P		37	N	43%	20.00 (NR)	18–29
Wolosin et al., 2013	USA	P		24	N	41.67%	22.00 (NR)	18–33
Yan et al., 2022	China	P		30	U	50%	21.2 (NR)	NR

Note. P = Peer-reviewed publication; D = Dissertation; $^{+}$ = total N = 152 (Reported Exp 1a n = 75, Exp 1b n = 77, but note a discrepancy with the degrees of freedom reported in the analyses used to calculate the effect sizes used in the meta-analysis, Exp 1a n = 74, Exp 1b n = 76); NR = Not Reported; * = age not reported, authors indicated sample was from an undergraduate population; %F = percent of the sample that reported female. Standard deviations in parentheses; U = university community (but not necessarily specified as students); N = not specified; S = students; C = community.

related to differences in reward motivation manipulations, followed by the analyses testing for moderators related to differences in encoding and retrieval tasks, and lastly by the analyses testing for moderators related to trial event timing. See Table 4 for details on all the moderators used in the cognitive control analyses.

10. Reward-related moderators

10.1. Reward type

The comparison of primary (e.g., juice) and secondary (e.g., money) reward motivation as a moderator could not be conducted for the memory studies because no included studies employed primary rewards. We did conduct a moderator analysis comparing secondary reward types

Table 2
Demographic Characteristics of Cognitive Control Studies Included in the Analysis.

First Author and Publication Year	Country	Source	Experiment	Sample Size	Sample Type	Gender % F	Age M (SD)	Age Range
Aarts et al., 2010	Netherlands	P		20	S	50%	21.60 (NR)	18–27
Arnau et al., 2024	Germany	P		26	N	88%	21.65 (2.15)	NR
Asci et al., 2019	Belgium	P		24	N	67%	23.42 (NR)	18–31
Bahlmann et al., 2015	USA	P		20	N	45%	22.00 (3.20)	NR
Beck et al., 2010	USA	P		31	U	55%	NR	19–34
Bräutigam et al., 2024	Germany	P	1	37	U	68%	21.82 (2.70)	18–30
			2	59	U	76%	21.88 (3.31)	18–30
Bundt et al., 2021	Belgium	P		38	N	66%	22.5 (2.1)	NR
Capa et al., 2011	Belgium	P		28	S	71%	NR	21–30
Capa and Bouquet, 2018	France	P		60	S	60%	21.18 (3.13)	NR
Chaillou et al., 2017	France	P		23	N	61%	21.00 (2.00)	NR
Chiew and Braver, 2013	USA	P		47	U	74%	20.60 (NR)	NR
Chiew and Braver, 2014	USA	P		112	U	54%	21.00 (2.86)	NR
Chiew and Braver, 2016	USA	P	1	24	U	54%	19.50 (1.71)	NR
			2	24	U	38%	20.30 (1.71)	NR
Crawford et al., 2020	USA	P	1	30 (age subset)	U	NR	20.27 (1.64)	18–26
			2	59 (age subset)	U	76%	25.86 (5.29)	18–35
Cubillo et al., 2019	USA	P		30	N	50%	24.00 (2.00)	NR
Diao et al., 2014	China	P		35	S	57%	21.76 (1.76)	19–24
Diao et al., 2016	China	P		18	S	56%	21.60 (NR)	18–23
Fröber and Dreisbach, 2014	Germany	P		80	S	82%	23.60 (4.04)	18–43
Fröber and Dreisbach, 2016	Germany	P	1	83	S	74%	22.48 (3.60)	18–41
			2	40	S	90%	21.26 (3.50)	18–36
Fröber et al., 2020	Germany	P		42	U	76%	23.26 (3.35)	18–31
Fröber et al., 2021	Germany	P	1	28	S	86%	22.90 (2.83)	19–30
Fröber and Dreisbach, 2021	Germany	P	2	30	S	87%	21.57 (2.51)	19–31
Frömer et al., 2021	USA	P	1	21	N	81%	21.14 (5.15)	NR
			2	44	N	86%	20.18 (2.30)	NR
Gilbert and Fiez, 2004	USA	P		22	S	NR	NR	18–23
Giuffrida et al., 2023	Italy	P		18	N	78%	26.5 (NR)	NR
Grogan et al., 2022	UK	P	1	30	N	57%	24.30 (5.07)	NR
	UK	P	2	34	N	74%	24.53 (5.77)	NR
	UK	P	3	30	N	50%	23.13 (4.73)	NR
	UK	P	4	30	N	33%	23.07 (4.72)	NR
Hippmann et al., 2019	Germany	P	1	23	N	52%	23.90 (NR)	20–30
			2	20	N	60%	23.3 (NR)	20–28
Jia et al., 2021	China	P		21	S	62%	22.20 (NR)	18–28
Jiang and Xu, 2014	China	P		20	S	60%	20.25 (1.21)	NR
Kang et al., 2019	China	P		19	S	42%	NR	20–25
Kleinsorge and Rinkenauer, 2012	Germany	P	1	16	N	56%	22.10 (NR)	18–30
Kostandyan et al., 2019	Belgium	P	2	22	N	71%	23.5 (NR)	NR
Kostandyan et al., 2020	Belgium	P		25	N	48%	23 (2.94)	NR
Krebs et al., 2011	USA	P		19	N	53%	22.60 (3.50)	NR
Krebs et al., 2012	USA	P		14	N	71%	21.70 (3.20)	NR
Krebs et al., 2013	USA	P		14	N	71%	22.60 (3.50)	NR
Le et al., 2020	USA	P		38 (age subset)	N	53%	25.40 (3.90)	18–34
Liegel et al., 2024	Germany	P		32	N	66%	24.90 (4.30)	NR
Marini et al., 2015	USA	P	1	16	N	50%	22.10 (NR)	18–35
			2	17	N	47%	22.7 (NR)	18–35
Padmala and Pessoa, 2011	USA	P		50	N	52%	22.0 (5.0)	NR
Padmanabhan et al., 2011	USA	P		10	N	60%	20.60 (2.20)	18–25
Phaneuf-Hadd et al., 2025	USA	P		41 (age subset)	N	NR	19.52 (0.83)	18–21
Fahey et al., 2025	USA	P		109	C	47%	23.35 (NR)	NR
Reyes et al., 2020	Chile	P		76	O	43%	22.6 (1.5)	NR
Savine et al., 2010	USA	P	1	26	U	46%	20.13 (NR)	NR
			2	30	U	57%	20.77 (NR)	NR
Schevernels et al., 2014	Belgium	P		22	N	86%	20 (NR)	18–23
Seifert et al., 2006	Germany	P		53	S	53%	23.40 (2.36)	20–31
Sullivan et al., 2023	Canada	P		26	N	54%	23.27 (4.57)	18–33
Taylor et al., 2004	USA	P		12	C	50%	24.20 (4.20)	NR
Thurm et al., 2018	Germany	P		21	C	48%	22.70 (1.90)	20–27
van den Berg et al., 2014	USA	P		29	N	48%	22.85 (4.00)	NR
Veling and Aarts, 2010	Netherlands	P		36	S	67%	NR	NR*
Wen et al., 2024	China	P		74	N	73%	21.42 (2.36)	NR
Williams et al., 2018	Canada	P		24	C	63%	20.50 (2.47)	18–28
Wolff et al., 2016	Germany	P	1	21	U	71%	26.10 (6.50)	NR
			2	21	U	76%	24.00 (5.10)	NR
Yamaguchi and Nishimura, 2019	UK	P	1	48	U	67%	20.44 (3.69)	NR
			2	48	U	73%	20.44 (3.27)	NR
			3	48	U	60%	20.98 (4.53)	NR
Yee et al., 2016	USA	P	1	39	U	69%	20.3 (2.5)	18–32
			2	38	U	47%	19.92 (2.17)	18–25
Yee et al., 2019	USA	P		53 (age subset)	U	NR	20.06 (2.51)	18–29

(*continued on next page*)

Table 2 (*continued*)

First Author and Publication Year	Country	Source	Experiment	Sample Size	Sample Type	Gender % F	Age M (SD)	Age Range
Yee et al., 2021	USA	P		27 (age subset)	N	59%	24.44 (3.18)	19–30
Zedelius et al., 2011	Netherlands	P	1	26	N	73%	21.70 (1.70)	NR
Zedelius et al., 2012	Netherlands	P	1	41	S	68%	NR	NR*
			2	33	S	73%	NR	NR*
Zedelius et al., 2012	Netherlands	P	1	91	S	70%	20.49 (2.39)	NR

Note. P = Peer-reviewed publication; D = Dissertation; NR = Not Reported/Available; * = age not reported, authors indicated sample was from an undergraduate population. %F = percent of the sample that reported female. Standard deviations in parentheses. U = university community (but not necessarily specified as students); N = not specified; S = students; C = community, O = other

of money versus points. This moderator was significant, *Q*(1) = 6.29, *p* = .012. The effect sizes for studies that used points as incentives (k = 19; *M* = 0.72, *SE* = 0.09, 95% CI = [0.54 – 0.90]) were larger than the effect sizes for studies that used monetary incentives (k = 40; *M* = 0.44, *SE* = 0.06, 95% CI = [0.31 – 0.56]), to induce reward motivation.

10.2. Reward amount

We created a reward amount moderator by calculating the difference between the high and low reward values of monetary incentives for each study using them, and a separate variable for the difference between the high and low reward values of points incentives for each study using them. In cases where multiple high reward values and multiple low reward values were used, the middle of the range from the high and low values was chosen to calculate the difference. Monetary and point incentive differences were analyzed separately because they were not on the same scale – for example, a reward amount difference of 1 point is not equivalent to a reward amount difference of $1. First, examining monetary reward (k = 27), the reward amount difference was not a significant moderator of the effect size, *Q*(1) = 0.40, *p* = 0.52. Including reward amount as a moderator of the effect did not significantly explain any more of the variance in effect size between studies ($\text{Tau}^2 = 0.10$, $I^2 = 82.36\%$, R^2 analog = −0.01). Turning to studies that used points (k = 19), the point difference between the high and low values was also not a significant moderator of the effect size, *Q*(1) = 1.36, *p* = .24. Including the point amount difference as a moderator of the effect did not significantly explain more of the variance in effect size between studies, $\text{Tau}^2 = 0.23$, $I^2 = 92.47\%$, R^2 analog = −0.07.

10.3. False alarm penalty

Inclusion of a punishment at the time of retrieval for false alarms in tasks that used recognition memory performance was a significant moderator in the effect size for reward influences on memory, *Q*(1) = 11.16, *p* = .001. The effect sizes for studies that included a false alarm penalty (k = 20) were significantly larger (*M* = 0.57, *SE* = 0.07, 95% CI = [0.43 – 0.71]) than studies that did not include a false alarm penalty (k = 24; *M* = 0.26, *SE* = 0.06, 95% CI = [0.14 – 0.38]).

10.4. Compensation

compensation was coded as being implemented either with money or with course credit (in the case of an undergraduate participant pool). Both compensation methods were associated with a significant reward effect on memory (money: *M* = 0.55, *SE* = 0.07, 95% CI = [0.41 –.70]); course credit (*M* = 0.50, *SE* = 0.14, 95% CI = [0.22 – 0.79]), but compensation type was not a significant moderator, *Q*(1) = 0.10, *p* = .75. Notably, more studies compensated participants with money (k = 38) compared to credit, (k = 9), and many studies were not included in this moderator analysis because study descriptions did not specify what type of compensation was provided.

10.5. Reward contingency

In most studies, reward incentives were contingent on memory performance (k = 49), but in some studies, the incentive was incidental to memory performance (i.e., unrelated to performance or tied to performance in an unrelated task during encoding; k = 11). Reward contingency was a significant moderator, *Q*(1) = 4.60, *p* = .02, as those with reward-contingent memory performance had significantly higher effect sizes (*M* = 0.58, *SE* = 0.06, 95% CI = [0.47 – 0.69]) than those where reward incentive contingent on performance on a different task at encoding, with memory incidental to the reward (*M* = 0.29, *SE* = 0.05, 95% CI = [0.05 – 0.53]).

10.6. Punishment at encoding

Very few studies employed a punishment for incorrect responses during the encoding task (k = 5; *M* = 0.27, *SE* = 0.19, 95% CI = [−0.09 – 0.64]) compared to those that did not (k = 55; *M* = 0.55, *SE* = 0.06, 95% CI = [−0.44 – 0.66]). The presence of a punishment incentive at encoding was not a significant moderator of the effect size, *Q*(1) = 2.07, *p* = .15.

11. Memory encoding and retrieval task-related moderators

11.1. Intentional versus incidental encoding

Many of the studies using intentional encoding (i.e., where participants were aware that memory retrieval would be tested) are also categorized as reward-contingent. In line with the results above, that reward contingency was a significant moderator, intentional versus incidental encoding was a significant moderator of effect size, *Q*(1) = 4.58, *p* = .03. Studies that included an intentional encoding paradigm had higher effect sizes (k = 47; *M* = 0.59, *SE* = 0.06, 95% CI = [0.47 – 0.71]) compared to those that used an incidental encoding task (k = 11; *M* = 0.29, *SE* = 0.13, 95% CI = [0.04 – 0.53]). In other words, reward had a larger effect on memory performance when participants knew at encoding that their memory for the stimuli would be tested on a subsequent test.

11.2. Type of memoranda

A variety of stimuli were used as memoranda, including images (k = 30; *M* = 0.33, *SE* = 0.07, 95% CI = [0.20 – 0.47]), words (k = 25; *M* = 0.77, *SE* = 0.08, 95% CI = [0.61 – 0.92]), and a combination of different stimuli (k = 5; *M* = 0.52, *SE* = 0.17, 95% CI = [0.19 – 0.86]). Type of memoranda was a significant moderator of the effect size, *Q*(2) = 16.82, $p < .001$. Effect sizes were larger for words compared to images, *Q*(1) = 16.57, $p < .001$, and the 95% CIs for these categories do not overlap. Effect sizes were not larger for words compared to multiple stimulus types, *Q*(1) = 1.19, *p* = .28. Effect sizes also did not significantly differ for studies that used images compared to those that used multiple stimulus types, *Q*(1) = 1.70, *p* = .19, but it is important to note that there were only five studies including multiple types of stimuli and the CI range is quite large.

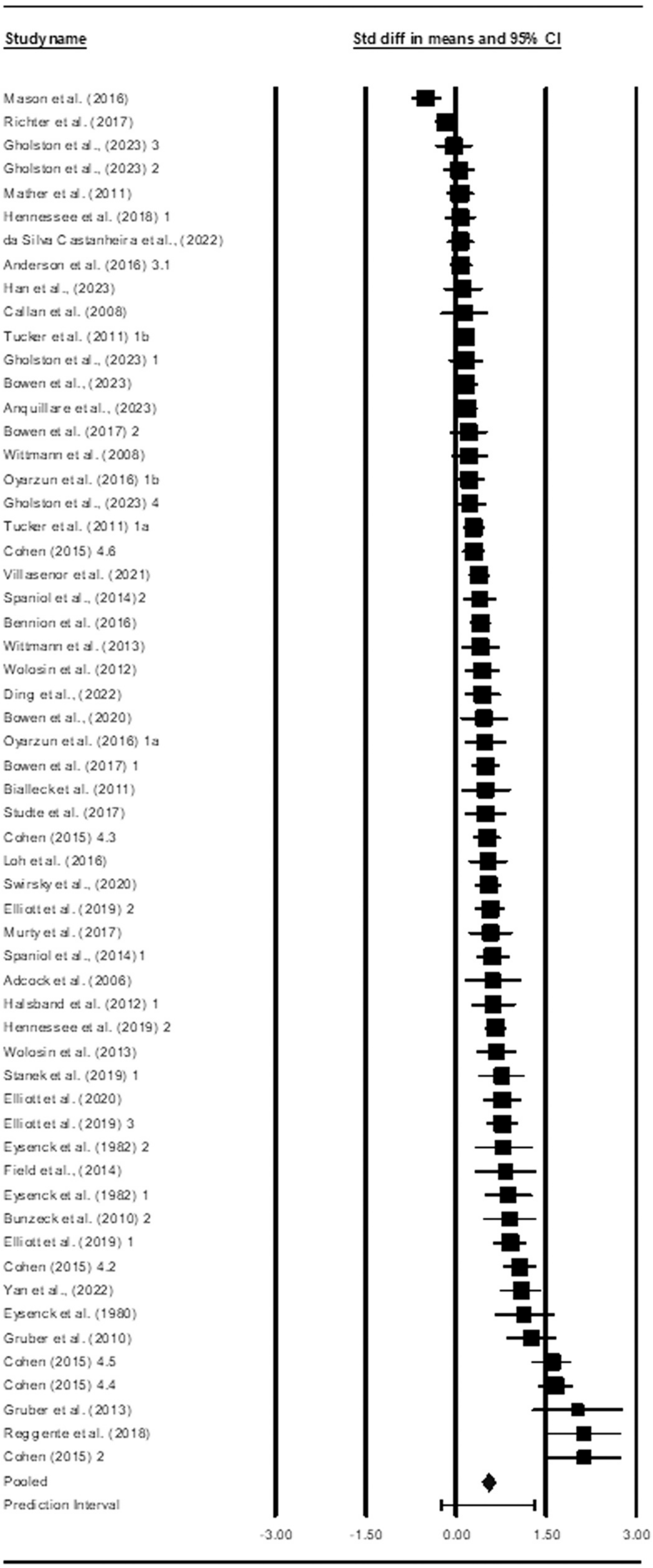

Fig. 2. *Forest Plot of Standard Difference in Means and 95% Confidence Intervals for Each Included Memory Study. Note.* The size of the boxes for each study is proportional to the weight of the study in relation to the pooled estimate (diamond). The prediction interval noted in the bottom line of the forest plot indicates how much the true effect size varies, in 95% of comparable studies, ranging from −0.24–1.31.

11.3. Type of memory retrieval task

Memory was tested using different task formats including paired-associates (k = 6), free recall (k = 10), and recognition (k = 44). The type of memory task was a significant moderator of the size of the effect of reward on memory, $Q(2) = 31.77$, $p < .001$. The effect size for recall ($M = 1.15$, $SE = 0.05$, 95% CI = [0.30 – 1.38]) was larger than recognition ($M = 0.41$, $SE = 0.05$, 95% CI = [0.30 – 0.51], $Q(1) = 29.45$, $p < .001$), but recognition and paired-associates ($M = 0.43$, $SE = 0.14$, 95% CI = [0.14 – 0.70) did not significantly differ in effect size, $Q(1) = 0.02$, $p = .90$.

When examining task-related moderators, we noted that point incentives, word memoranda, and recall tasks led to larger effects of reward on memory than the comparison conditions. Given this, it was important to verify that these effects did not reflect repeated analysis of the same set of studies. Specifically, we ensured that the studies using point incentives were not exclusively the same studies using word stimuli and recall tasks. While all recall tasks involved word stimuli, six used point incentives and four monetary incentives. Further, the recognition studies included a mix of image and word stimuli, as well as points and monetary incentives. See Table 1 for this information.

12. Trial event timing-related moderators

12.1. Reward cue length

The duration of the reward cue was not a significant moderator of effect size, $Q(1) = 1.21$, $p = .27$. When reward cue length (k = 52) was included as a covariate, it did not explain any more of the variance in effect size between studies, $\text{Tau}^2 = 0.16$, $\text{I}^2 = 88.65\%$, R^2 analog = −0.02, compared to leaving it out of the model.

12.2. Target length

The duration of the target stimulus was not a significant moderator of the effect size, $Q(1) = 0.29$, $p = .59$. When target length (k = 51) was included as a covariate in the regression model, it did not explain any more of the variance in effect size between studies, $\text{Tau}^2 = 0.16$, $\text{I}^2 = 88.81\%$, R^2 analog = −0.01, compared to leaving it out of the model.

12.3. Cue-target interval length

The amount of time between the offset of the reward cue and the onset of the target stimuli at encoding was not a significant moderator of the effect size, $Q(1) = 0.40$, $p = .53$. When cue-target interval length (k = 51) was included as a covariate in the regression model, it did not explain any more of the variance in effect size between studies, $\text{Tau}^2 = 0.16$, $\text{I}^2 = 88.81\%$, R^2 analog = −0.02, compared to leaving it out of the model.

12.4. Retention interval

The retention interval between encoding and retrieval was categorized into 3 groups to test for the effects of time and consolidation: immediate test (k = 31; $M = 0.71$, $SE = 0.08$, 95% CI = [0.56 – 0.86]), later same day as encoding (k = 5; $M = 0.38$, $SE = 0.18$, 95% CI = [0.02 – 0.73]), and the next day (k = 20; $M = 0.34$, $SE = 0.09$, 95% CI = [0.16 – 0.53]). Retention interval was a significant moderator of the effect size, $Q(2) = 10.43$, $p = .005$. The effect of reward on memory in studies that used an immediate retention interval did not significantly differ from that in studies using a same-day different session, as confirmed with overlapping CIs, $Q(1) = 2.62$, $p = .11$. There was a larger effect of reward on memory in studies that used immediate retrieval compared to next day retrieval, $Q(1) = 8.65$, $p = .003$. Studies with a later same-day, compared to next-day, retention intervals did not significantly differ and had overlapping CIs, $Q(1) = 0.11$, $p = .74$.

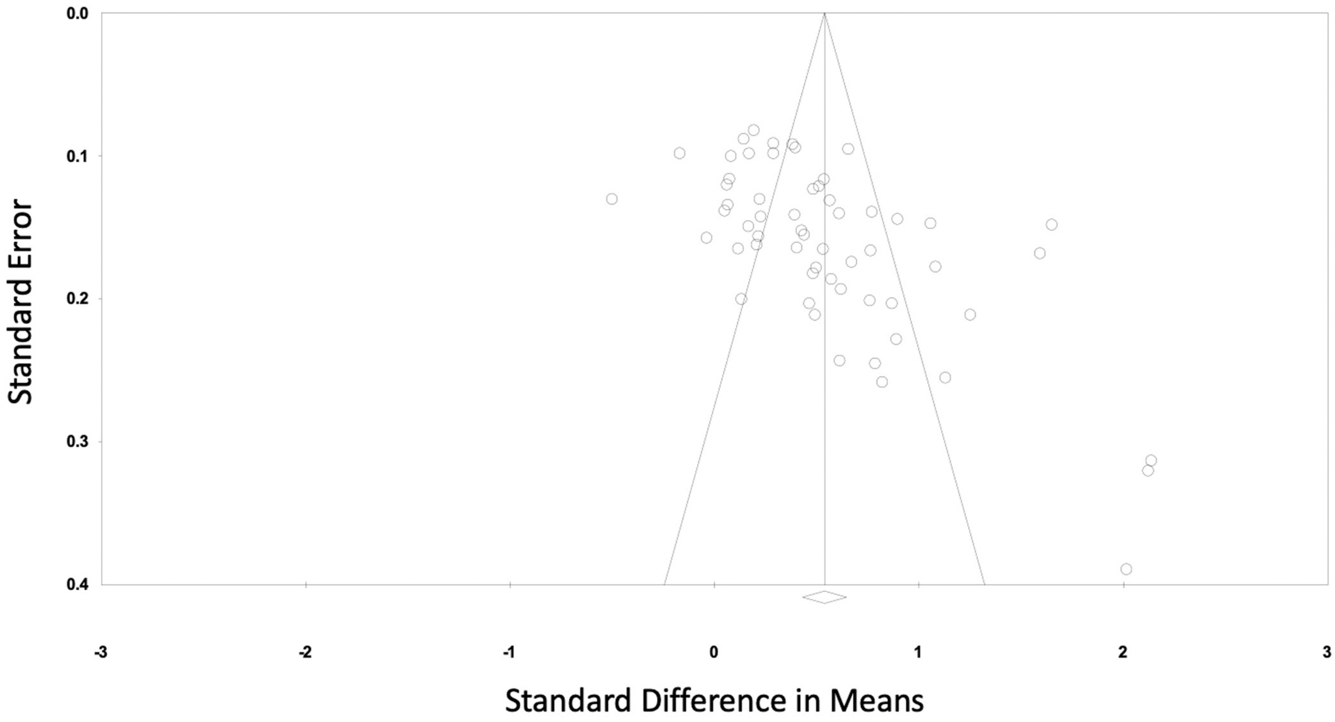

Fig. 3. *Funnel Plot of Standard Error by Standard Difference in Means for Each Included Memory Study. Note.* The white diamond indicates the point estimate = 0.537 (95% CI = [0.43 – 0.65]; and the circles indicate the effect sizes for individual memory studies included in the analysis.

13. Cognitive control accuracy outcomes

13.1. Relation between reward anticipation and cognitive control accuracy

This analysis is based on 53 publications (70 studies), with Cohen's d used as the measure of effect size. One publication (Bräutigam et al., 2024) contributed two studies as well as two non-independent effect sizes. Specifically, in Brautigan et al. (2024), one study sample completed a Simon task and a Stroop task, while the second study sample completed a Simon task and a Flanker task. To account for this non-independence, effects were pooled (i.e., $k = 68$) when they reflected the same task moderator across samples. Additional details about how these studies were handled when task type was a moderator are in the relevant section below. The overall mean effect size is $d = 0.286$ (see Fig. 4, forest plot diamond), a small to medium effect, with 95% CI = [0.16 – 0.41]. This mean effect size is significantly greater than zero, $Z = 4.49$, $p < .001$. There was significant between-study heterogeneity in the relation between reward and cognitive control accuracy, $Q(67) = 975.38$, $p < .001$, but a substantial proportion of variance in these 68 studies reflects variance in true effects $I^2 = 93.1\%$, as opposed to sampling error (~7%). The prediction interval of how much the true effect size varies in 95% of comparable studies, ranged from −0.72–1.29 (see Fig. 4, forest plot bottom line), $Tau^2 = 0.25$.

13.2. Sensitivity analyses

To ensure that the effect size was not driven by one particular study and that the results were robust, we first examined the relative weight that each study was assigned in the random effects model. Study weights ranged from 1.23 to 1.57, indicating that no study was overweighted in the analysis and each contributed fairly. Second, to ensure the results were not skewed by one study's particular effect size, we ran an iterative "one study removed" version of the model. Across these iterations, there were no significant changes to the overall mean effect size and all studies continued to have a p-value of < .001. This verified that the pattern of results was not driven by a single study's effect size and ensured the results were robust.

13.3. Publication bias

We used a funnel plot to visualize the effect sizes of the 68 included cognitive control studies against standard errors as an indication of precision (see Fig. 5). Visual inspection of this funnel plot revealed asymmetry, signaling the possibility of publication bias. This asymmetry was particularly apparent for effect sizes from studies with smaller samples – the funnel plot indicates an unequal number of studies to the right of the mean compared to the left, and the effect size tended to be larger for studies with smaller sample sizes. The average sample size was N = 37.36 (median N = 30, range: 10–109 participants).

This asymmetry was confirmed using a trim and fill procedure. As noted, under the random effects model, the point estimate for the combined studies is 0.286 (95% CI = [0.16 – 0.41]; indicated by the white diamond in Fig. 5. The white circles represent the effect size for each individual study included in the meta-analysis. The trim and fill procedure imputed 19 possible missing effect sizes to the left of the mean (see Supplemental Materials Fig. 2 funnel plot). With the addition of the imputed studies, the point estimate was reduced to 0.035 (95% CI = [−0.09 – 0.17]; indicated by a black diamond in Supplemental Materials Fig. 2 funnel plot. Egger's regression test of bias was significant ($b = 6.65$, $SE = 1.54$, $t(66) = 4.31$, $p < .001$).

14. Moderator effects on the relation between reward anticipation and cognitive control accuracy

There was significant heterogeneity in the effect size between studies, indicating that there might be important moderators influencing study effect sizes. We first describe our analyses testing for moderators related to differences in reward motivation manipulations, then our analyses testing for moderators related to differences in cognitive control task structure, and finally our analyses testing for moderators related to trial event timing. See Table 4 for details on all the moderators

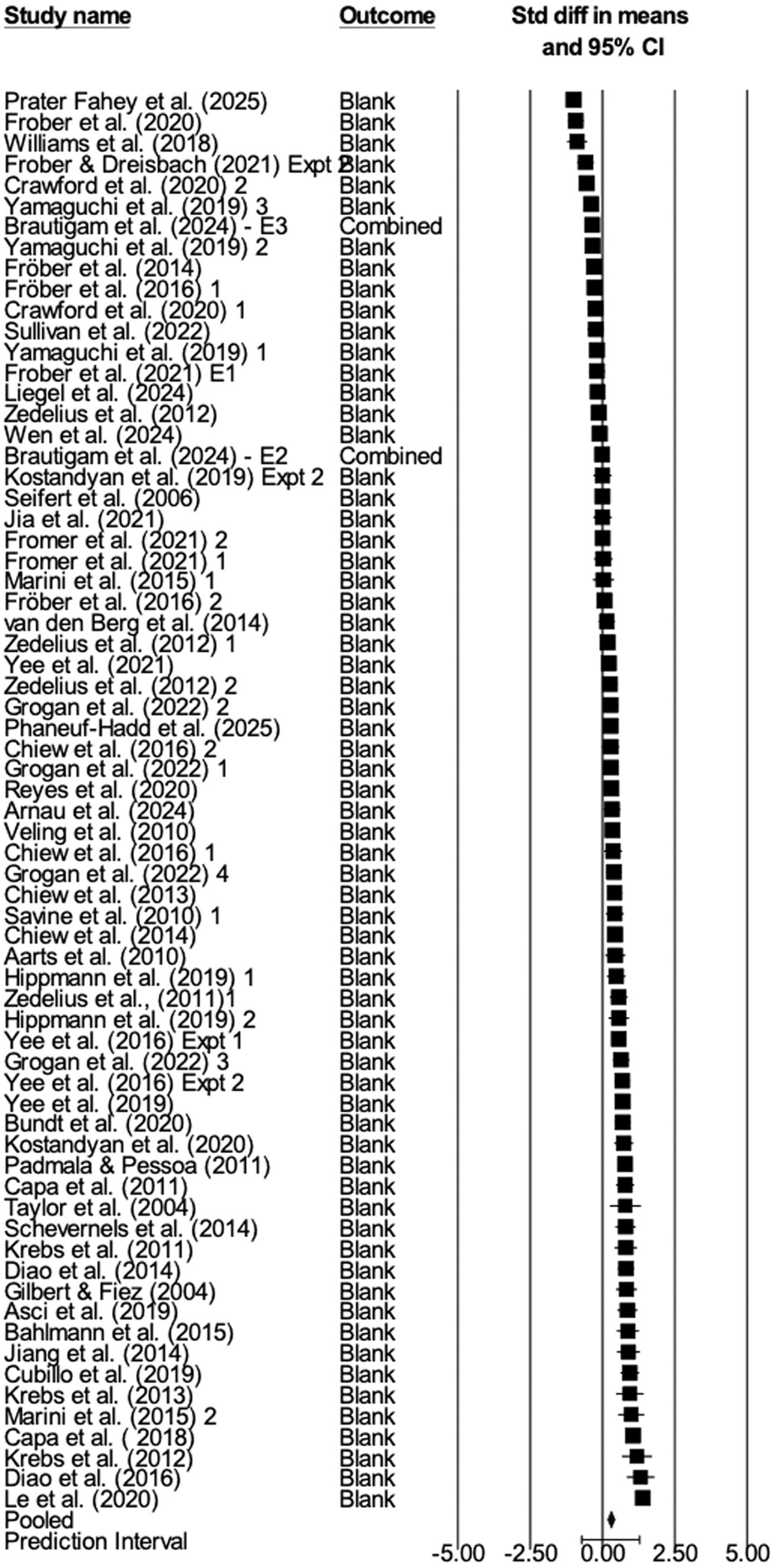

Fig. 4. *Forest Plot of Standard Difference in Means and 95% Confidence Intervals for Included Cognitive Control Accuracy Studies. Note*. The size of the boxes for each study is proportional to the weight of the study in relation to the pooled estimate. The diamond indicates the overall effect size estimate of across the meta-analysis cognitive control accuracy studies. The prediction interval noted in the bottom line of the forest plot is how much the true effect size varies, in 95% of comparable studies, ranges from −0.72–1.29.

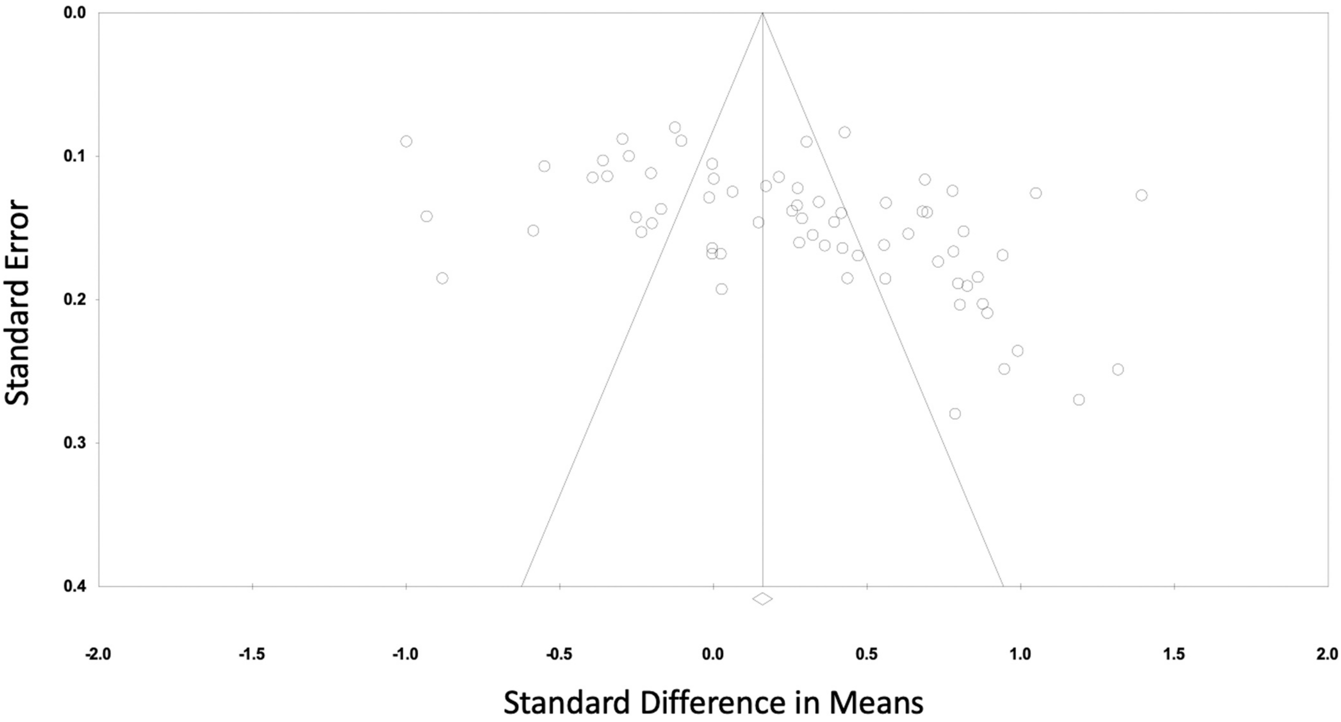

Fig. 5. *Funnel Plot of Standard Error by Standard Difference in Means for Included Cognitive Control Accuracy Studies. Note*. The white diamond indicates the point estimate = 0.286 (95% CI = [0.16 – 0.41]; the circles indicate the effect sizes for individual cognitive control accuracy studies included in the analysis.

used in the cognitive control analyses.

15. Reward-related moderators

15.1. Reward type

The comparison of primary (e.g., juice) and secondary (e.g., money) reward motivation as a moderator could not be conducted for cognitive control accuracy because only two studies used primary rewards. We did conduct a moderator analysis comparing secondary reward types of money versus points, and this was significant, $Q(1) = 5.68, p = .02$. The effect sizes for studies that used points as incentives (k = 16; $M = -0.15$, $SE = 0.03$, 95% CI = [−0.21 – −0.08]) were significantly smaller and negative (i.e., higher points were associated with lower accuracy), compared to studies that used monetary incentives, which showed higher accuracy with greater incentive (k = 50; $M = 0.26$, $SE = 0.02$, 95% CI = [0.22 – 0.29]); but note the discrepancy in the number of studies included in each of the two categories.

15.2. Reward amount

We created a reward amount moderator by calculating the difference between the high and low reward values of each study that used monetary incentives, and a separate variable for the difference between the high and low reward values for each study that used points as incentives. As in the memory analyses, in cases where multiple values were used, the middle of the range from the high and low values was chosen to calculate the difference, and monetary and point incentive differences were analyzed separately. When examining monetary reward (k = 36), reward amount was not a significant moderator of reward effect on cognitive control accuracy, $Q(1) = 0.14$, $p = .71$. Including reward amount as a moderator of the effect did not significantly explain any more of the variance in effect size between studies, $\text{Tau}^2 = 0.21$, $I^2 = 90.97\%$. R^2 analog < .001. Turning to studies that used points (k = 13), the difference in reward amount was also not a significant moderator of the effect, $Q(1) = 3.12$, $p = 0.08$. Including it as a moderator of the effect did not significantly explain any more of the variance in effect size between studies, $\text{Tau}^2 = 0.26$, $I^2 = 94.15\%$. R^2 analog = 0.21

15.3. Compensation

We planned to examine participant compensation as a moderator, comparing money to course credit. However, many studies did not specify what compensation was given and we could only identify four studies that specified using course credit as compensation, compared to identifying 47 that reported monetary compensation. Because of this large difference in the number of studies to compare, we could not carry out the proposed analysis testing for compensation type as a moderator.

15.4. Reward contingency

We planned to examine reward contingency as a moderator, comparing contingent (i.e., rewards related to cognitive control task performance) to incidental rewards (i.e., rewards are not contingent on performance in the task for which outcomes are examined, but received incidentally to task performance or earned via engagement in an unrelated task). However, only two studies used incidental rewards, so this comparison could not be conducted.

15.5. Punishment for errors

Studies that included punishment for incorrect responses (k = 12; $M = 0.16$, $SE = 0.04$, 95% CI = [.07 – 0.26]) were compared to those that did not (k = 56; $M = 0.16$, $SE = 0.02$, 95% CI = [0.13 – 0.19]), but this was not a significant moderator of the effect of incentives on cognitive control accuracy $Q(1) = 0.07$, $p = .80$.

16. Cognitive control task-related moderators

16.1. Type of cognitive control task

Studies were categorized based on the type of cognitive control task participants performed. As noted above, one publication (Bräutigam et al., 2024) contributed two studies with two non-independent effect sizes (corresponding to two tasks performed by the same participants) within each study. To account for this non-independence, we first excluded effect sizes from the Simon task from these samples and ran the moderator analysis (see Fig. 6 top panel). We then repeated this analysis, including the Simon task but removing effect sizes from the participants' other task (Stroop/Flanker; see Fig. 6 bottom panel).

There was only one study using an Anti-saccade task, two studies coded as using a Voluntary Switch task, and one using the Simon (after removing the two studies from Brautigam et al., 2024), so these categories were not included in this first analysis. Task type was a significant moderator of the effect of reward anticipation on cognitive control accuracy $Q(6) = 23.22$, $p < .001$. Effect sizes for AX-CPT (k = 5; $M = 0.05$, $SE = 0.05$, 95% CI = [−0.04 – 0.14]), Discrimination (k = 4, $M = 0.08$, $SE = 0.07$, 95% CI = [−0.05 – 0.21]), and Stroop (k = 12, $M = 0.06$, $SE = 0.04$, 95% CI = [−0.02 – 0.13]) tasks were not significantly different from zero ($Z \leq 1.37$, $p \geq .17$).

Additionally, Flanker (k = 12; $M = -0.15$, $SE = 0.04$, 95% CI = [−0.23 – −0.08]), Go/No-Go (k = 4, $M = 1.12$, $SE = 0.08$, 95% CI = [0.96 – 1.28]), Switch (k = 0.29, $M = 0.30$, $SE = 0.04$, 95% CI = [0.22 – 0.36]), and Working Memory (k = 11, $M = 0.51$, $SE = 0.05$, 95% CI = [0.42 – 0.60]), tasks all had effect sizes significantly different than zero, $Z \geq -3.89$, $p < .001$. Additionally, these effect sizes all significantly differed from each other, except Switch and Working Memory, $Q(1) = 1.09$, $p = .30$. Go/No-Go tasks had significantly larger effects sizes compared to other tasks confirmed with non-overlapping confidence

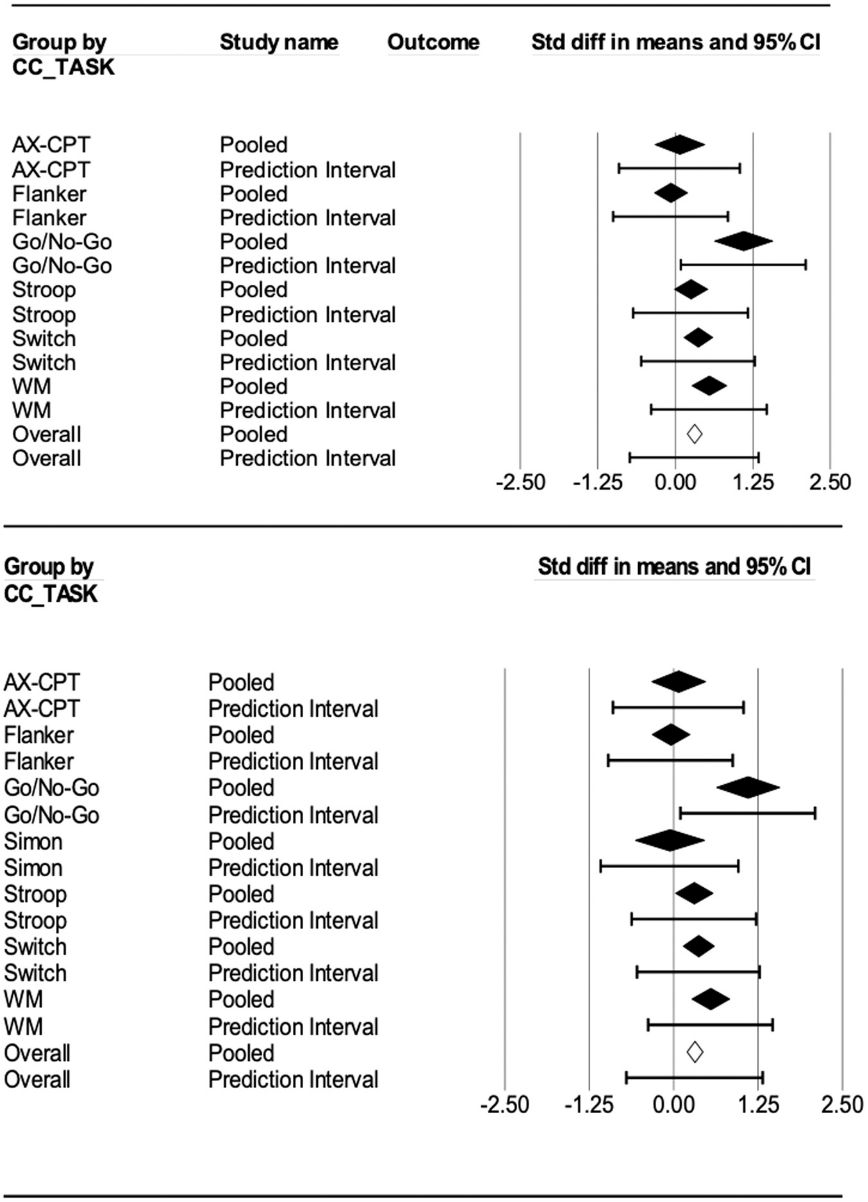

Fig. 6. *Plot of Pooled Standard Difference in Means and Prediction Interval for Each Included Cognitive Control Accuracy Study by Control Task Type. Note.* CC_Task = cognitive control task. The top panel represents the analyses excluding the two Simon tasks from Brautigam et al., 2024, and the bottom panel represents the analysis excluding the Stroop and Flanker tasks from Brautigam et al., 2024. The black diamonds indicate the pooled estimate for each task separately, and the prediction interval is noted underneath each pooled estimate. Overall effect size estimate (white diamond) and predicted interval are noted for reference in the bottom two lines of the figure.

intervals, but there were only four studies that used a Go/No-Go task. The pooled effect size for the Flanker task was negative, indicating that accuracy in this task was better overall for low/no reward compared to high reward conditions.

The same analysis was run again, but included effect sizes from the Simon tasks completed by the two samples in Brautigam et al., 2024 (and omission of effect sizes from these samples' Stroop/Flanker tasks). Three studies total used the Simon task (k = 3, $M = -0.11$, $SE = 0.06$, 95% CI = [0.42 – 0.60]), and the point estimate was not significantly different from zero, $Z = -1.85$, $p = .06$. After removing the Brautigan et al. (2024) Stroop and Flanker tasks, the point estimates for the remaining eleven Flanker studies (k = 11; $M = -0.11$, $SE = 0.04$, 95% CI = [−0.20 – −0.03]) and remaining eleven Stroop studies (k = 11, $M = 0.09$, $SE = 0.04$, 95% CI = [0.09 – 0.18]) changed numerically. With the removal of the Brautigan et al. (2024) study, the point estimate for Stroop tasks was now significantly different from zero, $Z = 2.17$, $p = .03$. Simon and Stroop were not significantly different, $Q(1) = 0.87$, $p = .35$, nor were Simon and Flanker, $Q(1) = 0.002$, $p = .97$. All other differences remained the same in terms of statistical significance (see Fig. 6). As above, the Go/No-Go tasks had significantly larger pooled effect size compared to other tasks, as confirmed with non-overlapping confidence intervals, but there were only four studies that used a Go/No-Go task. The pooled effect size for the Flanker task was negative, indicating that accuracy was better overall for low/no reward compared to high reward conditions.

16.2. Reaction time deadline

Studies were categorized based on whether the reward was contingent on accurate performance (k = 18; $M = 0.22$, $SE = 0.03$, 95% CI = [0.15 – 0.28]), or on both accuracy and speed (i.e., the presence of an RT deadline; k = 44; $M = 0.20$, $SE = 0.02$, 95% CI = [0.16 – 0.26]). RT deadline was not a significant moderator of the effect of reward on cognitive control accuracy, $Q(1) = 0.65$, $p = .42$.

17. Trial event timing-related moderators

17.1. Reward cue length

The duration of the reward cue was not a significant moderator of effect size, $Q(1) = 0.29$, $p = .59$. When reward cue length (k = 46) was included as a covariate, it did not explain any more of the variance in effect size between studies, $\mathrm{Tau}^2 = 0.24$, $I^2 = 93.05\%$. R^2 analog = −0.03, compared to leaving it out of the model.

17.2. Target length

The duration of the target stimulus was not a significant moderator of the effect size, $Q(1) = 0.46$, $p = .50$. When target length (k = 46) was included as a covariate in the regression model, it did not explain any more of the variance in effect size between studies, $\mathrm{Tau}^2 = 0.23$, $I^2 = 92.73\%$, R^2 analog = 0.01, compared to leaving it out of the model.

17.3. Cue-target interval length

The amount of time between the offset of the reward cue and the onset of the target stimuli at encoding was not a significant moderator of the effect size, $Q(1) = 1.47$, $p = .23$. When cue-target interval length (k = 46) was included as a covariate in the regression model, it did not explain any more of the variance in effect size between studies, $\mathrm{Tau}^2 = 0.23$, $I^2 = 92.83\%$, R^2 analog = 0.02, compared to leaving it out of the model.

18. Cognitive control reaction time outcomes

18.1. Relation between reward anticipation and cognitive control RT

This analysis is based on 54 publications (74 studies), with Cohen's d used as the measure of effect size. One publication (Bräutigam et al., 2024) contributed two studies with two non-independent effect sizes each. As described above in the *Cognitive Control Accuracy Outcomes* section, the two studies' participant samples completed both a Simon task and a Stroop or Flanker task. To account for this non-independence, effects were pooled (i.e., k = 72) when they reflected the same task moderator across samples. The details for the task moderator analysis are described in the relevant section below. The overall mean effect size is d = 0.807 (see Fig. 8 forest plot diamond), a large effect, with 95% CI = [0.68 – 0.94]. This mean effect size is significantly greater than zero, $Z = 12.08$, $p < .001$. There was significant between-study heterogeneity in the relation between reward and cognitive control accuracy, $Q(71) = 945.51$, $p < .001$, but a substantial proportion of variance in these 72 studies reflects variance in true effects $I^2 = 92\%$, as opposed to sampling error (8%). The prediction interval of how much the true effect size varies, in 95% of comparable studies, ranges from −0.27–1.88 (see forest plot bottom line), $\mathrm{Tau}^2 = 0.29$.

18.2. Sensitivity analyses

To ensure that the effect size was not driven by one particular study and that the results were robust, we first examined the relative weight that each study was assigned in the random effects model. Study weights ranged from 1.03 to 1.52, indicating that no study was overweighted in the analysis and each contributed fairly. Second, to ensure the results were not skewed by one study's particular effect size, we ran an iterative "one study removed" version of the model. Across these iterations, there were no significant changes to the overall mean effect size and all studies continued to have a *p*-value of < .001. This verified that the pattern of results was not driven by a single study's effect size and ensured the results were robust Fig. 7

18.3. Publication bias

We used a funnel plot to visualize the effect sizes of the 72 included cognitive control studies against standard errors as an indication of precision (Fig. 8). Visual inspection of this funnel plot revealed asymmetry, signaling the possibility of publication bias. This asymmetry was particularly apparent for effect sizes from studies with smaller samples – the funnel plot indicates an unequal number of studies to the right of the mean compared to the left, and the effect size tended to be larger for studies with smaller sample sizes. The average sample size was N = 34.51 (median N = 28.5, range: 10–109 participants).

This asymmetry was confirmed using a trim and fill procedure. As noted, under the random effects model, the point estimate for the combined studies is 0.807 (95% CI = [0.68 – 0.94]; indicated by the white diamond and open circles in the Fig. 9 funnel plot). The trim and fill procedure imputed 23 possible missing effect sizes to the left of the mean (see Supplemental Material Fig. 5 black filled circles in the funnel plot); with this addition, the imputed point estimate was 0.472 (95% CI = [0.33 – 0.61]. Egger's regression test of bias was significant b = 5.30, $SE = 1.14$, $t(70) = 4.64$, $p < .001$.

19. Moderator effects on the relation between reward anticipation and cognitive control RT

There was significant heterogeneity in the effect size between studies, indicating that there might be important moderators influencing study effect sizes. Following a similar organization to our results for cognitive control accuracy above, we first describe our analyses testing for moderators related to differences in reward motivation

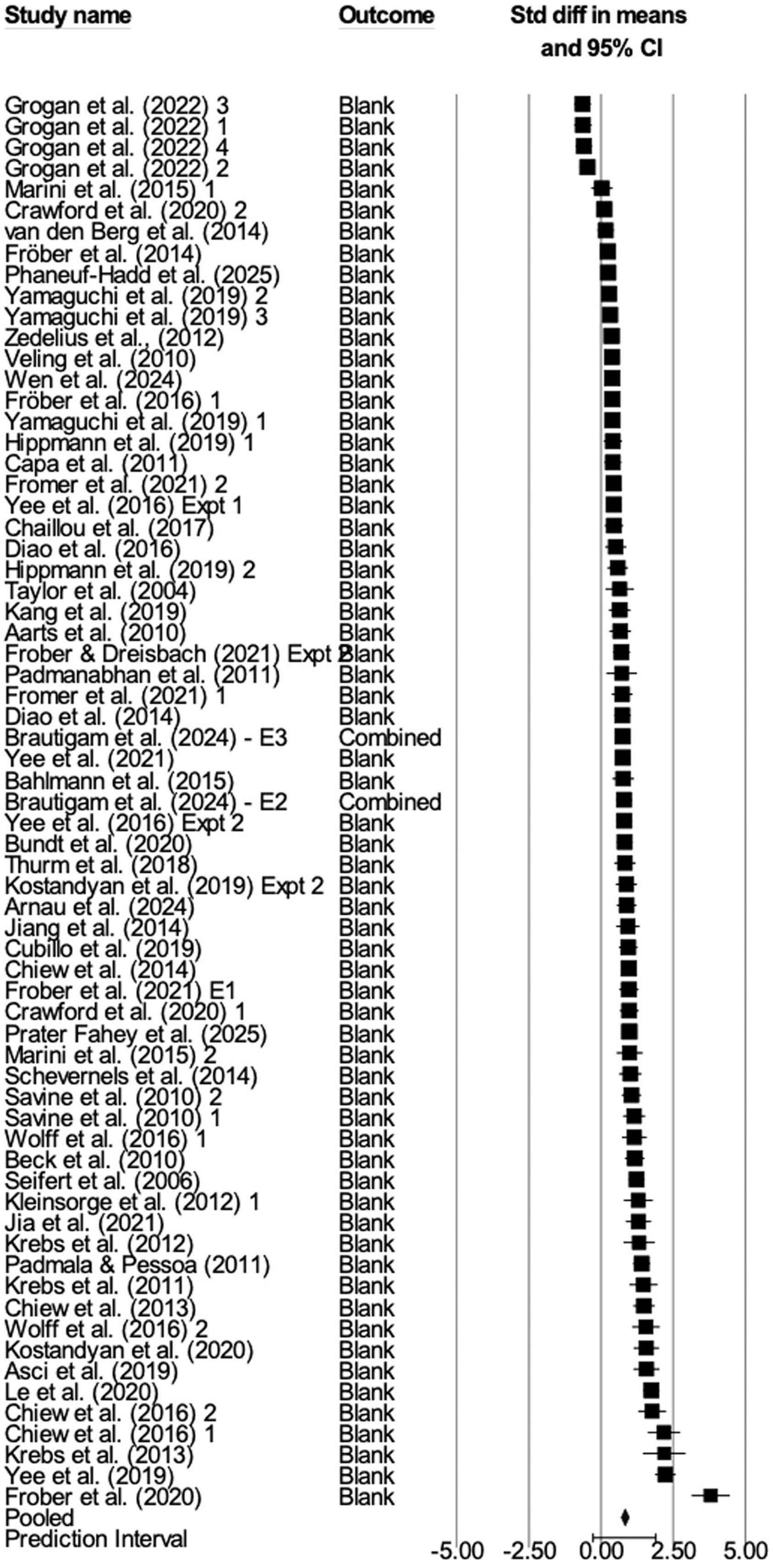

Fig. 7. *Forest Plot of Standard Difference in Means and 95% Confidence Intervals for each included Cognitive Control Reaction Time Studies. Note*. The size of the boxes for each study is proportional to the weight of the study in relation to the pooled estimate. The diamond indicates the overall effect size estimate of across the meta-analysis cognitive control accuracy studies. The prediction interval, noted in the bottom line of the forest plot indicates how much the true effect size varies in 95% of comparable studies, ranged from −0.27–1.88.

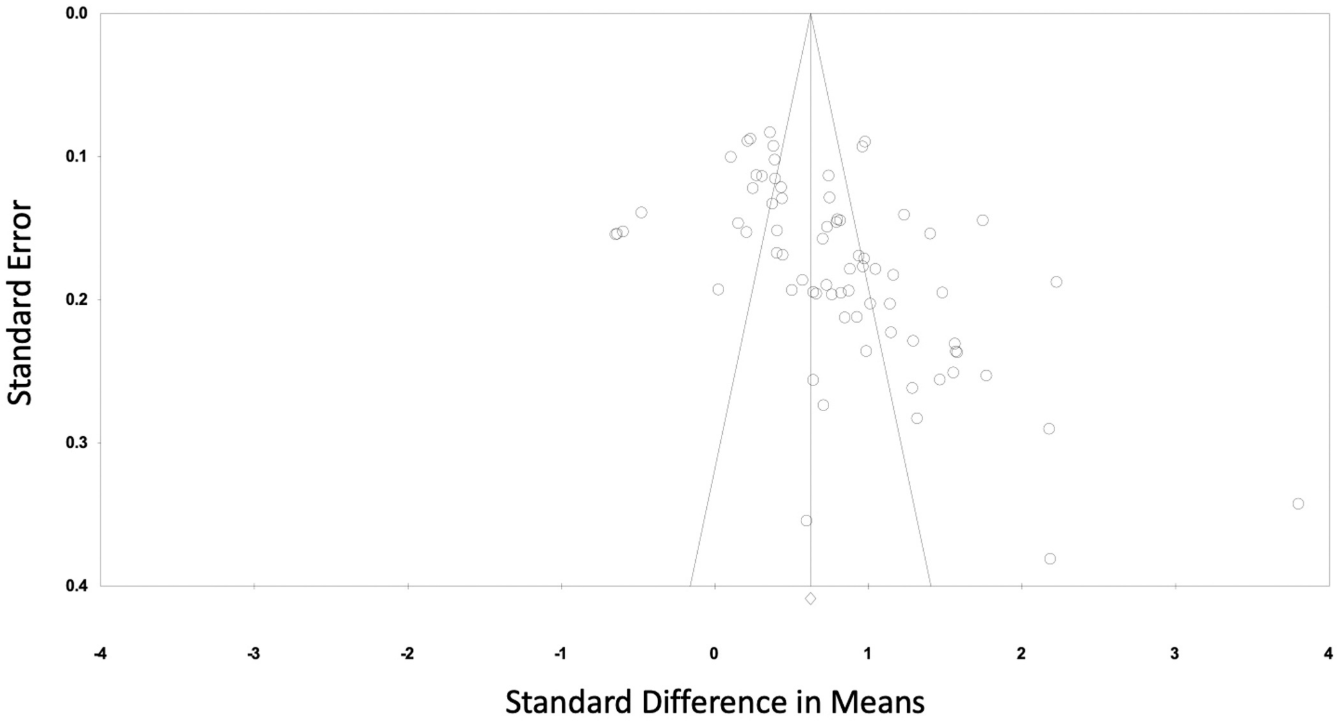

Fig. 8. *Funnel Plot of Standard Error by Standard Difference in Means for Each Included Cognitive Control Reaction Time Studies. Note.* The white diamond indicates the point estimate = 0.807 (95% CI = [0.68 – 0.94]; the circles indicate the effect sizes for individual cognitive control accuracy studies included in the analysis.

manipulations, then our analyses testing for moderators related to differences in cognitive control task structure, then our analyses testing for moderators related to trial event timing.

20. Reward-related moderators

20.1. Reward type

The use of primary (e.g., juice) versus secondary (e.g., money) reward as a moderator revealed a significant effect, *Q*(1) = .59, *p* = .01, with primary rewards leading to a larger effect than secondary rewards. However, this finding should be interpreted with caution, given the large discrepancy in the number of studies included in each of the two reward type conditions (primary rewards: k = 3, *M* = 1.47, *SE* = 0.13, 95% CI = [1.21 – 1.73]; secondary rewards: k = 68, (*M* = 0.60, *SE* = 0.02, 95% CI = [0.57 – 0.64]). We also conducted a moderator analysis comparing secondary reward types of money versus points, but this was not significant, *Q*(1) = 1.96, *p* = .27. The effect sizes for studies that used points as incentives (k = 18; *M* = 0.75; *SE* = 0.04, 95% CI = [0.69 – 0.82]) did not differ overall from studies that used monetary incentives (k = 50; *M* = 0.54, *SE* = 0.02, 95% CI = [0.50 – 0.59]). Again, the discrepancy in the number of studies included in each of the two categories should be considered).

20.2. Reward amount

We created a reward amount moderator by calculating the difference between the high and low reward values of each study that used monetary incentives, and a separate variable for the difference between the high and low reward values for each study that used points as incentives. As for the previous two outcomes, in cases where multiple reward values were used, the middle of the range from the high and low values was chosen to calculate the difference, and monetary and point incentive differences were analyzed separately. In studies that used monetary reward (k = 35), the differences in reward amount was a significant moderator *Q*(1) = 4.56, *p* = .03, such that the reward effect on cognitive control reaction time was larger with a smaller reward amount difference. However, it is important to note that the majority of included studies used small differences between reward values (see Fig. 9). In studies that used points (k = 15), the difference in reward amount was not a significant moderator of the effect, *Q*(1) = 1.27, *p* = .26, and including the reward amount as a moderator of the effect did not significantly explain any more of the variance in effect size between studies, $\text{Tau}^2 = 0.20$, $\text{I}^2 = 90.57\%$. R^2 analog = 0.07.

20.3. Compensation

We planned to examine participant compensation as a moderator, comparing money to course credit. However, many studies did not specify what compensation was given. Additionally, we could only identify 3 studies that specified using course credit as compensation, in contrast to 65 identifiable studies using monetary compensation. Because of this large difference in study numbers, we could not carry out the proposed analysis testing for compensation type as a moderator.

20.4. Reward contingency

We planned to examine reward contingency as a moderator, comparing contingent to incidental rewards. However, only two studies used incidental rewards, so this comparison could not be conducted.

20.5. Punishment for errors

Studies that included punishment for incorrect responses (k = 12; *M* = 0.71, *SE* = 0.05, 95% CI = [0.62 – 0.80]) were compared to those that did not (k = 60; *M* = 0.61, *SE* = 0.02, 95% CI = [0.57 –0.65]), but this was not a significant moderator of the effect of incentives on cognitive control RT *Q*(1) = 1.07, *p* = .31.

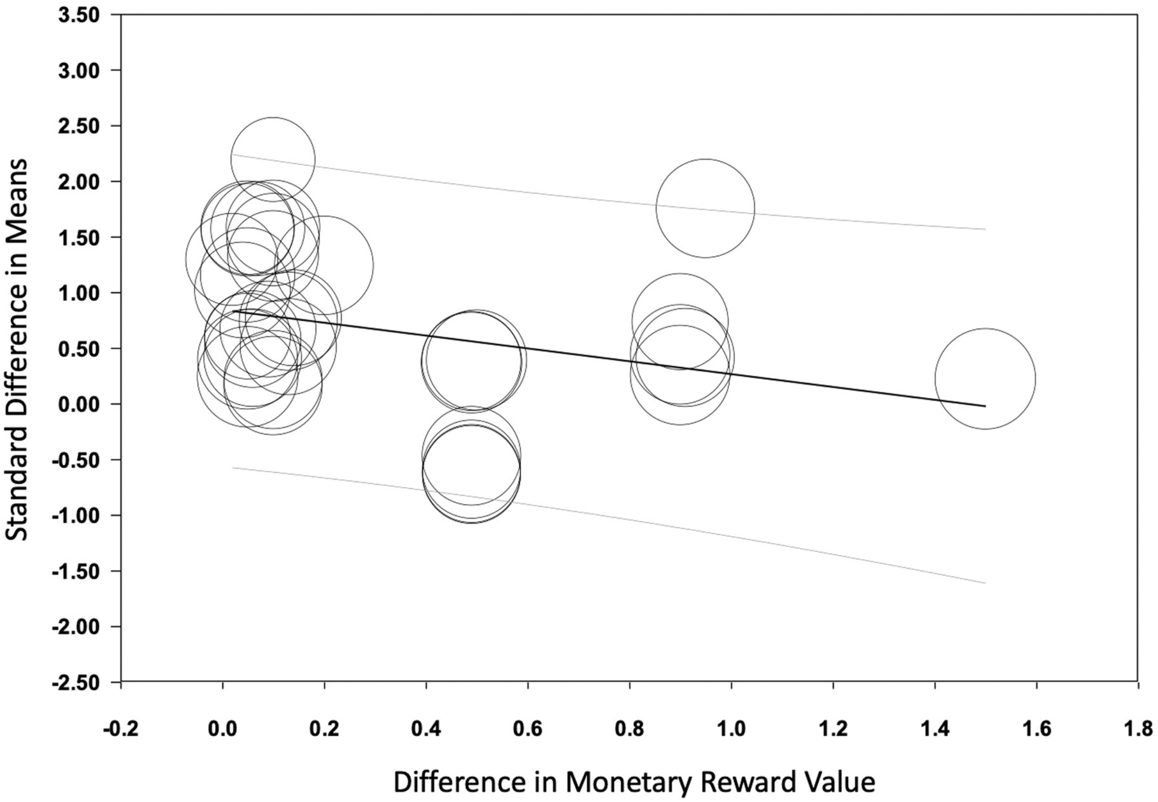

Fig. 9. *Regression of the Standard Difference in Means on Difference in Monetary Reward Value. Note.* The bold black line represents the regression line. Gray thinner lines represent the prediction interval line. Circles represent individual studies proportional to the weight of the study.

21. Cognitive control task-related moderators

21.1. Type of cognitive control task

Studies were categorized based on the type of cognitive control task participants performed. As noted above, one publication (Bräutigam et al., 2024) contributed two studies as well as two non-independent effect sizes within each study. To account for this non-independence, we first excluded the Simon task effect sizes from Brautigam et al. (2024) and ran the moderator analysis (see Fig. 6 top panel). We then repeated this analysis, now including the Simon task effect sizes from Brautigam et al. (2024) but removing these samples' Stroop/Flanker task effect sizes (see Fig. 6 bottom panel).

As when examining cognitive control RT as an outcome, there were only two studies coded as Anti-saccade, two as Voluntary Switch, one study coded as Stop-Signal, and one that used the Simon task (after excluding the two from Brautigam et al., 2024) so these three categories were not included in this analysis.

Task type was a significant moderator of the effect of reward anticipation on cognitive control RT, $Q(6) = 21.02$, $p = .01$, indicating that the effect of reward on cognitive control RT did varied with the type of task that was used. AX-CPT (k = 6; $M = 0.59$, $SE = 0.05$, 95% CI = [0.49 – 0.68]), Discrimination (k = 3, $M = 0.57$, $SE = .08$, 95% CI = [0.41 – 0.73], Flanker (k = 12; $M = 0.65$, $SE = 0.04$, 95% CI = [0.56 – 0.73]), Go/No-Go (k = 4; $M = 1.16$, $SE = 0.09$, 95% CI = [0.99 – 1.32]), Stroop (k = 15; $M = 0.86$, $SE = 0.04$, 95% CI = [0.78 –.94]), Switch (k = 18; $M = 0.70$, $SE = 0.04$, 95% CI = [0.63 – 0.77]), Working Memory (k = 8; $M = -0.07$, $SE = 0.06$, 95% CI = [−0.18 – 0.05]). The main differences were that Working Memory tasks had significantly smaller effects of reward on cognitive control RT compared to all other tasks, $Q(1) \geq 3.99$, $p \leq 0.05$, and the point estimate for Working Memory did not significantly differ from zero, $Z = -1.17$, $p = .24$. The effects for Go/No-Go and Stroop were larger than the other tasks, confirmed by non-overlapping confidence intervals (see Fig. 10 top panel for the pooled effects sizes by task type).

The same analysis was run again, but including the Simon tasks and omitting the Stroop/Flanker tasks from Brautigam et al. (2024). There was still a significant effect of task type, $Q(6) = 21.66$, $p = .003$. The point estimate for Simon (k = 3, $M = .53$, $SE = 0.06$, 95% CI [0.41 – 0.65], was significantly greater than zero, $Z = 8.65$, $p < .001$. After removing two studies the Flanker (k = 11; $M = 0.62$, $SE = 0.05$, 95% CI = [0.53 – 0.71]) and Stroop (k = 14; $M = 0.86$, $SE = 0.04$, 95% CI = [0.77 – 0.94]) values changes slightly. The main difference reported above remained the same – Working Memory tasks had significantly smaller effects of reward on cognitive control RT compared to all other tasks, and these effects were not significantly different than zero, $Z = -1.17$, $p = .24$. The effects for Go/No-Go and Stroop were larger than the other tasks confirmed by non-overlapping confidence intervals (see Fig. 10 bottom panel for the pooled effects sizes by task type).

21.2. Reaction time deadline

Studies were categorized based on whether the reward was contingent on accurate performance (k = 15; $M = 0.34$, $SE = 0.04$, 95% CI = [0.27 –.41]), or on both accuracy and speed (i.e., the presence of an RT deadline; k = 51; $M = 0.78$, $SE = 0.02$, 95% CI = [0.73 – 0.82]). RT deadline was a significant moderator of the effect of reward on cognitive control RT, $Q(1) = 13.62$, $p < .001$, with larger reward effects in studies where an RT deadline was present versus absent.

22. Trial event timing-related moderators

22.1. Reward cue length

The duration of the reward cue was not a significant moderator of effect size, $Q(1) = 0.05$, $p = .83$. When reward cue length (k = 49) was

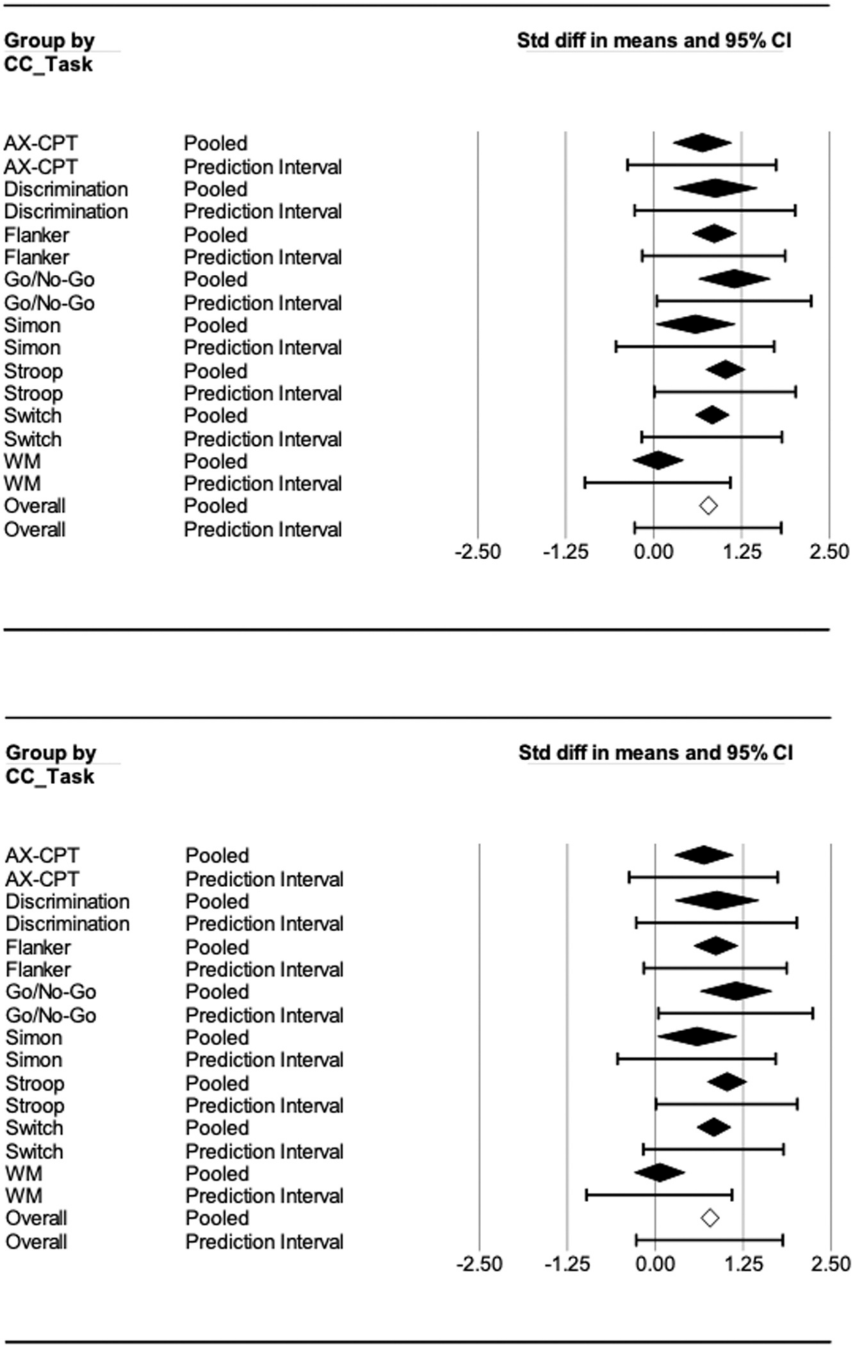

Fig. 10. *Plot of Pooled Standard Difference in Means and Prediction Interval for Each Included Cognitive Control RT Study by Cognitive Control Task. Note.* CC_Task = cognitive control task. The top panel represents the analyses excluding the two Simon tasks and the bottom panel represents the analysis excluding the Stroop and Flanker tasks from Brautigam et al., 2024. The black diamonds indicate the pooled estimate for each task separately, and the prediction interval is noted underneath each pooled estimate. Overall effect size estimate (white diamond) and predicted interval are noted for reference in the bottom two lines of the figure.

included as a covariate, it did not explain any more of the variance in effect size between studies, $\text{Tau}^2 = 0.29$, $I^2 = 92.83\%$, R^2 analog $= -0.03$, compared to leaving it out of the model.

22.2. Target length

The duration of the target stimulus was not a significant moderator of the effect size, $Q(1) = 0.17$, $p = .66$. When target length ($k = 49$) was included as a covariate in the regression model, it did not explain any more of the variance in effect size between studies, $\text{Tau}^2 = 0.29$, $I^2 = 92.83\%$, R^2 analog $= 0.01$, compared to leaving it out of the model.

22.3. Cue-Target Interval Length

The amount of time between the offset of the reward cue and the onset of the target stimuli at encoding was not a significant moderator of the effect size, $Q(1) = 2.11$, $p = .14$. When cue-target interval length ($k = 49$) was included as a covariate in the regression model, it did not explain any more of the variance in effect size between studies, $\text{Tau}^2 = 0.29$, $I^2 = 92.83\%$, R^2 analog $= -0.03$, compared to leaving it out of the model.

23. Comparing reward anticipation effects on memory versus cognitive control

To compare the magnitude of the reward effect in memory and cognitive control domains, we ran two analyses combining across memory effect sizes and cognitive control effect sizes (separately for cognitive control accuracy and RT) and compared between them using outcome (cognitive control accuracy or RT versus memory accuracy) as a moderator. Due to the non-independence of our cognitive control accuracy and cognitive control RT outcomes, we did not compare effect sizes across all three performance outcomes in the same analysis.

23.1. Memory accuracy versus cognitive control accuracy

To determine whether reward had a larger effect on memory accuracy (k = 58) or cognitive control accuracy (k = 68), we created a moderator variable that categorized study effect sizes based on outcome (see Figure 12). This moderator was significant, $Q(1) = 8.88$, $p = .003$, $I^2 = 991.88\%$. Reward effects were larger for memory accuracy (Cohen’s d = 0.53, *SE* = 0.06, 95% CI = [.41 –.68]) than for cognitive control accuracy (Cohen’s d = 0.28, *SE* = 0.06, 95% CI = [.17 –.40]).

23.2. Memory accuracy versus cognitive control RT

To determine whether reward had a larger effect on memory accuracy (k = 58) or cognitive control RT (k = 72), we created a moderator variable that categorized study effect sizes based on outcome (see Figure 12). This moderator was significant, $Q(1) = 10.79$, $p < .001$, $I^2 = 90.97\%$. Reward effects were larger for cognitive control RT (Cohen’s d = 0.81, *SE* = 0.06, 95% CI = [0.71 – 0.93]) than for memory accuracy (Cohen’s d = 0.54, *SE* = 0.06, 95% CI = [0.41 – 0.69]).

24. Discussion

The present meta-analysis examined the effects of reward anticipation on cognitive performance in two domains: cognitive control and episodic memory encoding. We focused on experimental paradigms that utilized the basic *Monetary-Incentive-Delay* (MID) paradigm structure, whereby a reward cue is presented prior to a target stimulus for processing on each trial. fMRI methods have demonstrated that this task manipulation leads to anticipatory activity in brain regions considered part of the mesolimbic dopamine system (Knutson et al., 2001; Knutson et al., 2000), potentially modulating activity in downstream brain areas such as prefrontal cortex and hippocampus, leading to reward-enhanced cognitive performance. While the basic structure of the MID paradigm has been widely used to study both cognitive control and memory encoding in relation to reward manipulations, many aspects of experimental design have varied between individual studies, potentially moderating results. It is also an open question whether reward anticipation might modulate outcomes differently across cognitive control and memory domains, given that the behavioral outputs for cognitive control and memory studies vary in their temporal proximity to the reward cue and putative dopaminergic activity elicited in response. Moreover, reward incentives for cognitive control performance are often contingent on both response accuracy and reaction time, while reward incentives for memory performance are typically based on accuracy alone.

We conducted meta-analyses on three outcomes: cognitive control accuracy (k = 70), cognitive control reaction time (k = 74), and memory accuracy (k = 58). We observed that reward anticipation was associated with improved cognitive performance across all three outcomes, in terms of increased accuracy for both cognitive control and memory performance, as well as decreased reaction times (i.e., increased speed) during cognitive control performance. However, the magnitude of the reward effect varied across the three examined outcomes, with the largest effect on cognitive control reaction times (Cohen’s d = 0.807), followed by memory accuracy (Cohen’s d = 0.537), and the smallest effect on cognitive control accuracy (Cohen’s d = 0.286). We also observed significant effects of several, but not all, of the moderators examined, suggesting that variability in study design can influence the magnitude of reward anticipation effects on cognitive performance. We first discuss comparisons of reward anticipation effects across cognitive domains and outcomes, then discuss contributions of moderators for memory and cognitive control outcomes separately.

25. Examining the effect of reward across cognitive domains and on speed versus accuracy

One novel contribution of the present study is its systematic examination and comparison of reward anticipation effects on performance outcomes across two cognitive domains (i.e., cognitive control and memory). We speculated that the amplitude of the reward effect might be larger in the cognitive control versus memory domain for two main reasons: 1) the temporal proximity between reward cue and behavioral response is, by design, typically much closer for cognitive control than memory paradigms; 2) cognitive control performance is typically evaluated on the basis of both response accuracy and speed, and thus outcomes might be shaped by dopaminergic enhancement of motoric vigor (Beierholm et al., 2013; Niv et al., 2007) to a greater extent than memory performance, which is typically evaluated after a longer temporal interval and on the basis of accuracy only. We conducted two analyses with outcome type as a moderator, comparing memory accuracy to cognitive control accuracy, as well as comparing memory accuracy to cognitive control RT. These analyses revealed that the effect of reward on cognitive control accuracy was significantly smaller than its effect on memory accuracy, and the effect of reward on memory accuracy was significantly smaller than the effect on cognitive control RT. While cognitive control accuracy and RT outcomes were not directly compared in the present meta-analysis due to their non-independence, it can be inferred that reward had a larger effect on cognitive control RTs (i.e., speeding) than on cognitive control accuracy, with the amplitude of the reward effect on memory accuracy falling between the two (see Fig. 11). While RT is less frequently examined as a dimension of memory performance, prior work suggests that response speed at retrieval might relate to memory strength and differentiate recollection- and familiarity-based responses, with lower RTs for recollection (Gimbel and

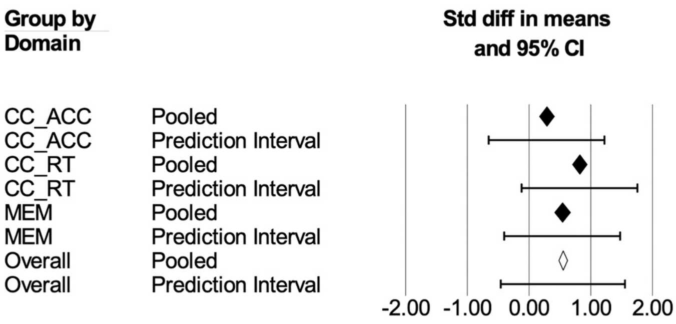

Fig. 11. *Plot of Pooled Standard Difference in Means and Prediction Interval for each included Cognitive Control Accuracy, Cognitive Control Reaction Time, and Memory Accuracy Study Included in the Analysis. Note.* Domain = the dependent variable; CC_ACC = cognitive control accuracy studies; CC_RT = cognitive control reaction time studies; MEM = memory accuracy studies. The black diamonds indicate the pooled estimate for each outcome separately, and the prediction interval is noted underneath each pooled estimate. The overall prediction interval across the three outcomes is noted for reference in the bottom line of the figure.

Brewer, 2011).

Interestingly, in the cognitive control studies that included both accuracy and RT outcomes in the current meta-analysis (k = 61),[2] we observed a significant and numerically positive correlation in reward-related effects on accuracy and RT (r(61) = .40, p = .002). This suggests that on a study-by-study basis, reward-related improvements in accuracy during cognitive control performance tended to be positively associated with reward-related response speeding (but note that between-study differences that may have influenced this are discussed further in the section on task type as a moderator). This finding is intriguing given that, as dimensions of cognitive performance more generally, speed and accuracy are typically at odds with one another; this leads to the *speed-accuracy tradeoff* whereby accuracy declines as speed increases (van Veen et al., 2008). Our results revealed that while reward had a larger effect on response speed than on accuracy in cognitive control, it was associated with benefits to both dimensions of performance on a within-study basis. Computational work suggests that simultaneous improvements in both cognitive speed and accuracy as a function of reward reflect increased effort expended, in response to increasing benefit of the prospective reward – hence “breaking” the speed-accuracy tradeoff. Prior evidence is consistent with the idea that increased effort mobilization with reward might be allocated towards improvements in speed versus accuracy. Dambacher et al. (Dambacher et al., 2011) examined the effects of different monetary incentive payoff schemes emphasizing speed versus accuracy on cognitive performance and reported that an emphasis on speed over accuracy improved performance to a greater extent than the reverse, potentially because focusing on both speed and accuracy increased the complexity of the task and identification of an optimal strategy. More recent work (Leng et al., 2021) has used drift-diffusion modeling to examine how reward influences cognitive control and demonstrated that rewards increased the drift rate, leading to increases in speed while maintaining stable accuracy. In general, reward seems to increase the speed of cognitive and motor responses, both in paradigms where rewards are contingent on responding before a time cutoff as well as in paradigms in which they are not. In the present meta-analysis, we did observe significant moderation of reward effects on cognitive control RTs by use of a reaction time deadline – while reward was associated with response speeding across all RT outcomes studied, its effect was amplified in studies where reward receipt was contingent on both speed and accuracy. While this moderation arguably reflects adjustment of performance to maximize reward, the robust reward effect on RT observed globally is consistent with proposals that rewards might promote speed as a general principle through enhanced dopaminergic activity and response vigor (Niv, 2007) and that, in turn, enhanced response speed might help maximize reward yield by increasing the rate of reward uptake per unit time (Otto and Daw, 2019; Ritz et al., 2022).

Investigations of other potential enhancements to cognitive performance and the extent to which such enhancements manifest in terms of improved accuracy versus speed might provide further insights into the effects of reward on cognitive control observed in the present analysis. For example, a meta-analysis of exercise-related benefits to cognitive control (McMorris and Hale, 2012) revealed that such benefits might primarily manifest through increases in speed rather than accuracy. McMorris and Hale (2012) suggested that this pattern might be due to one of two possibilities. The first possibility is simple and attributes the greater benefit of exercise to speed versus accuracy to use the relatively simple cognitive tasks and the emergence of ceiling effects. The second possibility is more complex, suggesting that exercise-induced enhancements in catecholamine neurotransmitter activity should increase speed but also neural noise, hindering improvements in accuracy. The presence of a significant positive effect of reward on cognitive control accuracy in our meta-analysis argues against the idea that accuracy was already at ceiling under baseline conditions. However, like McMorris and Hale (McMorris and Hale, 2012), the cognitive control studies included in the present meta-analysis employed relatively simple tasks in which accuracy may have already been strong at baseline, allowing for larger reward effects in the RT dimension. Indeed, our moderator analyses indicated that the effect size of reward effects on accuracy in studies that employed an AX-CPT, Discrimination or Stroop task were not significantly different from zero. While McMorris and Hale (McMorris and Hale, 2012) did not distinguish between potential contributions of dopamine and norepinephrine in their catecholamine account, it is possible that activity of both neurotransmitters may be enhanced during motivated cognitive control performance, given prior evidence that dopamine is critically implicated in reward processing and that norepinephrine activity has been associated with motor actions such as those typically executed during the study of controlled performance. We thus suggest that both of the possibilities proposed by McMorris and Hale in the context of exercise-related changes in cognition, could serve as candidate pathways by which reward might enhance speeding to a greater extent than accuracy in the cognitive control studies included in the current meta-analysis. Additional research will be required to gain a comprehensive understanding of the biological mechanisms underlying these behavioral effects.

As a final consideration of our examination of reward effects on accuracy and RT, we note that we examined these as separate outcomes in our meta-analysis. This approach was motivated by our interest in comparing reward effects across outcomes and our prediction that reward might specifically enhance response speed (reflecting dopaminergic modulation of motoric vigor). However, we recognize that with this approach, we examined reward effects on each dimension of performance (accuracy or RT) without accounting for the other dimension. Future meta-analyses could integrate accuracy and RT outcomes using composite metrics (such as inverse efficiency scores or balanced integration scores; Liesefeld and Janczyk, 2019) or utilize multivariate meta-analysis (Becker, 2000) to characterize reward effects on performance success across dimensions of both accuracy and speed.

26. Examining reward effects on memory encoding and the role of moderators

The meta-analysis examining reward anticipation on memory accuracy outcomes was conducted with 58 studies (from 43 publications) and revealed a medium effect, Cohen’s d = 0.537. While there was between-study variance, a large portion of this reflected the true effect size rather than sampling error. To examine sources of the variability, we assessed the influence of multiple moderators related to experimental differences in task design in modulating the effect of reward on memory encoding outcomes. We were interested in three key categories of moderators: differences associated with reward motivation, differences associated with aspects of the memory task at both encoding and retrieval stages, and differences relating to the temporal variability of trial events. We will discuss these moderators in this respective order below.

First, we were interested in comparing the effects of different types of reward. We intended to examine effects of primary versus secondary rewards, but no memory studies included in the meta-analysis utilized primary rewards. When comparing different types of secondary rewards, we found that points led to larger effects of reward on memory than monetary reward. We further observed that the relative reward amount difference between the high and low/no reward values for either points or monetary rewards did not significantly moderate the effect. The finding that points were associated with larger reward effect sizes on

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[5] This omits three studies that reported effect sizes for inverse efficiency scores, which are a composite measure of accuracy and RT. Because effect sizes for raw accuracy and RT outcomes were not available for these studies, we elected to include the same inverse efficiency score effect size for both accuracy and RT meta-analyses, but omitted them from this correlation, given its goal of examining similarities vs. differences in reward effects on accuracy and RT.

memory encoding is interesting but also unexpected, as many of the included studies using points did not offer a bonus based on the number of points accumulated for accurate memory performance. In contrast, in most of the included studies using monetary rewards, participants earned a bonus beyond compensation for participation, making rewards in such studies theoretically more salient and meaningful (see Table 3). Despite this difference, points appeared to be a stronger incentive than monetary rewards in this type of paradigm, although performance bonus was not assessed as a moderator. Related to this, comparing money and course credit as compensation for study participation did not reveal significant moderation of the effect. This was also surprising, given prior empirical work that specifically probed this question, reporting that reward effects on memory emerged when participants were offered a monetary bonus for memory performance coupled with monetary payment for participation, but not when the monetary bonus was coupled with course credit as compensation for participation (Bowen and Kensinger, 2017). Only a small number of studies (k = 5) employed a punishment for incorrect responses at encoding, and this did not emerge as a significant moderator. In studies employing a recognition memory test, we also examined whether use of a false alarm penalty at retrieval served as a moderator. Such penalties are employed to reduce liberal response bias and prevent participants from exclusively responding “old” to each stimulus, as doing so in the absence of penalties for false alarms would result in earning all possible rewards. Employing a false alarm penalty was a significant moderator and was associated with a larger effect of reward anticipation on memory than that observed in studies that did not include such a penalty. It may be the case that in studies employing such penalties, participants are much more cautious in making “old” judgments, and thus only make an “old” response to items when they are highly confident in their decision. This could result in a stronger effect of reward on memory performance than when no false alarm penalty is present and participants are less concerned about incorrect responding.

We predicted that reward contingency would be a significant moderator of motivational influences on memory performance. In the memory studies included in this meta-analysis, reward-contingent studies heavily overlapped with studies that used an intentional encoding paradigm; thus, conducting these as separate moderator analyses was somewhat redundant and yielded consistent patterns of results. Rewards had a larger effect on memory when they were performance-contingent and when participants were aware at the time of encoding that their memory for presented stimuli would be tested. These findings seem intuitive, but for the most part, the underlying mechanisms have not been examined directly in prior studies. It is possible that contingent rewards and intentional encoding increase attentional control to memoranda, or encourage the use of more effective encoding strategies, relative to incidental rewards and encoding; such differences during encoding could account for the memory benefit observed here. It should be noted that a larger proportion of studies used reward-contingent (k = 49) and intentional encoding (k = 47) designs, in comparison to those using incidental reward (k = 11) and incidental memory encoding (k = 11). The field would benefit from more studies that use incidental conditions.

In studies of motivated memory, a variety of memoranda have been used, including word and picture stimuli, which might vary in memorability (Oates and Reder, 2011). We observed stimulus type to be a significant moderator of reward anticipation effects on memory accuracy. Studies using word stimuli, compared to images, were associated with larger benefits of rewards on memory performance. Reward effects on studies using a mixture of stimulus types did not significantly differ from reward effects on studies using image stimuli or word stimuli alone, but included studies using a mixture of stimuli were relatively few in number (k = 5) and may not serve as a reliable comparison category. Reward anticipation may influence memory encoding differently for words and images because of systematic task design differences in studies that employ these stimuli. Further, studies using word stimuli and recall tests often use study-test blocks where stimulus encoding is immediately followed by a memory test. When testing for retention interval as a possible moderator, we indeed found that studies that used an immediate or same-day retrieval test had larger reward effect sizes, compared to those that included an overnight retention interval. The finding that rewards have a bigger effect on same-day versus next-day memory is surprising, given that next-day memory tests allow consolidation processes to unfold, and empirical work examining motivated memory with same-day versus subsequent-day retrieval has suggested enhanced reward effects at overnight intervals or longer (Murayama and Kitagami, 2014; Spaniol et al., 2014). We also observed that the type of memory retrieval task was a significant moderator, with studies using recall tasks showing larger effect sizes than studies using recognition and paired-associates tasks (the effect sizes of which did not significantly differ from one another). A second possibility that could potentially account for moderation of reward effects on memory encoding by words versus images is that these two types of stimuli might elicit different types of encoding strategies. Specifically, processing word versus image stimuli during a motivated memory paradigm might elicit more semantic processing that is cognitively effortful in nature. Such a strategy difference might engage different brain regions and lead to dopaminergic modulation of the hippocampus in different ways. Specifically, increased effort for semantic processing of word stimuli might be associated with more activity in frontal and temporal lobe regions linked to control and semantic processing functions, respectively. We speculate that in such a situation, prefrontal cortex regions supporting controlled processing might serve as the primary target of mesolimbic dopamine, as opposed to the hippocampus serving as a primary target of dopamine, whereby reward-related benefits to memory might be relatively automatic. An empirical investigation characterizing brain activity during a rewarded memory task using word stimuli reported reward-enhanced fronto-temporal engagement, which was argued to indicate semantic processing supporting the selective encoding of high-value words (Cohen et al., 2014). Future work testing for potential differences in encoding strategies and associated brain activity during motivated memory encoding of different kinds of stimuli could help clarify the extent to which differing pathways are potentially relied upon across encoding contexts.

In our moderator analyses, use of points rewards, recall tasks, and word memoranda were all associated with larger effects of reward on memory than their respective comparison conditions, so it was important to verify that these findings were not the product of the same set of studies being analyzed repeatedly. Specifically, we ensured that the studies using points rewards were not exclusively the same studies using recall tasks and word stimuli. While all recall tasks used word stimuli, 9 out of 25 memory studies in our meta-analysis using word stimuli employed recall tests, six of the studies using recall tests employed point incentives and four employed monetary incentives. Further, studies that used recognition tests at retrieval varied in their use of word and image stimuli as well as in their use of points and monetary incentives. See Table 3 for this information. While this examination verified that these aspects of task design were not always confounded, certain aspects of experimental design can co-occur somewhat idiosyncratically (i.e., when research groups tend to use a similar combination of design elements in successive studies). Given this tendency, effects of individual moderators in the present meta-analysis should be interpreted with caution.

Of particular interest was whether the temporal variability of trial events would moderate reward effects on memory encoding. Investigation of event timing was motivated by past evidence that neural responses to reward anticipation cues unfold over time and that such timing may have consequences for encoding of subsequent memoranda (Stanek et al., 2019). We examined duration of reward cue, duration of cue-target interval, and duration of target stimulus, but none of these significantly moderated the effect of reward anticipation on memory. We discuss these null effects in more depth following discussion of

Table 3

Moderator Variables used in Memory Studies Included in the Analysis.

First author and publication year	Exp.	Cohen's d	SE	Secondary Reward Type	Reward Difference	False Alarm Penalty	Compensation	Reward Contingent	Punishment at Encoding	Memory Type	Memoranda	Memory Task	Reward Cue length (ms)	Target length (ms)	Cue-Target length (ms)	Retention interval
Adcock et al., 2006	–	0.618	0.244	money	$4.90	yes	money	contingent	no	Intentional	images	Recognition	1000	2000	4500	next day
Anderson, 2016	3.1	0.086	0.101	money	$0.10	no	–	contingent	no	Intentional	images	Recognition	3000	3000	0	immediate
Anquillare and Selmeczy, 2023	–	0.198	0.083	points	9.5	Yes	credit	contingent	no	intentional	images	Recognition	1000	1000	0	immediate
Bennion et al., 2016	–	0.401	0.095	both	–	no	–	contingent	no	Both	images	Recognition	1000	4000	0	later same day
Bialleck et al., 2011	–	0.497	0.212	money	€0.39	no	money	non-contingent	no	Incidental	images	Recognition	1500	2500	8200	immediate
Bowen and Kensinger, 2017	1	0.488	0.124	money	$0.24	yes	–	contingent	no	Intentional	images	Recognition	–	–	–	later same day
	2	0.212	0.163	points	4	yes	credit	contingent	no	Intentional	images	Recognition	–	–	–	later same day
Bowen et al., 2020	–	0.469	0.204	money	$4.99	yes	money	contingent	no	Intentional	images	Recognition	1000	2000	500	next day
Bowen et al., 2023	–	0.174	0.099	money	$0.74	yes	money	contingent	no	Intentional	images	Recognition	1500	1500	0	immediate
Bunzeck et al., 2010	2	0.895	0.229	money	–	no	money	non-contingent	no	Incidental	images	Recognition	500	1000	4750	next day
Callan and Schweighofer, 2008	–	0.137	0.201	money	–	–	money	contingent	yes	Intentional	words	Recall	6000	6000	0	immediate
Cohen, 2015	2	2.142	0.314	points	9	–	money	contingent	no	Intentional	words	Recall	2000	3500	4875	immediate
	4.2	1.063	0.148	points	9	–	money	contingent	no	Intentional	words	Recall	1000	2500	500	immediate
=	4.3	0.516	0.122	points	9	yes	money	contingent	no	Intentional	words	Recognition	1000	2500	500	–
	4.4	1.656	0.149	points	9	–	money	contingent	no	Intentional	words	Recall	1000	2500	500	immediate
	4.5	1.598	0.169	points	9	–	money	contingent	no	Intentional	words	Recall	1000	2500	500	immediate
	4.6	0.293	0.099	points	9	yes	money	contingent	no	Intentional	words	Recognition	1000	2500	500	–
da Silva Castanheira et al., 2022	–	0.078	0.117	money	$0.24	no	–	contingent	no	Intentional	words	Recognition	–	---	–	–
Ding et al., 2022	–	0.444	0.156	money	0.20 CNY	yes	money	contingent	no	Intentional	images	Recognition	1000	1000	1000	immediate
Elliott and Brewer, 2019	1	0.9	0.145	points	6	yes	credit	contingent	no	Intentional	words	Recognition	2000	2000	0	immediate
	2	0.569	0.132	points	6	yes	credit	contingent	no	Intentional	words	Recognition	2000	2000	0	immediate
	3	0.775	0.14	points	6	yes	credit	contingent	no	Intentional	words	Recognition	2000	2000	0	immediate
Elliott et al., 2020	–	0.769	0.167	points	6	yes	credit	contingent	no	Intentional	words	Recognition	2000	2000	0	immediate
Eysenck and Eysenck, 1980	–	1.135	0.256	money	8 pence	–	–	contingent	no	Intentional	words	Recall	–	4000	0	immediate
Eysenck and Eysenck, 1982	1	0.873	0.204	money	8 pence	–	–	contingent	no	Intentional	words	Recall	–	5000	0	immediate
	2	0.791	0.246	money	8 pence	–	–	contingent	no	Intentional	words	Recall	–	5000	0	immediate
Feld et al., 2014	–	0.826	0.259	money	€0.98	yes	–	contingent	no	Intentional	images	Recognition	2000	1125	2250	next day
Gholston et al., 2023	1	0.171	0.158	money	–	no	money	contingent	no	Intentional	images	Recognition	1000	1000	2500	next day
	2 A	0.055	0.143	money	–	no	money	contingent	no	Intentional	images	Recognition	1000	1000	2500	next day
	2B	−0.033	0.158	money	–	no	money	contingent	no	Intentional	images	Recognition	1000	1000	2500	next day
	3	0.232	0.143	money	–	no	money	contingent	no	Intentional	images	Recognition	1000	1000	2500	next day

(*continued on next page*)

Table 3 (*continued*)

First author and publication year	Exp.	Cohen's d	SE	Secondary Reward Type	Reward Difference	False Alarm Penalty	Compensation	Reward Contingent	Punishment at Encoding	Memory Type	Memoranda	Memory Task	Reward Cue length (ms)	Target length (ms)	Cue-Target length (ms)	Retention interval
Gruber and Otten, 2010	–	1.257	0.212	money	£ 1.80	yes	money	contingent	no	Intentional	words	Recognition	1000	500	1000	immediate
Gruber et al., 2013	–	2.021	0.39	money	£ 1.80	yes	money	contingent	no	Intentional	words	Recognition	1000	500	1000	immediate
Halsband et al., 2012	1	0.624	0.194	money	€0.45	yes	money	contingent	no	Intentional	multiple	Recognition	300	1000	500	next day
Han et al., 2023	–	0.121	0.166	points	9	no	–	contingent	no	Intentional	words	Recognition	1500	5000	500	next day
Hennessee, 2018	1	0.07	0.135	points	9	yes	credit	contingent	no	Intentional	words	Recognition	3000	3000	0	immediate
Hennessee et al., 2019	2	0.66	0.096	points	9	yes	credit	contingent	no	Intentional	words	Recognition	2000	2000	0	immediate
Loh et al., 2016	–	0.536	0.166	money	50 pence	no	money	contingent	yes	Incidental	images	Recognition	4000	2000	2000	next day
Mason et al., 2017	–	0.496	0.131	money	–	no	money	non-contingent	no	Incidental	images	Recognition	1000	1000	1000	next day
Mather and Schoeke, 2011	–	0.066	0.121	money	$0.25	no	–	non-contingent	yes	Incidental	images	Recognition	2000	2000	3250	immediate
Murty and Adcock, 2017	–	0.577	0.187	money	–	–	money	contingent	no	Intentional	multiple	Paired-Associates	1000	4000	4000	next day
Oyarzún et al., 2016	1a	0.487	0.183	money	–	no	money	non-contingent	no	Incidental	images	Recognition	4500	4500	0	next day
	1b	0.226	0.131	money	–	no	money	non-contingent	no	Incidental	images	Recognition	4500	4500	0	immediate
Reggente, 2018	–	2.127	0.321	points	9	–	money	contingent	no	Intentional	words	Recall	2000	3500	4875	immediate
Richter et al., 2017	–	0.165	0.099	money	€0.98	no	money	non-contingent	no	Incidental	images	Recognition	1000	250	2000	next day
Spaniol et al., 2014	1	0.615	0.141	money	$0.99	yes	–	contingent	no	Intentional	images	Recognition	1000	2000	300	next day
	2	0.397	0.142	money	$0.99	yes	–	contingent	no	Intentional	images	Recognition	1000	2000	300	next day
Stanek et al., 2019	1	0.765	0.202	money	–	no	money	non-contingent	no	Incidental	images	Recognition	400	2000	0	next day
Studte et al., 2017	–	0.502	0.179	money	–	–	–	contingent	no	Intentional	words	Paired-Associates	1000	5000	500	later same day
Swirsky et al., 2020	–	0.541	0.117	points	9	no	money	non-contingent	no	–	images	Recognition	3000	2000	500	immediate
Tucker et al., 2011	1a	0.293	0.092	money	1	–	money	contingent	no	Intentional	multiple	Paired-Associates	–	–	–	later same day
	1b	0.148	0.089	money	1	–	money	contingent	no	Intentional	multiple	Paired-Associates	–	–	–	next day
Villaseñor et al., 2021	–	0.387	0.093	points	6	yes	money	contingent	no	Intentional	images	Recognition	1000	5000	250	immediate
Wittmann et al., 2008	–	0.22	0.157	money	€0.24	no	money	non-contingent	yes	Incidental	images	Recognition	350	1000	0	next day
Wittmann et al., 2013	–	0.408	0.165	money	€0.98	no	–	non-contingent	yes	Incidental	images	Recognition	1500	100	1600	next day
Wolosin et al., 2012	–	0.431	0.153	money	$1.90	–	money	contingent	no	Intentional	images	Paired-Associates	1500	4000	2000	immediate
Wolosin et al., 2013	–	0.676	0.175	money	$1.90	–	money	contingent	no	Intentional	images	Paired-Associates	2000	3000	4500	immediate
Yan et al., 2022	–	1.087	0.178	money	$0.02	no	credit	contingent	no	Intentional	multi	Recognition	1000	1000	900	immediate

Note. Exp = experiment number; SE = standard error; Reward Difference = the difference in amounts between the high and low/no reward condition (money and points); Compensation = participant compensation was coded as either with money or credit (in the case of an undergraduate participant pool course credit); – = not applicable, not reported, or could not be determined from the study description.

temporal variability of trial events in the context of our cognitive control outcomes below.

Finally, we examined country of origin, year of publication, and the percentage of female participants as potential moderators, which are reported in the Supplemental Material. Of the examined outcomes, the effect size for memory encoding was not moderated by these variables.

27. Examining reward effects on cognitive control and the role of moderators

The meta-analysis examining reward anticipation on cognitive control accuracy outcomes was conducted with 70 studies (53 publications), and the meta-analysis examining reward anticipation on cognitive control RT outcomes was conducted with 56 studies (74 publications). These meta-analyses revealed a small effect of reward on accuracy, Cohen's d = 0.286, and a large effect of reward on RT, Cohen's d = 0.807. When examining both outcomes, we observed between-study variance, but a large portion of this variance reflected the true effect size rather than sampling error (>92% for both accuracy and RT). To investigate sources of this variability, we assessed the influence of multiple moderators related to experimental differences in task design. Consistent with our approach to testing for potential moderators of reward effects on memory, we were interested in three key categories of moderators – differences associated with reward motivation, differences associated with aspects of the cognitive control task, and differences relating to the temporal variability of trial events. These potential moderators are discussed below in this respective order (also Table 4).

As in our memory analyses, we were interested in comparing the effects of different types of reward. We intended to examine primary versus secondary rewards in terms of their effects on cognitive control, but could only do this for the RT dimension, as we did not have a sufficient number of studies with primary reward effect sizes reported for the accuracy dimension (k = 2). For cognitive control RT, we observed that primary versus secondary reward type was a significant moderator, with a larger effect of reward on RT when primary rewards were used. While this finding should be considered tentative given the limited number of included studies using primary rewards (k = 3), this suggests the intriguing possibility that primary versus secondary rewards might lead to larger effects on cognitive control. Secondary rewards such as monetary incentives have been used much more frequently than primary rewards in studies of cognitive control, but neuroimaging evidence suggests that primary versus secondary reward processing can elicit both overlapping and distinct patterns of brain activity (Beck et al., 2010; Delgado et al., 2011; Yee et al., 2021). Theoretical accounts (Krug and Braver, 2014) have argued that primary rewards might, by definition, produce motivational effects that are more hard-wired and context-independent, as well as more precise in their timing, given that they are directly and immediately experienced. Despite these posited advantages, the present study provides the first meta-analytic evidence, to our knowledge, that anticipation of primary rewards may enhance response speed during cognitive performance to a greater extent than anticipation of secondary rewards. This observation remains tentative, given the small number of studies employing primary rewards in our meta-analysis and in the human cognitive literature more broadly, but provides an intriguing finding for future research to investigate further.

We also examined whether the kind of secondary reward (monetary versus points) would significantly moderate its effect on cognitive control outcomes. We did not observe that monetary versus points rewards significantly moderated cognitive control accuracy but not RT. This significant effect is in the opposite direction of our memory accuracy meta-analysis, which revealed that points were associated with a larger reward effect than monetary rewards. For cognitive control accuracy, points led to a smaller reward effect than monetary rewards. Importantly, we had a relatively small number of cognitive control studies using points versus monetary rewards (cognitive control accuracy: k = 16 points vs. k = 50 monetary; cognitive control RT: k = 18 points vs. k = 50 monetary), relative to the comparison we were able to make for memory encoding accuracy described above (k = 19 points vs. k = 40 monetary), so this difference across domains should be considered.

We next examined whether, for studies utilizing secondary rewards in explicit quantities, the relative difference in reward/point amount between the high and low/no-reward condition moderated the size of the reward effect on cognitive control. We did not observe significant moderation of cognitive control accuracy by relative differences when using either monetary or point rewards. However, cognitive control RT was significantly moderated by relative differences in monetary rewards, with no such effect observed for point rewards; this moderation effect was negative, such that larger monetary reward differences were associated with smaller changes in response speed. This finding should be taken with caution, given that the majority of studies included in our meta-analysis used relatively small reward differences; however, we might speculate on potential drivers of this surprising effect. Some cognitive control studies have been suggestive of the phenomenon of "choking under pressure" (Mobbs et al., 2009); that is, reduced benefits to performance under high-stakes reward; a reduced benefit of rewards with increasing magnitude differences could arguably be consistent with this phenomenon. Additionally, people arguably have more experience with monetary, versus point, values in their daily lives – as such, they may be more fluent in considering relative value differences between monetary amounts versus point manipulations and using such differences to adaptively guide cognition. Finally, we were interested in testing for effect of compensation type (i.e., money versus course credit) as a potential moderator of reward effects on cognitive control, given evidence suggesting that differing forms of compensation might be associated with differences in reward-motivated memory (Bowen and Kensinger, 2017), but we were not able to test for this moderator in the cognitive control domain given so few studies specified course credit as compensation, as well as insufficient detail on how compensation was provided or the use of multiple forms of compensation in the included studies.

We had originally proposed to examine whether reward contingency was a significant moderator of cognitive control performance, but did not have sufficient numbers of cognitive control studies with non-contingent reward (k = 2 for both cognitive control accuracy and RT). This stands in contrast to our meta-analysis examining reward anticipation on memory encoding, where a larger number of studies employing incidental rewards were included and reward contingency was found to be a significant moderator, with larger effect sizes in studies using contingent versus non-contingent rewards. We were somewhat surprised at the very small number of identified cognitive control studies employing incidental rewards, especially given prior studies suggesting that incidental, non-contingent rewards might decrease cognitive control (van Steenbergen et al., 2009), contrasting with findings that contingent rewards typically increase cognitive control (Botvinick and Braver, 2015; Braem et al., 2012). It has been suggested that incidental rewards might reduce cognitive control by enhancing positive affect but not motivational drive (Chiew and Braver, 2011; Goschke and Bolte, 2014). However, such affective influences tend to be subtle, with small and inconsistent effects on cognitive control performance (Chiew, 2021). Such subtlety may have led to a focus on contingent over incidental rewards in cognitive control research, given that such manipulations may be easier to operationalize and their effects may be larger in magnitude. However, given documented differences in the effects of contingent versus incidental rewards on controlled performance as noted above, it will be important for future research to investigate this further, making meta-analytic comparisons possible. These findings suggesting that non-contingent reward might decrease cognitive control also provide potential insight into the nature of the significant reward contingency moderator in memory accuracy. As noted above, it is possible that contingent rewards increase attentional control during memory encoding while incidental rewards do not, and

Table 4

Moderator Variables used in Cognitive Control Studies Included in the Analysis.

First Author and Publication Year	Exp.	Outcome	Cohen's d	SE	Reward Type	Secondary Reward Type	Reward Difference	Reward Contingent	Punishment for Errors	Task Type	RT Deadline	Reward Cue length (ms)	Target Length (ms)	Cue-Target Length (ms)
Aarts et al., 2010	–	ACC	0.44	0.186	Secondary	money	€0.09	Contingent	no	Switch	fast & accurate	600	–	8000
		RT	0.668	0.197										
Arnau et al., 2024	–	ACC	0.327	0.156	Secondary	points	9	Contingent	No	Switch	fast & accurate	800	Up to 1200	800
		RT	0.887	0.179										
Asci et al., 2019	–	ACC	0.864	0.185	Secondary	money	€0.05	Contingent	no	Go/No-Go	accurate	–	1000	0
		RT	1.578	0.237										
Bahlmann et al., 2015	–	ACC	0.88	0.204	Secondary	money	€0.14	Contingent	no	Switch	accurate	–	–	–
	–	RT	0.77	0.197										
Beck et al., 2010	–	RT	1.17	0.184	Both	–	–	Contingent	no	Switch	fast & accurate	1000	–	7000
Bräutigam et al., 2024	1	ACC	0.271	0.130	Secondary	points	10	Contingent	no	Simon	fast & accurate	800	Up to 3000	400
		RT	0.708	0.142										
	1	ACC	0.291	0.130	Secondary	Points	10	Contingent	no	Stroop	fast & accurate	800	Up to 3000	400
		RT	0.892	0.151										
	2	ACC	0.321	0.103	Secondary	points	10	Contingent	no	Simon	fast & accurate	800	Up to 3000	400
		RT	0.697	0.112										
	2	ACC	0.390	0.105	Secondary	points	10	Contingent	no	Stroop	fast & accurate	800	Up to 3000	400
First Author and Publication Year	Exp.	Outcome	Cohen's d	SE	Reward Type	Secondary Reward Type	Reward Difference	Reward Contingent	Punishment for Errors	Task Type	RT Deadline	Reward Cue length (ms)	Target Length (ms)	Cue-Target Length (ms)
		RT	0.801	0.116										
Bundt et al., 2021	–	ACC	0.699	0.140	Secondary	points	1	Contingent	no	Stroop	fast & accurate	300	Up to 1000	700
		RT	0.824	0.145										
Capa et al., 2011	–	ACC	0.785	0.127	Secondary	money	€0.91	Contingent	no	WM	accurate	162	7000	300
		RT	0.413	0.152										
Capa and Bouquet, 2018	–	ACC	1.053	0.167	Secondary	money	€0.91	Contingent	no	WM	accurate	1634	7000	264
Chaillou et al., 2017	–	RT	0.45	0.169	Secondary	money	–	Contingent	no	AX-CPT	fast & accurate	500	300	2900
Chiew and Braver, 2013	–	ACC	0.42	0.141	Secondary	money	–	Contingent	no	AX-CPT	fast & accurate	400	–	1800
		RT	1.49	0.196										
Chiew and Braver, 2014	–	ACC	0.431	0.084	Secondary	money	–	Contingent	no	AX-CPT	fast & accurate	1000	1000	1800
		RT	0.969	0.094										
Chiew and Braver, 2016	1	ACC	0.366	0.163	Primary	–	–	Contingent	no	Flanker	fast & accurate	800	200	0
		RT	2.185	0.291										
	2	ACC	0.283	0.161	Primary	–	–	Contingent	no	Flanker	fast & accurate	300	200	850
		RT	1.776	0.254										
Crawford et al., 2020	1	ACC	0.248	0.144	Secondary	money	–	Contingent	no	Switch	fast & accurate	500	2000	1850
First Author and Publication Year	Exp.	Outcome	Cohen's d	SE	Reward Type	Secondary Reward Type	Reward Difference	Reward Contingent	Punishment for Errors	Task Type	RT Deadline	Reward Cue length (ms)	Target Length (ms)	Cue-Target Length (ms)
		RT	0.980	0.172										

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Table 4 (*continued*)

First Author and Publication Year	Exp.	Outcome	Cohen's d	SE	Reward Type	Secondary Reward Type	Reward Difference	Reward Contingent	Punishment for Errors	Task Type	RT Deadline	Reward Cue length (ms)	Target Length (ms)	Cue-Target Length (ms)
	2	ACC	0.546	0.108	Secondary	money	–	Contingent	no	Switch	fast & accurate	500	2000	1850
		RT	0.112	0.101										
Cubillo et al., 2019	–	ACC	0.945	0.170	Secondary	points	–	Contingent	yes	Switch	–	750	1200	–
		RT	0.945	0.170										
Diao et al., 2014	–	ACC	0.818	0.153	Secondary	money	13 CNY	Contingent	no	Go/No-Go	accurate	159	125	2300
		RT	0.739	0.150										
Diao et al., 2016	–	ACC	1.32	0.250	Secondary	money	13 CNY	Contingent	no	Go/No-Go	accurate	1000	125	1000
		RT	0.51	0.194										
Fröber and Dreisbach, 2014	–	ACC	0.292	0.089	Secondary	money	€0.05	Both	no	AX-CPT	–	400	–	1700
		RT	0.239	0.088										
Fröber and Dreisbach, 2016	1	ACC	0.271	0.101	Secondary	money	€0.05	Both	no	AX-CPT	–	400	300	2100
		RT	0.398	0.103										
	2	ACC	0.066	0.126	Secondary	money	€0.05	Both	no	AX-CPT	–	400	300	2100
		RT	0.605	0.355										
Fröber et al., 2020	–	ACC	0.929	0.143	Secondary	Points	6	Contingent	no	Voluntary switch	fast & accurate	500	–	0
		RT	3.808	0.343										
Fröber et al., 2021	1	ACC	0.196	0.148	Secondary	Points	6	Contingent	no	Voluntary switch	fast & accurate	1000	–	0
First Author and Publication Year	Exp.	Outcome	Cohen's d	SE	Reward Type	Secondary Reward Type	Reward Difference	Reward Contingent	Punishment for Errors	Task Type	RT Deadline	Reward Cue length (ms)	Target Length (ms)	Cue-Target Length (ms)
		RT	0.972	0.178										
Fröber and Dreisbach, 2021	2	ACC	0.582	0.153	Secondary	points	6	Contingent	no	Switch	accurate	500	–	0
		RT	0.711	0.158										
Frömer et al., 2021	1	ACC	0.028	0.169	Secondary	money	$0.90	Both	no	Stroop	fast & accurate	1500	1000	0
		RT	0.735	0.190										
	2	ACC	0.005	0.117	Secondary	money	$0.90	Both	no	Stroop	fast & accurate	1500	1000	0
		RT	0.440	0.122										
Gilbert and Fiez, 2004	–	ACC	0.830	0.191	Secondary	money	$0.25	Contingent	no	WM	fast & accurate	6000	6000	18000
Giuffrida et al., 2023	–	RT	0.854	0.213	Secondary	points	25	Contingent	no	Stop Signal	fast & accurate	900–1200 (variable)	Up to 1500	0
Grogan et al., 2022	1	ACC	0.292	0.144	Secondary	money	49 pence	Contingent	no	WM	accurate	1200	500	0
		RT	0.629	0.155										
	2	ACC	0.276	0.135	Secondary	money	49 pence	Contingent	no	WM	accurate	1200	500	0
		RT	0.470	0.140										
	3	ACC	0.638	0.155	Secondary	money	49 pence	Contingent	no	WM	accurate	1200	500	0
		RT	0.638	0.155										
	4	ACC	0.397	0.147	Secondary	money	49 pence	Contingent	no	WM	accurate	1200	500	0
		RT	0.590	0.153										
First Author and Publication Year	Exp.	Outcome	Cohen's d	SE	Reward Type	Secondary Reward Type	Reward Difference	Reward Contingent	Punishment for Errors	Task Type	RT Deadline	Reward Cue length (ms)	Target Length (ms)	Cue-Target Length (ms)
Hippmann et al., 2019	1	ACC	0.474	0.170	Secondary	money	€0.06	Contingent	no	Switch	fast & accurate	1000	–	500
	1	RT	0.411	0.168										
	2	ACC	0.563	0.186	Secondary	money	€0.06	Contingent	no	Switch	fast & accurate	1000	–	500
		RT	0.578	0.187										

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Table 4 (*continued*)

First Author and Publication Year	Exp.	Outcome	Cohen's d	SE	Reward Type	Secondary Reward Type	Reward Difference	Reward Contingent	Punishment for Errors	Task Type	RT Deadline	Reward Cue length (ms)	Target Length (ms)	Cue-Target Length (ms)
Jiang and Xu, 2014	–	ACC	0.895	0.210	Secondary	points	10	Contingent	no	Switch	fast & accurate	–	600	–
		RT	0.933	0.213										
Jia et al., 2021	–	ACC	0	0.169	Secondary	money	–	Contingent	no	Stroop	fast & accurate	1000	500	600–1000
		RT	1.30	0.230										
Kang et al., 2019	–	RT	0.649	0.196	Secondary	money	–	Contingent	no	Stroop	fast & accurate	450	450	1350
Kleinsorge and Rinkenauer, 2012	1	RT	1.294	0.262	Secondary	money	€0.02	Contingent	no	Switch	fast & accurate	–	1000	–
Kostandyan et al., 2019	2	ACC	0	0.165	Secondary	money	–	Contingent	no	Flanker	fast & accurate	300	Up to 1000	1000–1300
		RT	0.880	0.195										
Kostandyan et al., 2020	–	ACC	0.735	0.175	Secondary	money	€0.07	Contingent	no	Stroop	fast & accurate	300	700	2000–7000
		RT	1.571	0.232										
Krebs et al., 2011	–	ACC	0.806	0.205	Secondary	money	€0.10	Contingent	yes	Stroop	fast & accurate	600	600	0
		RT	1.473	0.257										
Krebs et al., 2012	–	ACC	1.193	0.271	Secondary	money	€0.10	Contingent	yes	Discrimination	fast & accurate	800	100	2500
		RT	1.325	0.284										
First Author and Publication Year	Exp.	Outcome	Cohen's d	SE	Reward Type	Secondary Reward Type	Reward Difference	Reward Contingent	Punishment for Errors	Task Type	RT Deadline	Reward Cue length (ms)	Target Length (ms)	Cue-Target Length (ms)
Krebs et al., 2013	–	ACC	0.95	0.249	Secondary	money	€0.10	Contingent	yes	Stroop	fast & accurate	600	600	0
		RT	2.192	0.382	Secondary	money	–							
Le et al., 2020	–	ACC	1.397	0.128	Secondary	money	$0.95	Contingent	yes	Go/No-Go	fast & accurate	3000	–	0
		RT	1.753	0.145										
Liegel et al., 2024	–	ACC	0.166	0.138	Secondary	money	–	Contingent	no	Discrimination	fast & accurate	400	200	1600
Marini et al., 2015	1	ACC	0.031	0.194	Secondary	points	–	Contingent	no	Flanker	fast & accurate	500	200	1000
		RT	0.031	0.194										
	2	ACC	0.994	0.237	Secondary	points	–	Contingent	no	Flanker	fast & accurate	500	200	1000
		RT	0.994	0.237										
Padmala and Pessoa, 2011	–	ACC	0.782	0.125	Secondary	points	–	Contingent	no	Stroop	fast & accurate	750	1000	2000–6000
		RT	1.41	0.155										
Padmanabhan et al., 2011	–	RT	0.715	0.274	Secondary	money	–	Contingent	no	Anti-saccade	accurate	1500	1500	3000
Phaneuf-Hadd et al., 2025	–	ACC	0.278	0.123	Secondary	money	$0.90	Contingent	no	Switch	fast & accurate	2000	3000	1000
		RT	0.255	0.123										
Fahey et al., 2025	–	ACC	0.995	0.091	Secondary	points	9	Contingent	no	Stroop	accurate	1500	6000–9000	625
		RT	0.986	0.090										
Reyes et al., 2020	–	ACC	0.307	0.091	Secondary	Money	1000 pesos	Contingent	no	Antisaccade	accurate	2500	1000	0
First Author and Publication Year	Exp.	Outcome	Cohen's d	SE	Reward Type	Secondary Reward Type	Reward Difference	Reward Contingent	Punishment for Errors	Task Type	RT Deadline	Reward Cue length (ms)	Target Length (ms)	Cue-Target Length (ms)
		RT	0.221	0.090										
Savine et al., 2010	1	ACC	0.424	0.165	Secondary	money		Contingent	no	Switch	fast & accurate	1000	–	6000

(*continued on next page*)

Table 4 (*continued*)

First Author and Publication Year	Exp.	Outcome	Cohen's d	SE	Reward Type	Secondary Reward Type	Reward Difference	Reward Contingent	Punishment for Errors	Task Type	RT Deadline	Reward Cue length (ms)	Target Length (ms)	Cue-Target Length (ms)
	2	RT	1.148	0.204	Secondary	money		Contingent	no	Switch	fast & accurate	–	1250	–
	2	RT	1.054	0.179	Primary	-		Contingent	yes	WM	fast & accurate	1000	–	6000
Schevernels et al., 2014	–	ACC	0.80	0.190	Secondary	money	€0.04	Contingent	no	Discrimination	fast & accurate	400	100	1100–1600
		RT	1.02	0.204										
Seifert et al., 2006	–	ACC	0	0.106	Secondary	money	€0.20	Contingent	no	Flanker	fast & accurate	494	350	1294
		RT	1.24	0.142										
Sullivan et al., 2023	–	ACC	0.230	0.154	Secondary	Money	$0.10	Contingent	yes	Flanker	fast & accurate	200	1700	1550
		RT	0.214	0.154										
Taylor et al., 2004	2	ACC	0.79	0.281	Secondary	money		Contingent	yes	WM	accurate	–	2000	8000
	–	RT	0.648	0.257										
Thurm et al., 2018	–	RT	0.829	0.196	Secondary	points	10	Contingent	no	WM	accurate	1000	1800	300
van den Berg et al., 2014	–	ACC	0.151	0.147	Secondary	money	$0.10	Contingent	yes	Stroop	fast & accurate	400	900	–
		RT	0.16	0.147										
Veling and Aarts, 2010	–	ACC	0.347	0.133	Secondary	money	€0.49	Contingent	no	Stroop	fast & accurate	300	–	3550
		RT	0.381	0.134										
First Author and Publication Year	Exp.	Outcome	Cohen's d	SE	Reward Type	Secondary Reward Type	Reward Difference	Reward Contingent	Punishment for Errors	Task Type	RT Deadline	Reward Cue length (ms)	Target Length (ms)	Cue-Target Length (ms)
Wen et al., 2024	–	ACC	0.10	0.090	Secondary	money	0.5 CNY	Contingent	no	Discrimination	fast & accurate	1500	1000	0
		RT	0.39	0.093										
Williams et al., 2018	–	ACC	0.878	0.186	Secondary	money	$0.10	Contingent	yes	Flanker	fast & accurate	400	Up to 1600	600 or 900
		RT	1.586	0.238										
Wolff et al., 2016	1	RT	1.155	0.224	Secondary	money	€0.05	Contingent	no	Stroop	fast & accurate	1250	1250	0
	2	RT	1.561	0.252	Secondary	money	€0.05	Contingent	no	Stroop	fast & accurate	1250	1250	0
Yamaguchi and Nishimura, 2019	1	ACC	0.199	0.113	Secondary	points	1	Contingent	yes	Flanker	accurate	750	–	500
	1	RT	0.401	0.116										
	2	ACC	0.341	0.115	Secondary	points	1	Non-contingent	yes	Flanker	–	750	–	500
		RT	0.278	0.114										
	3	ACC	0.389	0.116	Secondary	points	1	Non-contingent	yes	Flanker	–	750	–	500
	3	RT	0.315	0.115										
Yee et al., 2016	1	ACC	0.565	0.134	Secondary	money	–	Contingent	no	Switch	fast & accurate	500	Up to 2000	1850
		RT	0.446	0.130										
	2	ACC	0.684	0.140	Secondary	money	–	Contingent	no	Switch	fast & accurate	500	Up to 2000	1850
		RT	0.806	0.145										
Yee et al., 2019	–	ACC	0.692	0.117	Secondary	Money	–	Contingent	No	Switch	fast & accurate	500	Up to 2000	1850
		RT	2.233	0.188										
First Author and Publication Year	Exp.	Outcome	Cohen's d	SE	Reward Type	Secondary Reward Type	Reward Difference	Reward Contingent	Punishment for Errors	Task Type	RT Deadline	Reward Cue length (ms)	Target Length (ms)	Cue-Target Length (ms)

(*continued on next page*)

Table 4 (*continued*)

First Author and Publication Year	Exp.	Outcome	Cohen's d	SE	Reward Type	Secondary Reward Type	Reward Difference	Reward Contingent	Punishment for Errors	Task Type	RT Deadline	Reward Cue length (ms)	Target Length (ms)	Cue-Target Length (ms)
Yee et al., 2021	–	ACC	0.217	0.116	Secondary	money	–	Contingent	no	Switch	fast & accurate	500	2000	4000
		RT	0.755	0.129										
Zedelius et al., 2011	–	ACC	0.559	0.081	Secondary	money	€0.49	Contingent	no	Auditory Simon Task	fast & accurate	17–300	250	1948.5
Zedelius et al., 2012	1	ACC	0.175	0.122	Secondary	money	€0.49	Contingent	no	WM	accurate	159	441.5	–
	2	ACC	0.26	0.139	Secondary	money	€0.49	Contingent	no	WM	accurate	159	441.5	–
Zedelius et al., 2012	1	ACC	0.121	0.163	Secondary	money	€0.49	Contingent	no	WM	accurate	17–300	400	441.5
	1	RT	0.367	0.084	Secondary	money	€0.49	Contingent	no	Auditory Simon Task	fast & accurate	159	250	1948.5

Note. Exp. = experiment number; SE = standard error; Reward Difference = the difference in amounts between the high and low/no reward condition (money and points); Compensation = participant compensation was coded as either with money or course credit (in the case of an undergraduate participant pool); – = not applicable, not reported, or could not be determined from the study description.

that such differences in control during encoding might account for the memory benefit observed with contingent versus non-contingent reward. Similarly, we tested whether punishment for errors significantly moderated cognitive control accuracy and RT, but did not find evidence of significant moderation for either outcome. These null effects were intriguing, given prior evidence suggesting that penalizing errors (versus emphasizing speed) has been associated with a decreased benefit of reward incentives to cognitive control performance (Dambacher et al., 2011), an effect interpreted as the result of error-related penalties introducing a competition between accuracy and speed requirements.

Next, we investigated whether task design-related differences across studies significantly moderated reward effects on cognitive control. First, we tested whether task type significantly moderated the effect of reward on either cognitive control accuracy or RT. We compared between several different cognitive control task types (AX-CPT, Flanker, Go/No-Go, Stroop, Switch, and Working Memory, and in one analysis the Discrimination and Simon Task) present in a sufficient number of studies to be compared using meta-analysis. The effect of reward anticipation on cognitive control accuracy and RT was highly task-dependent, rather than uniform across cognitive control domains. Some tasks were associated with substantial performance benefits under reward, others were associated with little effect, and some were even linked with performance costs. In the accuracy domain, task type was a significant moderator of reward effect, such that reward benefits to accuracy were observed in studies using Go/No-Go, Switch, and Working Memory tasks, but not in studies using AX-CPT or Discrimination tasks (where the reward effect did not significantly differ from zero). Of note, the meta-analytic reward effect size for Flanker accuracy was negative, indicating worse performance under high reward conditions. Effects on Stroop were unstable and only showed a slight reward benefit when one Stroop study was removed due to dependent samples. Task type was also a significant moderator of reward effects on cognitive control RT. Generally, the effects of reward on RT were more consistent across tasks, with reward leading to faster responses in studies that used an AX-CPT, Discrimination, Flanker, Go/No-Go, or Stroop task. The one exception to this pattern was Working Memory, which was not associated with a significant RT benefit from reward. For both accuracy and RT, the Go/No-Go task had the largest effect sizes (see Figs. 6 and 10); however, only four studies that employed this task. While these findings are tentative given the limited number of studies associated with some task types (AX-CPT $k = 5$; Discrimination $k = 4$, Go/No-Go $k = 4$; Simon $k = 3$), they suggest that reward might not significantly modulate accuracy in AX-CPT or Discrimination tasks (while increasing response speed, leading to a net performance benefit overall). Mechanisms that might lead to this moderation effect remain unclear, but one possibility is that accuracy in the AX-CPT and Discrimination tasks was already close to or at ceiling; thus, reward effects on performance primarily manifested in terms of changes in RT. A second possibility may be specific to the AX-CPT, given its sensitivity to separable proactive versus reactive cognitive control modes (Braver, 2012). Performance in differing task conditions in the AX-CPT improves or declines as a function of proactive and reactive cognitive control modes, allowing their characterization across contexts and individuals (Chiew and Braver, 2017). Specifically, increased proactive control leads to poorer performance in one AX-CPT condition (termed "AY trials") where cue-based expectancy must be overcome to successfully respond. Robust evidence suggests that reward incentives might specifically enhance proactive control, typically improving performance in all trial conditions except AY, where increases in error rates may be observed (Chiew and Braver, 2013; Fröber and Dreisbach, 2014). It is possible that this aspect of AX-CPT design might account for a reduced accuracy benefit with reward, compared to most other cognitive control tasks. Notably, the Flanker task was the only one where we had a decrease in accuracy with reward, which accompanied a speeding effect. While our overall effects do not indicate a speed-accuracy tradeoff with reward across our examined studies of cognitive control in general, we might speculate that certain characteristics of the Flanker paradigm may make it more sensitive to such effects. In the Flanker paradigm, the target stimulus and distracting information are shown simultaneously during response preparation (in contrast to some other paradigms such as the AX-CPT and Working Memory, which utilize a sequential series of events), which may make responses more prone to speed-accuracy tradeoff (Dambacher and Hübner, 2013). On the other hand, our meta-analysis also included paradigms such as the Stroop (which is also typically characterized by simultaneous presentation of both task-relevant and task-irrelevant dimensions at the time of response preparation), and our Stroop results were suggestive of a weak beneficial effect of reward to accuracy, rather than an impairment. Given this, it is difficult to definitively conclude why reward appeared to be associated with reduced accuracy in the Flanker, in contrast with all other studied task paradigms. Potential differences in control demands by task type, as well as the possibility of additional moderating variables accompanying differences in task type on a study-level basis, may be candidate factors to investigate further in addressing this issue.

We examined whether the duration of the reward cue, duration of the target, and length of the cue-target interval trial events significantly moderated reward effects on cognitive control. As in our memory meta-analysis, we did not observe evidence that the timing of any of these three types of trial events moderated reward effects on either cognitive control accuracy or RT. This nonsignificant result was somewhat surprising, given findings suggesting that reward anticipation cues require a sufficient preparatory (i.e., cue-target) interval to benefit cognitive control and do not improve control when this interval is too short (Chiew and Braver, 2016). As noted above, additional work in the memory domain suggests that cues signaling uncertain reward can enhance memory for target stimuli, but that such enhancement might critically depend on the time length of the cue-target interval (Stanek et al., 2019). While it has been suggested that reward-related dopaminergic activity can operate via temporally separable (i.e., phasic versus tonic) mechanisms with distinct functional consequences (Grace, 1991; Niv, 2007), the contexts under which different temporally-distinct mechanisms are elicited, with consequences for reward-motivated cognition, are not well understood or characterized. Indicating the potential importance of event timing for reward effects, Stanek et al. (Stanek et al., 2019) reported that cues signaling uncertain rewards specifically benefited memory encoding when a sustained (multi-second) cue-target interval separated reward cues and target memoranda, consistent with electrophysiological evidence that dopamine neurons show profiles of sustained, multi-second ramping in response to uncertain rewards (Fiorillo et al., 2003). However, this temporally-specific effect might be critically dependent on the *interaction* between reward value and reward uncertainty. It is currently an open question whether the timing of trial events during reward anticipation only modulates cognitive outcomes when constrained by contextual factors.

Finally, we tested country of origin, year of publication, and the percentage of female participants as potential moderators of the effect of reward on memory encoding and cognitive control. We did not have specific predictions about how these moderators would impact results, but there were some significant effects. The results and discussion of the findings are reported in the Supplemental Materials. Of note, to our knowledge, sex and gender differences are relatively under-characterized in motivated cognition and we discuss issues with the homogeneity of the samples included in this meta-analysis, and this literature more broadly, in more detail in the limitations section below.

28. Summary of significant moderators across memory and control domains

In this meta-analysis, we tested a large number of moderators related to differences in reward motivation as well as in design elements of the memory and cognitive control tasks. Not all of these moderators were significant, but we observed that several of them were associated with differences in reward anticipation effects. Further, a larger number of moderators influenced reward effects on memory accuracy, compared to cognitive control accuracy and RT. This might indicate that overall, reward effects on memory performance might be more sensitive to manipulations of reward and experimental design, compared to cognitive control outcomes. To summarize, reward effects on memory accuracy were moderated by 1) type of secondary reward (points > money); 2) inclusion of a false alarm penalty at retrieval in recognition memory studies (penalty > no-penalty); 3) reward-contingency and intentional encoding (contingent > non-contingent and intentional > incidental); 4) type of memoranda (words > images); 5) type of memory task (recall > recognition and paired associates). When examining reward effects on cognitive control, the only significant moderators that emerged for cognitive control accuracy were reward type (monetary > points) and the type of cognitive control task employed (Go/No-Go, Switch, Working Memory > AX-CPT, Discrimination, Stroop > Flanker). For cognitive control RT, the only significant moderators observed were reward type (primary > secondary), reward amount difference (smaller effect with greater difference, for monetary rewards only), and type of cognitive control task employed (Go/No-Go, Stroop, Switch, AX-CPT, Discrimination, Flanker > Working Memory). As noted, there were a limited number of studies that used primary rewards ($k = 3$), and some cognitive control task type (less than $k = 5$ in some conditions). Despite this, while our conclusions on task type are sensitive due to small numbers of studies per condition and a wide variety of tasks, it does suggest that reward effects on cognitive control might be meaningfully varied across task paradigms. Other meta-analyses like Swirsky et al. (Swirsky et al., 2023) did not separate out by task type, so this might be an important source of variability that needs to be investigated further.

29. Limitations

A number of limitations should be accounted for when considering the implications of our meta-analytic findings. First, many of the individual studies included in the present meta-analysis use relatively small convenience samples (average sample size ~35 participants per study, in both the cognitive control and memory domains), that are limited in their statistical power and potential population representation. Further, the percentage of female participants included in the samples was a significant moderator of the effect on cognitive control accuracy (but not cognitive control RT or memory). There may be interesting and important sex or gender differences in reward sensitivity, or reward-cognition interactions, that have not yet been empirically assessed. Additionally, the majority of studies included in the meta-analysis were conducted in “WEIRD” (White, Educated, Industrialized, Rich, Democratic) countries. Few studies reported race and ethnicity information for participants; thus, it was not possible to evaluate study samples in terms of their racial or ethnic diversity. These limitations may constrain the generalizability of observed results. Use of small samples with limited diversity and representation poses a widespread problem for generalizability in the psychology literature, more broadly (Rad et al., 2018; Thomas et al., 2023), but it may be a particularly important issue in studies of motivated cognition. Monetary incentives are commonly used as manipulations, and recent evidence suggests that monetary incentives are more motivating in individuals from WEIRD versus non-WEIRD cultures (Medvedev et al., 2024). Most of the studies included in this meta-analysis were from countries considered “WEIRD”, and even given this limited scope, country of origin was a significant moderator of the effect size for reward influences on cognitive control accuracy. Additionally, we observed evidence of publication bias for all three studied outcomes in terms of larger effect sizes for studies with smaller samples. While both published and unpublished studies (such as dissertations) were eligible for our meta-analysis, this publication bias might reflect fewer studies with null findings being publicly available. It has been argued that null results, as well as studies with low power or poor methodology, are less likely to be published and this may skew meta-analytic effects towards positive results (Thornton and Lee, 2000). Open science practices such as increased support for replication studies and sharing of null results may help mitigate such publication biases in the scientific literature over time.

An additional limitation of the current meta-analytic work is the limited variability across studies for many of the moderators examined. Our results indicate that significant between-study heterogeneity was present in the reward effect on all three examined outcomes, suggesting the presence of important moderators that might influence effect size from one study to the next. This was corroborated by our analyses revealing several factors to be significant moderators for each outcome. However, for many categorical moderators, a relatively small number of studies were included for each compared condition. In some cases, we could not test for potential moderators proposed in our pre-registration because we did not have a minimum number of eligible studies ($k = 3$) in each condition to be compared. Further, when examining for potential effects of continuous moderators (i.e., reward amount difference), we observed a limited amount of variability across study designs. These analyses should thus be interpreted with caution.

A further limitation of the present study was our choice to limit our focus to studies that employed a MID-style, cue-probe paradigm to induce and investigate the effects of reward on cognitive performance. We elected to use this approach on the basis of robust evidence that has linked the MID paradigm with anticipatory activity in mesolimbic brain regions associated with reward processing, as well as its widespread use in the literature, in order to maintain a certain degree of cross-study consistency in the putative reward-related brain activity that the motivational manipulation was thought to induce and better isolate variability associated with other task parameters of interest. However, the MID paradigm is one of several experimental paradigms used to study reward motivation effects on cognition; other studies have used sustained, block-level reward contexts (e.g., Locke and Braver, 2008), receipt of reward feedback without use of anticipatory cues (e.g., Gupta et al., 2024), or tasks whereby one kind of stimulus or task rule is linked with reward while others are not (e.g., Held et al., 2024). Future meta-analyses could investigate a wider range of designs integrating reward and cognitive performance to test whether our observed results generalize more broadly.

When we examined reward effects on cognitive control, we conducted meta-analyses separately for accuracy and RT outcomes. While this approach was taken intentionally, it also differs from other meta-analyses investigating reward effects on cognitive performance that have combined effect sizes from accuracy and RT outcomes (e.g., Burton et al., 2021; Swirsky et al., 2023). We argue that our approach provides greater precision and yields interesting insights regarding the benefit of reward on cognitive performance in terms of accuracy versus speed dimensions, as described above, but want to note that this could limit comparisons with findings from prior meta-analyses examining motivated cognition that have combined effects on speed and accuracy. We also note that we examined reward effects on cognitive control in terms of global accuracy and speed instead of examining reward effects on interference costs (i.e., the difference in performance outcome between conditions higher versus lower in control demand, such as incongruent – congruent trials). Interference costs have been used to characterize cognitive control more specifically than global performance does (Kiesel et al., 2010; Sternberg, 1969; although see Hedge et al., 2022 for concerns regarding the use of interference costs for measuring cognitive control), in which case examining the effect of reward on interference costs (i.e., the Reward × Task Condition interaction term) might provide a more specific characterization of reward effects on control processes. Indeed, some prior work has suggested that in conflict-based paradigms, reward might benefit performance on incongruent trials more than on congruent trials, leading to the presence of significant Reward x Task Condition interactions (e.g., Chiew and Braver, 2016). This may be an important effect, beyond the main effect of reward on cognitive control task performance, for future meta-analytic efforts to examine more systematically.

30. Conclusion

The current study provides a meta-analytic review of empirical literature on the relation between reward anticipation and cognitive performance in the cognitive control and episodic memory domains. We observed evidence that the magnitude of the reward anticipation effect might differ across cognitive outcomes, with the largest effects on cognitive control response speed, the smallest effects on cognitive control accuracy, and effects on memory accuracy intermediate between the two. We further observed evidence for potential publication bias in the literature, with a tendency towards larger effect sizes for smaller samples, as well as significant between-study heterogeneity across all three outcomes, suggesting the presence of moderator variables. When testing for potential moderators, we observed that variations in reward manipulations as well as in aspects of task design were associated with changes in reward effect size, but variations in trial event timing were not. While a larger number of moderator variables were observed to be significant for memory accuracy than for either cognitive control accuracy or RT, significant moderators were observed across all three outcomes. This evidence indicates that reward effects on cognitive performance might be highly sensitive to contextual parameters and that study-level variability in experimental designs may account for significant variability in observed results. Given these observations, we argue that understanding and accounting for potential sources of contextual variability, along with individual- and group-level variability, will be necessary to advance a comprehensive account of motivated cognition and its effects on human behavior.

Author note

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This project was preregistered on the Open Science Framework (OSF) https://osf.io/vc2ht. The objectives, search criteria, and strategy for data extraction were pre-registered and developed prior to conducting the meta-analysis. Data were modeled using Comprehensive Meta-Analysis Version 4.0 (Biostat Inc; Borstein Hedges, Higgins, & Rothstein, 2022). All data and research materials including our coding scheme are available at the OSF project page.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.neubiorev.2026.106793.

References

Aarts, E., Roelofs, A., Franke, B., Rijpkema, M., Fernández, G., Helmich, R.C., Cools, R., 2010. Striatal dopamine mediates the interface between motivational and cognitive control in humans: evidence from genetic imaging. Neuropsychopharmacology 35 (9), 1943–1951.

Adcock, R.A., Thangavel, A., Whitfield-Gabrieli, S., Knutson, B., Gabrieli, J.D.E., 2006. Reward-motivated learning: mesolimbic activation precedes memory formation. Neuron 50 (3), 507–517. https://doi.org/10.1016/j.neuron.2006.03.036.

Anderson, M.L., 2016. *An Evaluation of the Influences of Extra-Hippocampal Processes on Pattern Separation.* Dissertation, Brigham Young University.

Anquillare, E., Selmeczy, D., 2023. Developmental differences in value-based remembering: The role of feedback and metacognition. Developmental Psychology 59 (7), 1181.

Arnau, S., Liegel, N., Wascher, E., 2024. Frontal midline theta power during the cue-target-interval reflects increased cognitive effort in rewarded task-switching. Cortex 180, 94–110.

Asci, O., Braem, S., Park, H.R.P., Boehler, C.N., Krebs, R.M., 2019. Neural correlates of reward-related response tendencies in an equiprobable Go/NoGo task. Cognitive, Affective, & Behavioral Neuroscience 19 (3), 555–567.

Badre, D., Wagner, A.D., 2007. Left ventrolateral prefrontal cortex and the cognitive control of memory. Neuropsychologia 45 (13), 2883–2901.

Bahlmann, J., Aarts, E., D'Esposito, M., 2015. Influence of motivation on control hierarchy in the human frontal cortex. J Neurosci 35 (7), 3207–3217.

Beck, S.M., Locke, H.S., Savine, A.C., Jimura, K., Braver, T.S., 2010. Primary and secondary rewards differentially modulate neural activity dynamics during working memory. PLoS. One 5 (2), e9251.

Becker, B.J., 2000. Multivariate meta-analysis. Handb. Appl. Multivar. Stat. Math. Model. 499–525.

Beierholm, U., Guitart-Masip, M., Economides, M., Chowdhury, R., Düzel, E., Dolan, R., Dayan, P., 2013. Dopamine modulates reward-related vigor. Neuropsychopharmacology 38 (8), 1495–1503.

Beilock, S.L., Carr, T.H., 2001. On the fragility of skilled performance: what governs choking under pressure? J. Exp. Psychol. General. 130 (4), 701–725. https://doi.org/10.1037/0096-3445.130.4.701.

Bennion, K.A., Payne, J.D., Kensinger, E.A., 2016. The impact of napping on memory for future-relevant stimuli: Prioritization among multiple salience cues. Behavioral Neuroscience 130 (3), 281.

Berridge, K.C., 2004. Motivation concepts in behavioral neuroscience. Physiol. Behav. 81 (2), 179–209.

Bialleck, K.A., Schaal, H.-P., Kranz, T.A., Fell, J., Elger, C.E., Axmacher, N., 2011. Ventromedial prefrontal cortex activation is associated with memory formation for predictable rewards. PLoS One 6 (2), e16695.

Borenstein, M., Hedges, L.V., Higgins, J.P.T., Rothstein, H.R., 2010. A basic introduction to fixed-effect and random-effects models for meta-analysis. Res. Synth. Methods 1 (2), 97–111.

Borenstein, M., Hedges, L., Higgins, J., Rothstein, H., 2022. Comprehensive Meta-Analysis (Version 4) [Computer software]. Biostat. https://www.meta-analysis.com/.

Botvinick, M., Braver, T., 2015. Motivation and cognitive control: from behavior to neural mechanism. Annu. Rev. Psychol. 66, 83–113. https://doi.org/10.1146/annurev-psych-010814-015044.

Bowen, H.J., 2020. Examining memory in the context of emotion and motivation. Curr. Behav. Neurosci. Rep. 7, 193–202.

Bowen, H.J., Hargis, M.B., Moon, D.H., Gallant, S.N., 2023. Reward motivation more consistently modulates memory for younger compared to older adults in a directed forgetting task. Psychology and Aging 38 (5), 468.

Bowen, H.J., Kensinger, E.A., 2017. Cash or credit? Compensation in psychology studies: Motivation matters. Collabra Psychol. 3 (1).

Bowen, H.J., Marchesi, M.L., Kensinger, E.A., 2020. Reward motivation influences response bias on a recognition memory task. Cognition 203, 104337.

Braem, S., Verguts, T., Roggeman, C., Notebaert, W., 2012. Reward modulates adaptations to conflict. Cognition 125 (2), 324–332.

Bräutigam, L.C., Leuthold, H., Mackenzie, I.G., Mittelstädt, V., 2024. Proactive reward in conflict tasks: Does it only enhance general performance or also modulate conflict effects? *Attention*. Percept. & Psychophys. 86 (6), 2153–2168.

Braver, T.S., 2012. The variable nature of cognitive control: a dual mechanisms framework. Trends Cogn. Sci. 16 (2), 106–113. https://doi.org/10.1016/j.tics.2011.12.010.

Braver, Todd S., Krug, M.K., Chiew, K.S., Kool, W., Westbrook, J.A., Clement, N.J., Carver, C.S., 2014. Mechanisms of motivation–cognition interaction: challenges and opportunities. Cogn. Affect. & Behav. Neurosci. 14 (2), 443–472.

Bundt, C., Boehler, C.N., Verbruggen, F., Brass, M., Notebaert, W., 2021. Reward does not modulate corticospinal excitability in anticipation of a Stroop trial. European Journal of Neuroscience 53 (4), 1019–1028.

Bunzeck, N., Dayan, P., Dolan, R.J., Duzel, E., 2010. A common mechanism for adaptive scaling of reward and novelty. Human. Brain Mapp. 31 (9), 1380–1394.

Burton, S., Knibb, G., Jones, A., 2021. A meta-analytic investigation of the role of reward on inhibitory control. Q. J. Exp. Psychol. 74 (10), 1818–1828.

Callan, D.E., Schweighofer, N., 2008. Positive and negative modulation of word learning by reward anticipation. Human Brain Mapping 29 (2), 237–249.

Capa, R.L., Bouquet, C.A., 2018. Individual differences in reward sensitivity modulate the distinctive effects of conscious and unconscious rewards on executive performance. Frontiers in Psychology 9, 148.

Capa, R.L., Bustin, G.M., Cleeremans, A., Hansenne, M., 2011. Conscious and unconscious reward cues can affect a critical component of executive control. Experimental Psychology.

Castel, A.D., Benjamin, A.S., Craik, F.I.M., Watkins, M.J., 2002. The effects of aging on selectivity and control in short-term recall. Mem. & Cogn. 30 (7), 1078–1085.

Chaillou, A.-C., Giersch, A., Hoonakker, M., Capa, R.L., Bonnefond, A., 2017. Differentiating motivational from affective influence of performance-contingent reward on cognitive control: the wanting component enhances both proactive and reactive control. Biological Psychology 125, 146–153.

Chee, M.W.L., Weekes, B., Lee, K.M., Soon, C.S., Schreiber, A., Hoon, J.J., Chee, M., 2000. Overlap and dissociation of semantic processing of Chinese characters, English words, and pictures: evidence from fMRI. Neuroimage 12 (4), 392–403.

Chiew, K.S., 2021. Revisiting positive affect and reward influences on cognitive control. Curr. Opin. Behav. Sci. 39, 27–33.

Chiew, K.S., Bowen, H.J., 2022. Neurobiological mechanisms of selectivity in motivated memory. In: Elliot, A. (Ed.), Advances in Motivation Science. Elsevier.

Chiew, K.S., Braver, T.S., 2011. Positive affect versus reward: emotional versus motivational influences on cognitive control. Front. Psychol. 2 (279). https://doi.org/10.3389/fpsyg.2011.00279.

Chiew, K.S., Braver, T.S., 2013. Temporal dynamics of motivation-cognitive control interactions revealed by high-resolution pupillometry. Front. Psychol. 4, 15.

Chiew, K.S., Braver, T.S., 2014. Dissociable influences of reward motivation and positive emotion on cognitive control. Cogn Affect Behav Neurosci 14 (2), 509–529.

Chiew, K.S., Braver, T.S., 2016. Reward favors the prepared: Incentive and task-informative cues interact to enhance attentional control. J. Exp. Psychol. Hum. Percept. Perform. 42 (1), 52–66. https://doi.org/10.1037/xhp0000129.

Chiew, K.S., Braver, T.S., 2017. Context processing and cognitive control: From gating models to dual mechanisms. Wiley Handb. Cogn. Control. 143–166.

Chiew, Kimberly S., Hashemi, J., Gans, L.K., Lerebours, L., Clement, N.J., Vu, M.-A.T., Adcock, R.A., 2018. Motivational valence alters memory formation without altering exploration of a real-life spatial environment. PloS. One.

Cohen, M.S., 2015. *Neural Mechanisms of Value-Directed Remembering In Young and Older Adults*. Dissertation, University of California, Los Angeles.

Cohen, M.S., Rissman, J., Suthana, N.A., Castel, A.D., Knowlton, B.J., 2014. Value-based modulation of memory encoding involves strategic engagement of fronto-temporal semantic processing regions. Cogn. Affect. & Behav. Neurosci. 14 (2), 578–592. https://doi.org/10.3758/s13415-014-0275-x.

Cohen, M.S., Rissman, J., Suthana, N.A., Castel, A.D., Knowlton, B.J., 2016. Effects of aging on value-directed modulation of semantic network activity during verbal learning. NeuroImage 125, 1046–1062.

Craig, M., Butterworth, K., Nilsson, J., Hamilton, C.J., Gallagher, P., Smulders, T.V., 2016. How does intentionality of encoding affect memory for episodic information? Learn. & Mem. 23 (11), 648–659.

Crawford, J.L., Yee, D.M., Hallenbeck, H.W., Naumann, A., Shapiro, K., Thompson, R.J., Braver, T.S., 2020. Dissociable effects of monetary, liquid, and social incentives on motivation and cognitive control. Front. Psychol. 11, 2212.

Cubillo, A., Makwana, A.B., Hare, T.A., 2019. Differential modulation of cognitive control networks by monetary reward and punishment. Social. Cogn. Affect. Neurosci. 14 (3), 305–317.

da Silva Castanheira, K., Lalla, A., Ocampo, K., Otto, A.R., Sheldon, S., 2022. Reward at encoding but not retrieval modulates memory for detailed events. Cognition 219, 104957.

Dambacher, M., Hubner, R., Schlosser, J., 2011. Monetary incentives in speeded perceptual decision: effects of penalizing errors versus slow responses. Front. Psychol. 2 (248). https://doi.org/10.3389/fpsyg.2011.00248.

Dambacher, Michael, Hübner, R., 2013. Investigating the speed–accuracy trade-off: Better use deadlines or response signals? Behav. Res. Methods 45 (3), 702–717.

Delgado, M., Jou, R., Phelps, E., 2011. Neural Systems Underlying Aversive Conditioning in Humans with Primary and Secondary Reinforcers. Front. Neurosci. 5, 71. https://doi.org/10.3389/fnins.2011.00071.

Devereux, B.J., Clarke, A., Marouchos, A., Tyler, L.K., 2013. Representational similarity analysis reveals commonalities and differences in the semantic processing of words and objects. J. Neurosci. 33 (48), 18906–18916.

Diao, L., Ding, C., Qi, S., Zeng, Q., Huang, B., Xu, M., Yang, D., 2014. Influence of supraliminal reward information on unconsciously triggered response inhibition. Plos One 9 (9), e108530.

Diao, L., Qi, S., Xu, M., Li, Z., Ding, C., Chen, A., Yang, D., 2016. Neural signature of reward-modulated unconscious inhibitory control. International Journal of Psychophysiology 107, 1–8.

Dickinson, A., Balleine, B., 1994. Motivational control of goal-directed action. Anim. Learn. & Behav. 22 (1), 1–18.

Ding, Q., Zhu, J., Yan, C., 2022. Encoding tasks moderated the reward effect on brain activity during memory retrieval. Scientific Reports 12 (1), 8246.

Dudukovic, N.M., Kuhl, B.A., 2017. Cognitive control in memory encoding and retrieval. Wiley Handb. Cogn. Control. 355–375.

Düzel, E., Bunzeck, N., Guitart-Masip, M., Düzel, S., 2010. NOvelty-related Motivation of Anticipation and exploration by Dopamine (NOMAD): Implications for healthy aging. Neurosci. & Biobehav. Rev. 34 (5), 660–669. https://doi.org/10.1016/j.neubiorev.2009.08.006.

Elliott, B.L., Blais, C., McClure, S.M., Brewer, G.A., 2020. Neural correlates underlying the effect of reward value on recognition memory. NeuroImage 206, 116296.

Elliott, B.L., Brewer, G.A., 2019. Divided attention selectively impairs value-directed encoding. Collabra: Psychology 5 (1).

Eysenck, M.W., Eysenck, M.C., 1980. Effects of monetary incentives on rehearsal and on cued recall. Bulletin of the Psychonomic Society 15 (4), 245–247.

Eysenck, M.W., Eysenck, M.C., 1982. Effects of incentive on cued recall. The Quarterly Journal of Experimental Psychology Section A 34 (4), 489–498.

Fahey, M.P., Yee, D.M., Leng, X., Tarlow, M., Shenhav, A., 2025. Motivational context determines the impact of aversive outcomes on mental effort allocation. Cognition 254, 105973.

Feld, G.B., Besedovsky, L., Kaida, K., Münte, T.F., Born, J., 2014. Dopamine D2-like receptor activation wipes out preferential consolidation of high over low reward memories during human sleep. Journal of Cognitive Neuroscience 26 (10), 2310–2320.

Fiorillo, C.D., Tobler, P.N., Schultz, W., 2003. Discrete coding of reward probability and uncertainty by dopamine neurons. Science 299 (5614), 1898–1902. https://doi.org/10.1126/science.1077349.

Freitas, A.L., Bahar, M., Yang, S., Banai, R., 2007. Contextual adjustments in cognitive control across tasks. Psychol. Sci. 18 (12), 1040–1043.

Fröber, K., Dreisbach, G., 2014. The differential influences of positive affect, random reward, and performance-contingent reward on cognitive control. Cogn. Affect. Behav. Neurosci. 14 (2), 530–547. https://doi.org/10.3758/s13415-014-0259-x.

Fröber, K., Dreisbach, G., 2016. How performance (non-) contingent reward modulates cognitive control. Acta Psychologica 168, 65–77.

Fröber, K., Dreisbach, G., 2021. How sequentially changing reward prospect modulates meta-control: Increasing reward prospect promotes cognitive flexibility. Cognitive, Affective, & Behavioral Neuroscience 21 (3), 534–548.

Fröber, K., Jurczyk, V., Mendl, J., Dreisbach, G., 2021. Investigating anticipatory processes during sequentially changing reward prospect: An ERP study. Brain and Cognition 155, 105815.

Fröber, K., Pittino, F., Dreisbach, G., 2020. How sequential changes in reward expectation modulate cognitive control: Pupillometry as a tool to monitor dynamic changes in reward expectation. International Journal of Psychophysiology 148, 35–49.

Frömer, R., Lin, H., Dean Wolf, Inzlicht, M., Shenhav, A., 2021. Expectations of reward and efficacy guide cognitive control allocation. Nature communications 12 (1), 1030.

Gholston, A.S., Thurmann, K.E., Chiew, K.S., 2023. Contributions of transient and sustained reward to memory formation. Psychol. Res. 87 (8), 2477–2498.

Gilbert, A.M., Fiez, J.A., 2004. Integrating rewards and cognition in the frontal cortex. Cognitive, Affective, & Behavioral Neuroscience 4 (4), 540–552.

Gimbel, S.I., Brewer, J.B., 2011. Reaction time, memory strength, and fMRI activity during memory retrieval: Hippocampus and default network are differentially responsive during recollection and familiarity judgments. Cogn. Neurosci. 2 (1), 19–26.

Giuffrida, V., Marc, I.B., Ramawat, S., Fontana, R., Fiori, L., Bardella, G., Pani, P., 2023. Reward prospect affects strategic adjustments in stop signal task. Frontiers in Psychology 14, 1125066.

Goschke, T., Bolte, A., 2014. Emotional modulation of control dilemmas: the role of positive affect, reward, and dopamine in cognitive stability and flexibility. Neuropsychologia 62, 403–423. https://doi.org/10.1016/j.neuropsychologia.2014.07.015.

Gower, T., Pham, J., Jouriles, E.N., Rosenfield, D., Bowen, H.J., 2022. Cognitive biases in perceptions of posttraumatic growth: A systematic review and meta-analysis. Clin. Psychol. Rev. 94, 102159.

Grace, A.A., 1991. Phasic versus tonic dopamine release and the modulation of dopamine system responsivity: a hypothesis for the etiology of schizophrenia. Neuroscience 41 (1), 1–24. Retrieved from. http://www.ncbi.nlm.nih.gov/pubmed/1676137.

Grogan, J.P., Randhawa, G., Kim, M., Manohar, S.G., 2022. Motivation improves working memory by two processes: Prioritisation and retrieval thresholds. Cognitive Psychology 135, 101472.

Gruber, M.J., Otten, L.J., 2010. Voluntary control over prestimulus activity related to encoding. Journal of Neuroscience 30 (29), 9793–9800.

Gruber, M.J., Ritchey, M., Wang, S.F., Doss, M.K., Ranganath, C., 2016. Post-learning Hippocampal Dynamics Promote Preferential Retention of Rewarding Events. Neuron 89 (5), 1110–1120. https://doi.org/10.1016/j.neuron.2016.01.017.

Gruber, M.J., Watrous, A.J., Ekstrom, A.D., Ranganath, C., Otten, L.J., 2013. Expected reward modulates encoding-related theta activity before an event. Neuroimage 64, 68–74.

Guitart-Masip, M., Huys, Q.J.M., Fuentemilla, L., Dayan, P., Duzel, E., Dolan, R.J., 2012. Go and no-go learning in reward and punishment: interactions between affect and effect. Neuroimage 62 (1), 154–166.

Gupta, R.S., Simmons, A.N., Dugas, N.N., Stout, D.M., Harlé, K.M., 2024. Motivational context and neurocomputation of stop expectation moderate early attention responses supporting proactive inhibitory control. Front. Human. Neurosci. 18, 1357868.

Halsband, T.M., Ferdinand, N.K., Bridger, E.K., Mecklinger, A., 2012. Monetary rewards influence retrieval orientations. Cognitive, Affective, & Behavioral Neuroscience 12 (3), 430–445.

Han, L.T., Cohen, M.S., He, L.K., Green, L.M., Knowlton, B.J., Castel, A.D., Rissman, J., 2023. Establishing a causal role for left ventrolateral prefrontal cortex in value-directed memory encoding with high-definition transcranial direct current stimulation. Neuropsychologia 181, 108489.

Hedge, C., Powell, G., Bompas, A., Sumner, P., 2022. Strategy and processing speed eclipse individual differences in control ability in conflict tasks. J. Exp. Psychol. Learn. Mem. Cogn. 48 (10), 1448.

Held, L.K., Vermeylen, L., Dignath, D., Notebaert, W., Krebs, R.M., Braem, S., 2024. Reinforcement learning of adaptive control strategies. Commun. Psychol. 2 (1), 8.

Hennessee, J.P., 2018. *Value-directed remembering and aging: Examination of supporting mechanisms and effects on memory quality*. Dissertation, University of California, Los Angeles.

Hennessee, J.P, Patterson, T.K., Castel, A.D., Knowlton, B.J., 2019. Forget me not: Encoding processes in value-directed remembering. Journal of Memory and Language 106, 29–39.

Hippmann, B., Kuhlemann, I., Bäumer, T., Bahlmann, J., Münte, T.F., Jessen, S., 2019. Boosting the effect of reward on cognitive control using TMS over the left IFJ. Neuropsychologia 125, 109–115.

Hughes, B.L., Zaki, J., 2015. The neuroscience of motivated cognition. Trends Cogn. Sci. 19 (2), 62–64.

Jia, Y., Cui, L., Pollmann, S., Wei, P., 2021. The interactive effects of reward expectation and emotional interference on cognitive conflict control: An ERP study. Physiology & Behavior 234, 113369.

Jiang, H., Xu, B., 2014. Reward enhances backward inhibition in task switching. Journal of Cognitive Psychology 26 (2), 178–186.

Kang, G., Chang, W., Wang, L., Zhou, X., 2019. Reward expectation modulates multiple stages of auditory conflict control. International Journal of Psychophysiology 146, 148–156.

Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A.M., Koch, I., 2010. Control and interference in task switching–a review. Psychol. Bull. 136 (5), 849–874. https://doi.org/10.1037/a0019842.

Kleinsorge, T., Rinkenauer, G., 2012. Effects of monetary incentives on task switching. Experimental Psychology 59 (4), 216–226. https://doi.org/10.1027/1618-3169/a000146.

Knowlton, B.J., Castel, A.D., 2022. Memory and reward-based learning: A value-directed remembering perspective. Annu. Rev. Psychol. 73, 25–52.

Knutson, B., Adams, C.M., Fong, G.W., Hommer, D., 2001. Anticipation of increasing monetary reward selectively recruits nucleus accumbens. Journal Neuroscience Official Journal Society Neuroscience 21 (16), RC159.

Knutson, Brian, Westdorp, A., Kaiser, E., Hommer, D., 2000. FMRI visualization of brain activity during a monetary incentive delay task. Neuroimage 12 (1), 20–27.

Kornblum, S., Hasbroucq, T., Osman, A., 1990. Dimensional overlap: cognitive basis for stimulus-response compatibility–a model and taxonomy. Psychol. Rev. 97 (2), 253–270.

Kostandyan, M., Bombeke, K., Carsten, T., Krebs, R.M., Notebaert, W., Boehler, C.N., 2019. Differential effects of sustained and transient effort triggered by reward–A combined EEG and pupillometry study. Neuropsychologia 123, 116–130.

Kostandyan, M., Park, H.R.P., Bundt, C., González-García, C., Wisniewski, D., Krebs, R. M., Boehler, C.N., 2020. Are all behavioral reward benefits created equally? An EEG-fMRI study. Neuroimage 215, 116829.

Krebs, R.M., Boehler, C.N., Appelbaum, L.G., Woldorff, M.G., 2013. Reward associations reduce behavioral interference by changing the temporal dynamics of conflict processing. PLoS One 8 (1), e53894.

Krebs, R.M., Boehler, C.N., Egner, T., Woldorff, M.G., 2011. The neural underpinnings of how reward associations can both guide and misguide attention. J Neurosci 31 (26), 9752–9759.

Krebs, R.M., Boehler, C.N., Roberts, K.C., Song, A.W., Woldorff, M.G., 2012. The involvement of the dopaminergic midbrain and cortico-striatal-thalamic circuits in the integration of reward prospect and attentional task demands. Cereb Cortex 22 (3), 607–615. https://doi.org/10.1093/cercor/bhr134.

Krug, M.K., Braver, T.S., 2014. Motivation and cognitive control: going beyond monetary incentives. In: Bijleveld, In.E., Aarts, H. (Eds.), The Psychological Science of Money. Springer, New York.

Lakens, D., 2013. Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. Front. Psychol. 4, 863.

Lang, P.J., Bradley, M.M., Cuthbert, B.N., 2013. Motivated attention: Affect, activation, and action. Attention and orienting. Psychology Press, pp. 97–135.

Le, T.M., Chao, H., Levy, I., Li, C.-S.R., 2020. Age-related changes in the neural processes of reward-directed action and inhibition of action. Frontiers in Psychology 11, 1121.

Leng, X., Yee, D., Ritz, H., Shenhav, A., 2021. Dissociable influences of reward and punishment on adaptive cognitive control. PLoS. Comput. Biol. 17 (12), e1009737.

Liegel, N., Schneider, D., Wascher, E., Klatt, L., Arnau, S., 2024. The effect of performance contingent reward prospects flexibly adapts to more versus less specific task goals. Psychophysiology 61 (12), e14678.

Liesefeld, H.R., Janczyk, M., 2019. Combining speed and accuracy to control for speed-accuracy trade-offs (?). Behav. Res. Methods 51 (1), 40–60.

Locke, H.S., Braver, T.S., 2008. Motivational influences on cognitive control: behavior, brain activation, and individual differences. Cogn. Affect. Behav. Neurosci. 8 (1), 99–112.

Loh, E., Kumaran, D., Koster, R., Berron, D., Dolan, R., Duzel, E., 2016. Context-specific activation of hippocampus and SN/VTA by reward is related to enhanced long-term memory for embedded objects. Neurobiology of Learning and Memory 134, 65–77.

Mandler, G., 1980. Recognizing: The judgment of previous occurrence. Psychol. Rev. 87 (3), 252.

Marini, F., van den Berg, B., Woldorff, M.G., 2015. Reward prospect interacts with trial-by-trial preparation for potential distraction. Visual Cognition 23 (1–2), 313–335.

Mason, A., Ludwig, C., Farrell, S., 2017. Adaptive scaling of reward in episodic memory: a replication study. Q. J. Exp. Psychol. 70 (11), 2306–2318.

Mather, M., Schoeke, A., 2011. Positive Outcomes Enhance Incidental Learning for Both Younger and Older Adults. Frontiers in Neuroscience 5, 129. https://doi.org/10.3389/fnins.2011.00129.

McMorris, T., Hale, B.J., 2012. Differential effects of differing intensities of acute exercise on speed and accuracy of cognition: a meta-analytical investigation. Brain Cogn. 80 (3), 338–351.

Medvedev, D., Davenport, D., Talhelm, T., Li, Y., 2024. The motivating effect of monetary over psychological incentives is stronger in WEIRD cultures. Nat. Human. Behav. 8 (3), 456–470.

Miendlarzewska, E.A., Bavelier, D., Schwartz, S., 2016. Influence of reward motivation on human declarative memory. Neurosci. & Biobehav. Rev. 61, 156–176.

Miller, E.K., 2000. The prefrontal cortex and cognitive control. Nat. Rev. Neurosci. 1 (1), 59–65.

Mobbs, D., Hassabis, D., Seymour, B., Marchant, J.L., Weiskopf, N., Dolan, R.J., Frith, C. D., 2009. Choking on the Money: Reward-Based Performance Decrements Are Associated With Midbrain Activity. Psychol. Sci. 20 (8), 955–962. https://doi.org/10.1111/j.1467-9280.2009.02399.x.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Ann. Intern. Med. 151 (4), 264–269.

Murayama, K., Kitagami, S., 2014. Consolidation power of extrinsic rewards: Reward cues enhance long-term memory for irrelevant past events. J. Exp. Psychol. General. 143 (1), 15–20. https://doi.org/10.1037/a0031992.

Murayama, K., Matsumoto, M., Izuma, K., Matsumoto, K., 2010. Neural basis of the undermining effect of monetary reward on intrinsic motivation. Proc. Natl. Acad. Sci. USA 107 (49), 20911–20916. https://doi.org/10.1073/pnas.1013305107.

Murphy, D.H., Hoover, K.M., Castel, A.D., Knowlton, B.J., 2025. Memory and automatic processing of valuable information in younger and older adults. Aging Neuropsychol. Cogn. 32 (1), 142–168.

Murty, V.P., Adcock, R.A., 2017. Distinct medial temporal lobe network states as neural contexts for motivated memory formation. In: Hannula, D.E., Duff, C., Melissa (Eds.), The hippocampus from cells to systems. Springer International Publishing, Cold Spring, New York, pp. 467–501.

2020 NIH. Quality assessment tool for observational cohort and cross-sectional studies 2020 National Institutes of Health, Department of Health and Human Services.Bethesda https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools.

Niv, Y., 2007. Cost, benefit, tonic, phasic: what do response rates tell us about dopamine and motivation? Ann. N. Y Acad. Sci. 1104, 357–376.

Niv, Y., Daw, N.D., Joel, D., Dayan, P., 2007. Tonic dopamine: opportunity costs and the control of response vigor. Psychopharmacol. (Berl.) 191 (3), 507–520.

Oates, J.M., Reder, L.M., 2011. Memory for pictures: Sometimes a picture is not worth a single word. Successful remembering and successful forgetting. Psychology Press, pp. 465–480.

Olds, J., Milner, P., 1954. Positive reinforcement produced by electrical stimulation of septal area and other regions of rat brain. J. Comp. Physiol. Psychol. 47 (6), 419–427. https://doi.org/10.1037/h0058775.

Otto, A.R., Daw, N.D., 2019. The opportunity cost of time modulates cognitive effort. Neuropsychologia 123, 92–105.

Oyarzún, J.P., Packard, P.A., de Diego-Balaguer, R., Fuentemilla, L., 2016. Motivated encoding selectively promotes memory for future inconsequential semantically-related events. Neurobiology of Learning and Memory 133, 1–6.

Padmala, S., Pessoa, L., 2011. Reward Reduces Conflict by Enhancing Attentional Control and Biasing Visual Cortical Processing. J Cogn Neurosci 23, 3419–3432.

Padmanabhan, A., Geier, C.F., Ordaz, S.J., Teslovich, T., Luna, B., 2011. Developmental changes in brain function underlying the influence of reward processing on inhibitory control. Developmental Cognitive Neuroscience 1 (4), 517–529.

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Brennan, S.E., 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Bmj 372.

Phaneuf-Hadd, C. V, Jacques, I. M., Insel, C., Otto, A. R., & Somerville, L. H. (2025). Characterizing age-related change in learning the value of cognitive effort. *Journal of Experimental Psychology: General*.

Poh, J.-H., Vu, M.-A.T., Stanek, J.K., Hsiung, A., Egner, T., Adcock, R.A., 2022. Hippocampal convergence during anticipatory midbrain activation promotes subsequent memory formation. Nat. Commun. 13 (1), 6729.

Rad, M.S., Martingano, A.J., Ginges, J., 2018. Toward a psychology of Homo sapiens: Making psychological science more representative of the human population. Proc. Natl. Acad. Sci. 115 (45), 11401–11405.

Reggente, N., 2018. *Neurocognitive Determinants of Memory Enhancement*. Dissertation, University of California, Los Angeles.

Reyes, S., Rimkus, C. de M., Lozoff, B., Biswal, B. B., Peirano, P., & Algarin, C. (2020). Assessing cognitive control and the reward system in overweight young adults using sensitivity to incentives and white matter integrity. *PloS One*, *15*(6), e0233915.

Richter, A., Barman, A., Wüstenberg, T., Soch, J., Schanze, D., Deibele, A., Zenker, M., 2017. Behavioral and neural manifestations of reward memory in carriers of low-expressing versus high-expressing genetic variants of the dopamine D2 receptor. Frontiers in Psychology 8, 654.

Ritz, H., Leng, X., Shenhav, A., 2022. Cognitive control as a multivariate optimization problem. J. Cogn. Neurosci. 34 (4), 569–591.

Ryan, R.M., Deci, E.L., 2000. Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions. Contemp. Educ. Psychol. 25 (1), 54–67. https://doi.org/10.1006/ceps.1999.1020.

Salamone, J.D., Correa, M., 2002. Motivational views of reinforcement: implications for understanding the behavioral functions of nucleus accumbens dopamine. Behav. Brain Res. 137 (1–2), 3–25.

Savine, A.C., Beck, S.M., Edwards, B.G., Chiew, K.S., Braver, T.S., 2010. Enhancement of cognitive control by approach and avoidance motivational states. Cogn Emot 24 (2), 338–356.

Schevernels, H., Krebs, R.M., Santens, P., Woldorff, M.G., Boehler, C.N., 2014. Task preparation processes related to reward prediction precede those related to task-difficulty expectation. Neuroimage 84, 639–647. https://doi.org/10.1016/j.neuroimage.2013.09.039.

Schultz, W., 2007. Multiple dopamine functions at different time courses. Annu. Rev. Neurosci. 30 (1), 259–288.

Schuman, D.L., Bricout, J., Peterson, H.L., Barnhart, S., 2019. A systematic review of the psychosocial impact of emotional numbing in US combat veterans. J. Clin. Psychol. 75 (4), 644–663.

Seifert, J., Naumann, E., Hewig, J., Hagemann, D., Bartussek, D., 2006. Motivated executive attention–incentives and the noise-compatibility effect. Biol Psychol 71 (1), 80–89.

Shigemune, Y., Tsukiura, T., Kambara, T., Kawashima, R., 2014. Remembering with Gains and Losses: Effects of Monetary Reward and Punishment on Successful Encoding Activation of Source Memories. Cereb. Cortex (New. Y. NY) 24 (5), 1319–1331. https://doi.org/10.1093/cercor/bhs415.

Shohamy, D., Adcock, R.A., 2010. Dopamine and adaptive memory. Trends Cogn. Sci. 14 (10), 464–472. https://doi.org/10.1016/j.tics.2010.08.002.

Spaniol, J., Schain, C., Bowen, H.J., 2014. Reward-enhanced memory in younger and older adults. J. Gerontol. Ser. B Psychol. Sci. Social. Sci. 69 (5), 730–740.

Stanek, J.K., Dickerson, K.C., Chiew, K.S., Clement, N.J., Adcock, R.A., 2019. Expected reward value and reward uncertainty have temporally dissociable effects on memory formation. J. Cogn. Neurosci. 31 (10), 1443–1454.

Sternberg, S., 1969. The discovery of processing stages: extensions of Donders' method. Acta Psychol. 30, 276–315.

Studte, S., Bridger, E., Mecklinger, A., 2017. Sleep spindles during a nap correlate with post sleep memory performance for highly rewarded word-pairs. Brain and Language 167, 28–35.

Sullivan, M.D., Kudus, F., Dyson, B.J., Spaniol, J., 2023. Adult age differences in the Temporal dynamics of motivated attention. Journal of Cognitive Neuroscience 35 (3), 421–438.

Swirsky, L.T., Marinacci, R.M., Spaniol, J., 2020. Reward anticipation selectively boosts encoding of gist for visual objects. Scientific Reports 10 (1), 20196.

Swirsky, L.T., Spaniol, J., 2019. Cognitive and motivational selectivity in healthy aging. Wiley Interdisciplinary Reviews Cognitive Science 10 (6), e1512.

Swirsky, L.T., Sparrow, E.P., Sullivan, M.D., Valenzano, S.L., Chowdhury, S., Spaniol, J., 2023. Age differences in motivated cognition: A meta-analysis. J. Gerontol. Ser. B 78 (7), 1169–1181.

Taylor, S.F., Welsh, R.C., Wager, T.D., Phan, K.L., Fitzgerald, K.D., Gehring, W.J., 2004. A functional neuroimaging study of motivation and executive function. Neuroimage 21 (3), 1045–1054.

Thomas, A.K., McKinney de Royston, M., Powell, S., 2023. Color-evasive cognition: The unavoidable impact of scientific racism in the founding of a field. Curr. Dir. Psychol. Sci. 32 (2), 137–144.

Thornton, A., Lee, P., 2000. Publication bias in meta-analysis: its causes and consequences. J. Clin. Epidemiol. 53 (2), 207–216.

Thurm, F., Zink, N., Li, S.-C., 2018. Comparing effects of reward anticipation on working memory in younger and older adults. Frontiers in Psychology 9, 2318.

Tucker, M.A., Tang, S.X., Uzoh, A., Morgan, A., Stickgold, R., 2011. To sleep, to strive, or both: how best to optimize memory. PloS One 6 (7), e21737.

Tulving, E., 1993. What is episodic memory? Curr. Dir. Psychol. Sci. 2 (3), 67–70.

van den Berg, B., Krebs, R.M., Lorist, M.M., Woldorff, M.G., 2014. Utilization of reward-prospect enhances preparatory attention and reduces stimulus conflict. Cogn Affect Behav Neurosci 14 (2), 561–577. https://doi.org/10.3758/s13415-014-0281-z.

van Steenbergen, H., Band, G.P., Hommel, B., 2009. Reward counteracts conflict adaptation. Evidence for a role of affect in executive control. Psychol. Sci. 20 (12), 1473–1477.

van Veen, V., Krug, M.K., Carter, C.S., 2008. The neural and computational basis of controlled speed-accuracy tradeoff during task performance. J. Cogn. Neurosci. 20 (11), 1952–1965. https://doi.org/10.1162/jocn.2008.20146.

Veling, H., Aarts, H., 2010. Cueing task goals and earning money: Relatively high monetary rewards reduce failures to act on goals in a Stroop task. Motivation and Emotion 34 (2), 184–190.

Villaseñor, J.J., Sklenar, A.M., Frankenstein, A.N., Levy, P.U., McCurdy, M.P., Leshikar, E.D., 2021. Value-directed memory effects on item and context memory. Memory & Cognition 49 (6), 1082–1100.

Wen, H., Wu, M., Wang, Z., Gao, B., Zheng, Y., 2024. Aberrant effort-based reward dynamics in anhedonia. Cerebral Cortex 34 (5), bhae193.

Williams, R.S., Kudus, F., Dyson, B.J., Spaniol, J., 2018. Transient and sustained incentive effects on electrophysiological indices of cognitive control in younger and older adults. Cognitive, Affective, & Behavioral Neuroscience 18 (2), 313–330.

Wise, R.A., Rompre, P.P., 1989. Brain dopamine and reward. Annu. Rev. Psychol. 40, 191–225. Retrieved from. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=2648975.

Wittmann, B.C., Schott, B.H., Guderian, S., Frey, J.U., Heinze, H.-J., Düzel, E., 2005. Reward-Related fMRI activation of dopaminergic midbrain is associated with enhanced hippocampus- dependent long-term memory formation. Neuron 45 (3), 459–467. https://doi.org/10.1016/j.neuron.2005.01.010.

Wittmann, B. C., Schiltz, K., Boehler, C. N., & Düzel, E. (2008). Mesolimbic interaction of emotional valence and reward improves memory formation. *Neuropsychologia*, *46*(4), 1000–1008.

Wittmann, B. C., Tan, G. C., Lisman, J. E., Dolan, R. J., & Düzel, E. (2013). DAT genotype modulates striatal processing and long-term memory for items associated with reward and punishment. *Neuropsychologia*, *51*(11), 2184–2193.

Wolff, M., Krönke, K.-M., Goschke, T., 2016. Trait self-control is predicted by how reward associations modulate Stroop interference. Psychological Research 80 (6), 944–951.

Wolosin, Sasha, M, Zeithamova, D., Preston, A.R., 2013. Distributed hippocampal patterns that discriminate reward context are associated with enhanced associative binding. Journal of Experimental Psychology: General 142 (4), 1264.

Wolosin, S.M, Zeithamova, D., Preston, A.R., 2012. Reward modulation of hippocampal subfield activation during successful associative encoding and retrieval. J Cogn Neurosci 24 (7), 1532–1547. https://doi.org/10.1162/jocn_a_00237.

Yamaguchi, M., Nishimura, A., 2019. Modulating proactive cognitive control by reward: Differential anticipatory effects of performance-contingent and non-contingent rewards. Psychological Research 83 (2), 258–274.

Yan, C., Ding, Q., Wu, M., Zhu, J., 2022. The effects of reward on associative memory depend on unitization depths. Frontiers in Psychology 13, 839144.

Yebra, M., Galarza-Vallejo, A., Soto-Leon, V., Gonzalez-Rosa, J.J., de Berker, A.O., Bestmann, S., Strange, B.A., 2019. Action boosts episodic memory encoding in humans via engagement of a noradrenergic system. Nat. Commun. 10 (1), 3534.

Yee, D.M., Adams, S., Beck, A., Braver, T.S., 2019. Age-Related differences in motivational integration and cognitive control. Cognitive, Affective, & Behavioral Neuroscience 19 (3), 692–714.

Yee, D.M., Braver, T.S., 2018. Interactions of motivation and cognitive control. Curr. Opin. Behav. Sci. 19, 83–90.

Yee, D.M., Crawford, J.L., Lamichhane, B., Braver, T.S., 2021. Dorsal anterior cingulate cortex encodes the integrated incentive motivational value of cognitive task performance. J. Neurosci. 41 (16), 3707–3720.

Yee, D.M., Krug, M.K., Allen, A.Z., Braver, T.S., 2016. Humans integrate monetary and liquid incentives to motivate cognitive task performance. Frontiers in Psychology 6, 2037.

Yonelinas, A.P., 2002. The nature of recollection and familiarity: a review of 30 years of research. J. Mem. Lang. 46 (3), 441–517.

Yu, R., 2015. Choking under pressure: the neuropsychological mechanisms of incentive-induced performance decrements. Front. Behav. Neurosci. 9, 19. https://doi.org/10.3389/fnbeh.2015.00019.

Zedelius, C.M., Veling, H., Aarts, H., 2011. Boosting or choking–How conscious and unconscious reward processing modulate the active maintenance of goal-relevant information. Consciousness and Cognition 20 (2), 355–362.

Zedelius, C.M., Veling, H., Aarts, H., 2012. When unconscious rewards boost cognitive task performance inefficiently: The role of consciousness in integrating value and attainability information. Frontiers in Human Neuroscience 6, 219.

Zedelius, C.M., Veling, H., Bijleveld, E., Aarts, H., 2012b. Promising high monetary rewards for future task performance increases intermediate task performance. PLoS ONE 7 (8), e42547. https://doi.org/10.1371/journal.pone.0042547.