EXPLORING MOTIVATION: AGE DIFFERENCES IN GOAL-DIRECTED EXPLORE-EXPLOIT DECISION MAKING

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Author's Note

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Abstract

Decision making involves a trade-off between exploring unfamiliar options to acquire new information and exploiting known rewards. Although older adults demonstrate an exploitation bias, less is known about how motivation impacts these choice behaviors in later life. This thesis examined whether motivational context differentially affects explore-exploit choices in younger (n = 45; M_{age} = 19 yrs.) versus older adults (n = 44; M_{age} = 70 yrs.). Participants completed a decision-making task using a real-world scenario emphasizing either planning (exploration) or executing (exploitation) an art heist. Across motivation conditions, older adults exploited more and engaged in less directed exploration than younger adults. Across age groups, both younger and older adults exploited more in the action-oriented condition and explored more in the planning-oriented condition. These findings demonstrate that decision biases are modulated by motivational context across the adult lifespan, suggesting novel avenues to promote optimal decision-making strategies in later life.

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INTRODUCTION AND BACKGROUND

Human behaviour is shaped by a series of decisions that guide individuals through complex and dynamic physical and social environments. Central to many of these decisions is the tension between exploiting known sources of reward or exploring new alternatives with less certain, but potentially better, outcomes. This tension, known as the explore-exploit trade-off, is ubiquitous in everyday life and is thought to be a fundamental driver of human volition (Hills et al., 2015). For example, an individual might find themselves deliberating between rewatching their favourite movie or trying a newly released film, uncertain of whether the latter will be as enjoyable. Such decisions require balancing the need for gathering sufficient information to evaluate the potential reward of new information (exploration; in this example, watching the new movie's trailer and checking reviews on Rotten Tomatoes) against the benefits of choosing the option with the highest probable reward (exploitation, e.g., choosing the familiar movie that you know to be enjoyable). The ability to flexibly shift between these strategies is thought to underlie adaptive decision making (Cohen et al., 2007; Hills et al., 2015; Mehlhorn et al., 2015; Spreng & Turner, 2021).

Across the adult lifespan, tendencies to explore or exploit appear to shift systematically, promoting an exploitation bias in older adulthood. This shift has been attributed to a constellation of cognitive, affective, and neural changes that occur with age (Samanez-Larkin & Knutson, 2015; Spreng & Turner, 2019). Specifically, age-related reductions in cognitive control and increased reliance on accumulated knowledge may bias decision making toward familiar and reliable outcomes. Consistent with this account, several studies have demonstrated a greater tendency toward exploitative decision making in older adults relative to younger adults (Chin et al., 2016; Fastrich et al., 2024; Mata et al., 2013; Turner et al., 2024; Wiegand et al., 2019).

Further, studies have identified distinct neural networks underlying exploration- and exploitation-based choice, implicating frontal-parietal and default network brain regions respectively (Wyatt et al., 2024). Critically, these networks are among the most impacted in normal aging (Setton et al., 2023; Spreng & Turner, 2019; Spreng & Turner, 2015), suggesting a neural basis for altered choice behaviors in later life. Consistent with this idea, recent work has demonstrated that age-related microstructural brain changes to the locus coeruleus, a core subcortical node in the exploration-exploitation circuit (Aston-Jones & Cohen, 2005), are associated with this exploitation bias (Turner et al., 2024). However, less is known about how socioemotional factors, such as motivational state, impact explore-exploit decision making across the adult lifespan. To address this question, the aim of this thesis was to investigate how shifts in motivational states differentially impact explore-exploit behaviour in younger versus older adults.

Explore-Exploit Decision Making

Decision making is a fundamental cognitive process that underlies much of human behaviour and critically shapes the course of our lives. A central aspect of this process is the explore-exploit trade-off, which refers to the tension between exploring less familiar options to reduce uncertainty and acquire new information, and exploiting one's current knowledge to choose the option with the highest expected value, thereby maximizing reward. This trade-off arises in daily life situations where people must make choices without complete knowledge of all possible outcomes, requiring them to balance immediate rewards against the longer-term benefit of information gain (Cohen et al., 2007; Hills et al., 2015). Research on the explore-exploit trade-off has identified two distinct subtypes of exploration: directed exploration, which involves deliberately sampling options with the least amount of information in order to reduce uncertainty, and random, or undirected, exploration (Wilson et al., 2021). In contrast, exploitation involves

relying on existing knowledge or past experiences to guide individuals toward options with the highest expected value. Importantly, the balance between exploration and exploitation is context dependent. Individuals tend to explore more when uncertainty is high, when environments contingencies are unpredictable, or when the perceived benefit of information gain outweighs the perceived benefit of immediate reward. Conversely, individuals exploit more when they have acquired sufficient knowledge of the decision landscape in order to maximize gain, or when they need to prioritize immediate reward. Adaptive decision making therefore depends on flexibly adjusting choice behaviour in response to environmental demands as well as cognitive constraints (Mehlhorn et al., 2015).

The explore-exploit trade-off is typically studied using one of three main experimental paradigms: foraging, information search, and reinforcement learning. Foraging tasks require participants to navigate patchy environments in search of resources within their environment, capturing the ecological tension between seeking new, resource-rich areas and exploiting known, resource-limited ones. While foraging paradigms have traditionally modelled environmental search (e.g., berry foraging; van Dooren et al., 2021), other scholars have extended this concept to search within internal cognitive spaces. For example, semantic fluency tasks require individuals to generate category examples (e.g., animals), necessitating shifts between semantic clusters (e.g., mammals versus reptiles; Todd & Hills, 2020). In contrast, information search paradigms measure how information is acquired from multiple sources, emphasizing the reduction of uncertainty and the accumulation of knowledge over time (Gonzalez & Dutt, 2016). A classic example of this is the secretary problem, where candidates applying for a secretary position arrive one at a time and must be accepted or rejected on the spot. The challenge is to explore early candidates to learn enough about the distribution of the quality of candidates, then switch to exploiting this knowledge by selecting the best possible candidate. Information search

tasks like the secretary problem allow participants to first sample the decision space to gain enough information about each available option, then shift toward exploiting the option that will maximize their reward. Finally, reinforcement learning provides a computationally precise framework for studying reward-based explore-exploit decision making. This approach models how individuals learn to optimize behaviour through repeated interactions with their environment, often using multi-armed bandit tasks (Sutton & Barto, 1998).[1] In such tasks, participants must choose among multiple options with different, unknown reward distributions. Over time, participants learn the relative value of each option and adjust their behaviour accordingly to maximize their overall reward. Beyond decision-making frameworks, explore-exploit decision making has been studied across a variety of contexts, including learning and memory (Wyble et al., 2019), mate search (Kolze et al., 2021; Todd & Miller, 1999), organizational psychology (Cegarra-Navarro, 2007; March, 1991), and psychopathology (Lloyd et al., 2024; Tsypes et al., 2024), underscoring its relevance across myriad domains of human behaviour.

Age Differences in Explore-Exploit Decision Making

There is a growing body of literature demonstrating a robust pattern of reduced exploration and increased exploitation in older adulthood. Older adults are less likely to sample novel or uncertain options and instead show a strong tendency to rely on previously rewarding or familiar options. This pattern has been observed in older adults across foraging (Mata et al., 2013; Wiegand et al., 2019) information search (Chin et al., 2016; Fastrich et al., 2024), and

[1] Multi-armed bandit tasks, named after a metaphor of a gambler facing several slot machines ("one-armed bandits"; Robbins, 1952), each with an unknown probability of payout, are a classic paradigm for studying how individuals balance exploration and exploitation in decision making.

reinforcement learning paradigms (Mizell et al., 2024), suggesting that exploitative choice preferences consistently emerge across multiple experimental domains. Several mechanisms have been proposed to explain these age-related changes in decision-making behaviour. One account is the Shifting Mental Mode hypothesis, which asserts that aging is accompanied by a systematic shift toward an exploitative decision-making 'mode,' driven by interacting neural, cognitive, and affective changes that occur in later life (Spreng & Turner, 2019, 2021). Rather than characterizing aging as a process of generalized cognitive decline, this framework argues that aging reflects a broader reorganization of the cognitive architecture that alters how information is prioritized and used to guide behaviour. This hypothesis builds on seminal findings in cognitive psychology demonstrating that the architecture of human cognition undergoes a marked shift with age. Cognitive control processes that support fluid and adaptive cognitive thinking, including processing speed, working memory, and cognitive flexibility, tend to decline with age. In contrast, semantic knowledge and accumulated life experience continues to expand, or remains relatively preserved, across older adulthood (Park et al., 2001). These dual cognitive trajectories have been described as the 'semanticization of cognition,' whereby older adults increasingly rely on semantic knowledge and past experiences to interpret information and guide behaviour (Spreng & Turner, 2019). Consequently, decision making becomes increasingly reliant on accumulated knowledge rather than fast and flexible processing of novel information.

Age-related changes in cognitive processing are paralleled by changes in the functional organization of the brain. Fluid cognitive processing is reliant on an assembly of frontal and parietal brain regions that collectively form the frontoparietal control network, which is vulnerable to age-related decline (Setton et al., 2023). Therefore, functional decline within the frontoparietal control network may reduce the cognitive control resources necessary for exploratory behaviour, particularly in contexts that require uncertainty tracking, flexible

updating, or the evaluation of novel alternatives (Baror & Bar, 2016; Mata & von Helverson, 2015). At the same time, regions within the default network, implicated in semantic representation, autobiographical memory, and affective valuation become more integrated with control networks in older adulthood (Setton et al., 2023; Turner & Spreng, 2015). This large-scale neural reorganization may strengthen the influence of prior knowledge on attention and reward systems that guide choice behaviour. Together, reductions in cognitive control, alongside increased reliance on prior knowledge, are thought to bias decision making toward exploitation in later life (Spreng & Turner, 2021).

This perspective suggests that aging is not adequately characterized as a uniform or global decline in neurocognitive functioning. Instead, aging reflects a dynamic reorganization of cognitive and neural systems in which some capacities weaken while others are preserved or even strengthened. While the emergence of an exploitation decision-making bias in later life may be partly attributable to these shifts in cognitive abilities, other age-related changes may also play a role (Sparrow & Spaniol, 2016; Spreng & Turner, 2021). Among these are changes that occur in socioemotional functioning in later life (Carstensen, 2021).

Motivation as a Modulator of Decision Behaviour

In addition to age-related neurocognitive changes, decision-making behaviour is shaped by a range of social, emotional, and motivational factors that influence how individuals evaluate, prioritize, and pursue goals (Carstensen & Reynolds, 2023; Lerner et al., 2015; Löckenhoff & Carstensen, 2004; Sparrow & Spaniol, 2016). One such factor, motivation, is critical in shaping decision behaviour. Although explore-exploit decision making is often examined in terms of uncertainty, reward, and learning, the balance between exploration and exploitation is also inherently goal dependent. Exploration and exploitation represent distinct strategies for achieving

desired outcomes. Exploration prioritizes acquiring new information and identifying potentially better alternatives despite greater uncertainty, whereas exploitation prioritizes obtaining reliable rewards by relying on existing knowledge. Consequently, neither strategy is inherently optimal. Rather, the adaptive value of exploration or exploitation depends on the individual's current goals and motivational priorities.

Motivation is a longstanding construct in psychology, with diverse theoretical perspectives spanning animal learning, cognitive neuroscience, social psychology, developmental psychology, and aging (for in-depth reviews, see Braver et al., 2014; Graham & Weiner, 2012; Wasserman & Wasserman, 2020a). Classical theories emphasized rudimentary biological drives and reinforcement, whereas more contemporary perspectives have focused on intrinsic versus extrinsic motivation, expectancy-value processes, abstract goals, self-regulation, and effort allocation (Braver et al., 2014; Graham & Weiner, 2012). Although these perspectives differ in what aspect of human behaviour they emphasize, they share a common assumption that motivation shapes which goals individuals pursue and how behaviour is directed to achieve them. Broadly, motivation refers to any goal-directed behaviour, whereby effort is allocated toward achieving desired outcomes. Rather than simply determining how much effort individuals exert, motivation influences which goals are prioritized, how outcomes are evaluated, and which behavioural strategies are selected to achieve those goals. Accordingly, changes in motivational priorities should systematically influence the balance between exploratory and exploitative decision making, as these strategies serve fundamentally different behavioural goals.

Motivation has been conceptualized from several complimentary perspectives. One common distinction within the literature is between extrinsic and intrinsic motivation (Morris et al., 2022; Ryan & Deci, 2000). Extrinsic motivation refers to behaviour driven by external rewards or outcomes, such as monetary incentives, academic achievement, or social recognition.

Conversely, intrinsic motivation refers to behaviour driven by an individual's inherent interest or enjoyment of the activity itself (Morris et al., 2022). Motivation has also been conceptualized both as a relatively stable individual trait, or as a transient, context-dependent state that fluctuates across situations (Wasserman & Wasserman, 2020b). Although these perspectives emphasize different aspects of motivation, they converge on the idea that motivation influences behavioural priorities and goal pursuit. Moreover, motivation is a multidimensional construct that is influenced by numerous interacting psychological processes, including reward sensitivity, affective state, effort allocation, and goal prioritization (Braver et al., 2014; Le Heron et al., 2019; Treadway et al., 2012). The present thesis conceptualizes motivation as a transient state that alters goal priorities. Specifically, motivation is operationalized here as an experimentally induced, state-dependent process reflecting extrinsically motivated goal-directed behaviour. From this perspective, motivational states are expected to bias individuals toward either exploratory or exploitative patterns of decision-making depending on the goals that are emphasized.

Motivational Priorities Across the Adult Lifespan

Several theoretical frameworks propose that motivational priorities shift systematically across the adult lifespan. A prominent account, socioemotional selectivity theory, proposes that as perceived future time horizons become increasingly limited with age, motivational priorities shift toward emotionally meaningful goals and experiences (Carstensen, 2021). Consistent with this framework, older adults exhibit a robust positivity effect, characterized by preferential attention to and memory for positively valenced information (Mather & Carstensen, 2005). This effect is thought to arise from chronically activated goals that prioritize emotional well-being and life satisfaction (Reed & Carstensen, 2012). Complementing socioemotional selectivity theory, lifespan models of motivation also suggest that aging is associated with greater emphasis on

maintaining existing resources and avoiding losses (i.e., prevention focus) relative to acquiring gains (promotion focused; Ebner et al., 2006). Compared to younger adults, older adults demonstrate greater risk aversion and a preference for options associated with more predictable outcomes (Sparrow & Spaniol, 2016). This shift in valuation may lead to more risk-averse behaviour and a preference for options with more certain outcomes.

Collectively, these frameworks suggest that aging influences decision making not only through neurocognitive change but also through systematic changes in the goals individuals prioritize and the outcomes they seek. These motivational shifts have direct implications for the explore-exploit trade-off because exploration and exploitation represent different goal states. Exploration facilitates information acquisition and the discovery of potentially better alternatives but entails greater uncertainty and the possibility of short-term costs. In contrast, exploitation capitalizes on existing knowledge to maximize immediate and predictable outcomes. As future opportunities are perceived as increasingly limited and emphasis on maintenance and loss prevention increases, the relative advantages of exploitation become greater. Consequently, motivational changes associated with aging are expected to bias decision behaviour toward exploitative strategies. Importantly, this pattern should not be viewed as inherently maladaptive. Rather, it may reflect an adaptive strategy aligned with motivational priorities in later life. This underscores a critical aspect of the explore-exploit trade-off: the benefit of either strategy depends heavily on the decision-maker's goals.

State-Based Models of Motivation and Decision Making

While lifespan theories such as socioemotional selectivity theory describe relatively enduring changes motivational priorities across adulthood, they do not account for within-person variability in motivation, or how fluctuations in motivational states influence decision making

over shorter timescales. Motivation is a dynamic process and can vary across situations. Recent evidence demonstrates that daily fluctuations in motivational states can systematically influence decision-making strategies (Hewitt et al., 2025). Consistent with this perspective, Murty & Adcock (2017) proposed a state-based framework that distinguishes between two motivational states that support different goal types. Imperative motivational states prioritize the attainment of immediate goals through efficient information processing. In contrast, interrogative states prioritize the resolution of uncertainty through the acquisition of new information, thereby supporting future-oriented goals. These motivational states represent flexible shifts in behavioural priorities that allow individuals to adapt to changing environmental demands. This framework closely aligns with the explore-exploit trade-off. Imperative states are hypothesized to promote exploitative decision making, while interrogative states should facilitate exploratory decision making. Support for this account was demonstrated by Sinclair and colleagues (2023), who experimentally induced imperative and interrogative motivational states in two large samples of young adults. Consistent with theoretical predictions, they found that imperative states increased exploitative decision making, whereas interrogative states promoted exploratory choices (Sinclair et al., 2023). These findings provide empirical evidence that transient motivational states can shift the balance between exploration and exploitation by altering goal priorities. However, despite growing evidence linking motivational states to decision strategies in young adults, it remains unclear whether these effects generalize across the adult lifespan and interact with age-related decision biases. To our knowledge, no study to date has directly examined whether manipulating acute goal states can modulate explore-exploit decision making in older adults.

The Present Study

The overarching goal of this thesis was to investigate whether motivational influences on decision-making strategies observed in young (Sinclair et al., 2023) differ in older adults. For ease of exposition, interrogative and imperative motivational states are hereafter referred to as planning- and action-oriented conditions, respectively. By drawing upon broad, lifespan theories of neurocognitive and socioemotional aging to study transient motivational states, we can construct a more complete understanding of how individuals balance the trade-off between exploration and exploitation as a result of shifting motivational priorities across adulthood. Consistent with socioemotional selectivity theory and the Shifting Mental Mode hypothesis of decision making (Carstensen, 2021; Spreng & Turner, 2019), we hypothesized that motivational state would exert less influence overall on decision-making behaviour for older compared to younger adults. Extending the findings from Sinclair et al. (2023), we predicted that older adults, unlike young, would show an exploitative decision-making bias irrespective of motivational state. Further, we hypothesized that older adults, compared to young, would show a greater exploitation bias during task planning (interrogative motivational state) relative to task execution (imperative motivational state).

METHODS

Participants. Between 2025 and 2026, a total of 53 younger adults were recruited from the York University undergraduate research participant pool and were compensated with course credit. Fifty-one older adults were recruited through the York University Retirees Association, community centres in the Toronto area (n = 37), and the McGill University Retirees Association in Montréal, Quebec (n = 14) and received monetary compensation for their participation. Older adult participants completed the Montréal Cognitive Assessment (MoCA) and were required to score a 23 or higher for inclusion in the final analyses, following recommendations from large

meta-analytic evaluations of appropriate MoCA cut-off scores (Carson et al., 2017; Thomann et al., 2020). Older adults recruited in Montréal completed the study in French, whereas all other participants completed the study in English. All participants were free of any major neurological or psychiatric disorders and provided informed written consent prior to the study. Eight younger adults and six older adults were excluded from the final sample due to between-site version-control issues that resulted in differences in task implementation (i.e. software update failure from pilot version), self-reported mental health concerns, or technological errors encountered during data collection. The final sample consisted of 45 younger adults and 44 older adults (see Table 1 for sample characteristics).

Table 1. *Demographic characteristics.*

	Young Adults (n = 45)			**Older Adults** (n = 44)		
	M	*SD*	Range	*M*	*SD*	Range
Gender, n						
Women		35			32	
Men		10			12	
Transgender/Undisclosed		0			0	
Age (years)	19.0	1.4	18 – 24	70.2	6.4	60 – 83
Education (years)	13.1	1.4	12 – 17	16.7	3.3	11 – 27
MoCA (/30)[1]	-	-	-	27.0	1.9	23 – 30

[1]MoCA = Montréal Cognitive Assessment

Procedure. In a single session, participants completed adapted version of the Art Museum Heist task developed by Sinclair and colleagues (2023; see Figure 1). Participants were instructed to

locate the most valuable paintings within a simulated museum environment. This task was designed to manipulate motivational state using real-world scenarios involving either the planning or the execution of an art heist. In the planning-oriented condition, participants were instructed to explore the museum in order to *plan* which paintings they would steal in a future heist. This condition was intended to promote an exploratory decision-making strategy focused on acquiring information about the reward landscape. In contrast, the action-oriented condition instructed participants to execute the heist, and steal the most valuable paintings right away, thereby encouraging an exploitative strategy to maximize immediate rewards. On each trial, participants selected one of four differently coloured doors, each associated with a distinct, unknown reward distribution. While one door yielded the highest average reward across the task, the average reward associated with each door drifted over time to encourage periodic exploration. After each selection, a painting and its corresponding value were displayed on-screen for 4s. Participants repeated this for 100 trials. To ensure the maintenance of task engagement, periodic attention checks were included throughout the task. Specifically, an image of a museum guard would occasionally appear on screen for 2s. Participants were instructed to press the spacebar as quickly as possible to avoid getting caught, prior to the start of the task. This task was self-paced and administered in-person via PsychoPy, version 2023.2.3 at York University and version 2024.1.5 at McGill University (Peirce et al., 2019).

Participants completed both conditions across two experimental blocks (200 trials in total). Condition order was counterbalanced across participants. To minimize potential carryover effects between blocks, participants were told that the second block took place in a different museum. This was reinforced through distinct contextual cues, including a different museum guard, a visually distinct set of doors, and new paintings. There was a 15-minute delay in between blocks, during which participants completed several self-report questionnaires and

distractor tasks. Prior to the start of the second block, participants completed a comprehension check in which they were asked to verbally explain how the goal of the second experimental condition differed from the first.

Task Development

The present procedure represented a substantial methodological modification of the original between-subjects paradigm developed by Sinclair et al. (2023). A within-subjects design was selected to allow direct within-person comparisons while reducing between-subject variability and increasing statistical power. Converting the task to a within-subjects design required participants to complete both motivational conditions while minimizing potential block order and carryover effects that could otherwise influence performance. To achieve this, the task underwent multiple iterative pilot phases. Initial piloting evaluated the feasibility of administering both conditions within the same session using counterbalanced condition order. Subsequent pilot phases introduced new stimuli and distinct contextual cues in the second block (e.g., new paintings, different doors and museum guards) and refined task instructions to ensure participants correctly interpreted the motivational goals associated with each condition. These modifications resulted in the final paradigm used in the present study, described above.

Figure 1. *The Art Museum Heist task*. Reproduced from Sinclair et al., 2023, Proceedings of the National Academy of Sciences, 120(31), e2304881120.



Task scoring. Each trial decision was classified as either exploitation, directed exploration, or random exploitation, defined and described below. This classification followed the previously described within-subjects modification of the procedure implemented by Sinclair et al. (2023), which was a between-subjects experimental design. A reinforcement learning model was used to estimate participants' beliefs about the expected value of each door to then predict their decisions on each trial. The model included a learning rule that updated expected values based on observed rewards and a choice rule that estimated the probability of selecting each option on any given trial. This model captured three motivational influences on decision behavior: exploitation (choosing the door with the highest expected value), perseveration (repeating the previous choice), and directed exploration (sampling options associated with greater uncertainty). Model parameters governing the relative influence of each of these tendencies, along with the learning rate, were estimated for each participant using hierarchical Bayesian modeling. Based on these

model estimates, trials were classified into three choice types. Trials were classified as exploitation when the door with the highest expected value was chosen and directed exploration when the door that had not been selected in the greatest number of trials was chosen. Random exploration was defined as selecting one of the remaining options.

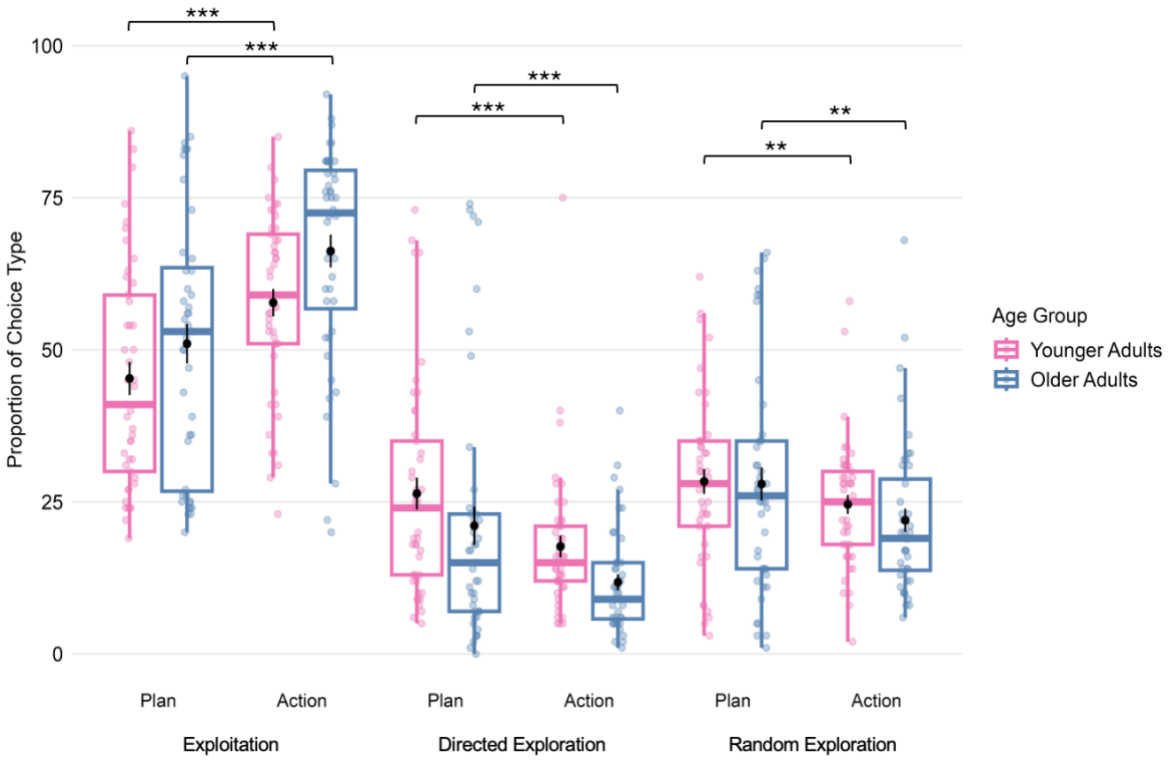
To accommodate the present within- and between- subjects design, we used the Delta learning model with the fourth-choice rule described in Sinclair et al. (2023). The trial-level learning and choice equations were unchanged. Modifications were limited to the hierarchical parameter estimation. Specifically, motivational condition was modeled as a within-subjects factor allowing reinforcement learning parameters to vary across conditions yet within individuals, while age group was incorporated as a between-subject factor at the group level. Full model specifications and model comparisons are provided in Sinclair et al. (2023).

Planned Analysis. To examine the effects of age and motivational state on explore-exploit behavior, we first calculated the proportion of trials classified as exploitation, directed exploration, or random exploration for each participant within each condition. These classifications were derived from the task scoring procedure described above. A mixed-factorial ANOVA was then conducted to examine the effects of condition (2: plan, action) and choice type (3: exploitation, directed exploration, random exploration) as within-subject factors and age group (2: younger adult, older adults) as a between-subjects factor, as well as their interactions, on the proportion of trials allocated to each choice type. Significant effects were followed by pairwise comparisons, Bonferroni corrected for multiple comparisons ($\alpha = .05$). Effect sizes for (a) ANOVAs were reported using partial eta squared (η_p^2), and (b) pairwise assessments were reported using Cohen's *d*.

RESULTS

The proportion of trials classified as exploitation, directed exploration, and random exploration across task conditions and age groups is shown in Figure 1. We observed a significant main effect of choice type ($F(2, 174) = 134.49$, $p < .001$, $\eta_p^2 = .61$), such that participants made more exploitative choices than either directed exploration ($p < .001$, $d = 1.48$) or random exploration ($p < .001$, $d = 1.3$). Participants also engaged in significantly less directed exploration than random exploration ($p = .005$, $d = –0.35$). There was a significant interaction between choice type and age group ($F(2, 174) = 3.86$, $p = .026$, $\eta_p^2 < .04$). Post hoc comparisons showed that older adults made more exploitative choices than younger adults ($p = .022$, $d = 0.50$). Conversely, older adults engaged in less directed exploration than younger adults ($p = .035$, $d = –0.45$). Random exploration did not significantly differ across age groups ($p = .527$, $d = –0.13$). A significant interaction between condition and choice type was found ($F(2, 174) = 22.69$, $p < .001$, $\eta_p^2 = .21$). Regardless of age, participants made more exploitative choices in the action condition than the planning condition ($p < .001$, $d = 0.6$). In contrast, both directed and random exploration were lower in the action condition than the planning condition (directed exploration: $p < .001$, $d = –0.48$; random exploration: $p = .007$, $d = –0.29$). The three-way interaction between condition, choice type, and age group was not significant ($F(2, 174) = 0.24$, $p = .755$, $\eta_p^2 = .003$).

Figure 2. *Motivational states influence explore-exploit choices in younger and older adults*. The proportion of trials classified as exploitation, direction exploration, or random exploration for younger adults and older adults in the planning and action task conditions. Boxplots depict the distribution of participant-level proportions for each choice type (central line = median; box limits = upper and lower quartiles; whiskers = 1.5x interquartile range). Individual points represent participants. Black circles denote group means, and black bars denote standard error. Older adults made more exploitative choices than younger adults, whereas younger adults engaged in more directed exploration than older adults. Across age groups, exploitative choices were more frequent in the action-oriented condition, whereas both directed and random exploration were more frequent in the planning condition. Please refer to the Results section for the results of the statistical tests. * $p < 0.01$, *** $p < 0.001$



DISCUSSION

We investigated whether motivational states differentially modulate explore-exploit decision-making across the adult lifespan. Using a 'real-world' reinforcement learning based paradigm, we measured explore-exploit choices across two motivation conditions: interrogative (planning-oriented) and imperative (action-oriented). Based on earlier work (Sinclair et al., 2023) we predicted greater exploration-based choice during planning versus action-oriented motivational states. Building upon lifespan theories of age-related neurocognitive (Spreng & Turner, 2019; 2021) and socioemotional change (Carstensen, 2021), we also predicted that older adults would demonstrate an exploitation bias relative to young across both conditions. Finally, we expected that an exploitation bias would lessen the impact of motivational state on explore-exploit decision-making for older adults. Consistent with previous findings, both age groups showed greater exploration- and lower exploitation-based choice in the planning versus action-oriented condition. Older adults made more exploitation-based choices across both motivational states, consistent with an age-related exploitation-bias. Both age-groups modulated their choice strategies based on motivational state. Younger and older adults demonstrated a similar decision-shift, with higher exploration during planning versus action and greater exploitation during action versus planning. These findings provide evidence that despite a generalized exploitation-bias, older adults modulate their decision strategies in response to shifting motivational or goal states.

Explore-Exploit Decision Making Changes with Age

The age-related exploitation bias we observed here replicates a growing body of literature demonstrating an age-related shift towards greater exploitation, and less directed exploration-based decision-making. Older adults make more exploitative choices and engage in less directed

exploration than younger adults during foraging (Mata et al., 2013; Turner et al., 2024; Wiegand et al., 2019) information search (Chin et al., 2016; Fastrich et al., 2024), and reinforcement learning (Mizell et al., 2024). The emergence of an exploitation bias has been attributed to age-related shifts in cognitive capacities, with declining cognitive control abilities occurring in the context of increasing semantic knowledge and lived experience (Spreng and Turner, 2019). We have argued that this shifting cognitive (and neural) architecture sets older adults at a different starting-point than younger adults when initiating choice behaviors. More ready access to a larger repertoire of knowledge representations amplifies the influence of this accumulated prior knowledge, creating a prepotent tendency towards exploitation-based choices, options with known reward probabilities and lower risks. In the context of declining control processes necessary to flexibly shift between exploitation and directed exploration, older adults demonstrate an exploitation-bias (see Spreng and Turner, 2021 for an elaboration of this model).

Older Adults Remain Sensitive to Motivational Context

However, choice behaviors are multifactorial, influenced by myriad intra- and extra-personal factors. Among these is the motivation, or goal state, of the decision-maker. Here we examined whether and how transient motivational states modulate explore-exploit behavior in the context of a putative age-related exploitation bias. Consistent with predictions derived from motivated cognition frameworks (Murty & Adcock, 2017), planning-oriented motivational states increased exploration relative to action-oriented states to align with task goals. When participants were instructed to plan for a future art heist, they explored uncertain options more frequently, prioritizing information over reward. In contrast, when the task instructions motivated action (the art heist is happening now), participants shifted their response strategy to lower their risk exposure, placing greater priority on reward over information. These findings replicate prior

work demonstrating that motivational framing can systematically shift explore-exploit behavior in younger adults (Sinclair et al., 2023). Importantly, this interaction between motivational state and choice behavior was observed for both younger and older adult decision-makers, suggesting that older adults are able to flexibly adjust their decision strategies based on shifting goal states.

These findings provide evidence that a bias towards exploitative choice behaviors in older adulthood can be shaped by motivational priorities that occur alongside the cognitive and neural changes that occur with age (Samanez-Larkin & Knutsen, 2015; Turner and Spreng, 2021). Socioemotional selectivity theory (Carstensen, 2021) proposes that perceived time horizons become narrower with age, leading individuals to prioritize emotionally meaningful and present-oriented goals. Within this framework, exploitative strategies may be advantageous because they maximize rewards and minimize risks associated with the more uncertain outcomes associated with exploration. Our findings show that while older adults have an exploitation bias, they remain sensitive to motivational context. When encouraged to prioritize information gathering (i.e. planning), older adults increased their exploratory behavior, reducing age differences observed during the action-oriented motivational state. These findings align with preexisting evidence for adaptability in older age. Previous work has demonstrated that transient changes in motivational states can shift older adult choice strategies towards greater exploration, when information-gathering is prioritized (Löckenhoff & Carstensen, 2007). Consistent with this account, other work suggests that age differences are sensitive to contextual demands, with older adults flexibly adapting their decision strategies depending on task demands (Mata et al., 2007; Spaniol & Wegier, 2012). However, the current findings are the first we are aware of to demonstrate this shift in the context of a prepotent age-related exploitation bias.

Given this context, we argue that while an exploitation bias emerges as a result of normal age-related changes, motivational priorities continue to modulate choice behaviors into later life.

This conclusion is further strengthened by our choice to adopt a within-subject experimental design. In the original study (Sinclair et al., 2023), the authors used a between-subject design, with independent groups receiving the interrogative and imperative versions of the task. While they reported robust evidence that motivational state influenced choice behaviors between these two groups, here we were able to demonstrate this modulation *within-subject* and *within a single testing session*. By simply altering the context from task planning to task execution we were able to shift decision-strategies. Demonstrating this effect within subjects is important because it indicates that changes in explore-exploit behaviour reflect dynamic adjustments in response to motivational context rather than stable differences between groups of participants. By observing both motivational conditions within the same individuals, the present design provides stronger evidence that motivational states can flexibly shift decision strategies, independent of individual differences in baseline explore-exploit tendencies. Critically for the current study, we were able to demonstrate this for both age groups, despite robust evidence for an age-related exploitation bias. As such, these findings raise the intriguing possibility that while an emergent exploitation bias may lead to an insidious shift away from exploration and new learning into older adulthood, altering the motivational context may attenuate this bias. More broadly, these findings suggest that age-related differences in explore-exploit behaviour should not be viewed as fixed characteristics of later adulthood. Rather, they appear to reflect decision biases that remain sensitive to contextual influences. If motivational framing can reliably shift older adults toward greater exploration in support of new learning, relatively simple interventions that emphasize future information value rather than immediate outcomes may promote more adaptive decision making. Such approaches may be particularly important in everyday contexts that require continued learning and adaptation, such as healthcare decisions, technology adaptation, and financial planning.

KEY AVENUES FOR FUTURE INQUIRY

The present thesis establishes the foundation for two complementary avenues of future inquiry that will form the basis of my doctoral work. First, I will adapt the within-subject Art Museum task, developed and validated in the present thesis, for task-based functional magnetic resonance imaging (fMRI) to investigate the neural mechanisms through which motivational states influence explore-exploit decision making across the adult lifespan. Second, I will extend this work by developing ecologically valid measures of explore-exploit decision making that better capture the complexity and personal relevance of everyday choices. Together, these two lines of inquiry aim to identify both the neural mechanisms and real-world relevance of goal-directed explore-exploit decision making across the adult lifespan. These are reviewed briefly in the following sections.

Neural Mechanisms of Motivated Decision Making

Building directly on the behavioural findings reported in this thesis, the first component of my doctoral work will adapt the within-subjects Art Museum Heist task for task-based fMRI. The behavioural findings demonstrate that both younger and older adults flexibly adjust their decision strategies in response to the motivational context, raising the question of how these behavioural shifts are supported at the neural level. Using the same experimental paradigm reported here, this work will examine how planning- and action-oriented motivational states differentially recruit neural systems supporting exploration and exploitation in younger versus older adults. Existing neuroimaging work suggests that exploration and exploitation are supported by dissociable but interacting large-scale brain networks (Daw et al., 2006; Hogeveen et al., 2022; Laureiro-Martínez et al., 2014; Wyatt et al., 2024). Exploratory decisions

preferentially recruit frontoparietal control regions, including the frontopolar cortex, dorsolateral prefrontal cortex, dorsal anterior cingulate cortex, and intraparietal sulcus, regions implicated in uncertainty monitoring, cognitive flexibility, and evaluation of alternative choices (Badre et al., 2012; Boorman et al., 2009; Wyatt et al., 2024). In contrast, exploitative decisions rely more heavily on cortico-striatal valuation systems, including the ventromedial prefrontal cortex, orbitofrontal cortex, ventral striatum, and posterior cingulate cortex, regions that support value integration, reward representation, and reliance on accumulated knowledge (Bartra et al., 2013; Levy & Glimcher, 2012; Wyatt et al., 2024). From a network neuroscience perspective, explore-exploit decision making therefore reflects dynamic interactions between executive control and valuation systems.

Importantly, these systems are critically shaped by affective and motivational states. The affect-integration-motivation framework proposed by Samanez-Larkin and Knutson (2015) characterizes how motivational states may modulate explore-exploit decision making. According to this framework, decisions emerge from a hierarchical sequence of interacting neural processes. Affective circuits first encode the anticipated value of potential gains and losses, with reward anticipation linked to the ventral striatum (particularly the nucleus accumbens) and loss anticipation associated with the anterior insula. The medial prefrontal cortex then plays a critical role in integrating these affective signals with other decision attributes and broader contextual information to guide decision-making behaviour. Applied to explore-exploit decision-making, this framework suggests that motivational states may dynamically alter the relative value of information versus reward, thereby biasing behaviour toward exploration or exploitation. Planning-oriented goal states may increase the perceived value of information gathering and the resolution of uncertainty, thereby favouring exploratory control systems, whereas action-oriented

states may prioritize reward certainty and stable value representations, favouring exploitative valuation systems.

This integrated framework is particularly relevant for understanding age-related changes in explore-exploit decision making. Across adulthood, shifts in explore-exploit decision making likely reflect the combined influence of changes in neural systems that support affective evaluation, value integration, and cognitive control (Samanez-Larkin & Knutson, 2015; Spreng & Turner, 2019; 2021), alongside systematic changes in goal priorities (Carstensen, 2021). Behavioural and neuroimaging evidence suggests that aging is associated with relatively preserved reward anticipation but reduced sensitivity to anticipated losses and uncertainty, alongside age-related changes in prefrontal systems responsible for integrating these signals during decision making (Samanez-Larkin & Knutson, 2015). These changes may reduce the subjective value of information seeking while increasing reliance on familiar, reliable options. These neurobiological changes likely interact with age-related shifts in motivational priorities. According to socioemotional selectivity theory, perceived time horizons narrow with age, leading individuals to prioritize emotionally meaningful, present-oriented goals over delayed or future-oriented goals (Carstensen, 2021). From this perspective, exploration may carry diminished motivational value because it often involves uncertainty, effort, and delayed payoff, whereas exploitative choice behaviours offer more reliable emotional and instrumental outcomes. Together, these neurobiological and motivational changes may reduce the subjective value of exploration while increasing reliance on familiar, reliable options.

These ideas converge with the default-executive coupling hypothesis of aging which proposes that aging is characterized by increased reliance on internally oriented default network systems and altered coupling between default and executive-control systems in older adulthood (Turner & Spreng, 2015). Since exploitative decisions preferentially recruit the default network,

whereas exploratory decisions rely more heavily on frontoparietal control systems, the default-executive coupling hypothesis of aging provides a potential systems-level account of the age-related exploitation bias. Specifically, aging may bias decision making toward exploitation through increased reliance on internally guided valuation processes and reduced engagement of executive control systems. However, the present behavioural findings demonstrate that despite a generalized exploitation bias, older adults remain sensitive to motivational context. Both younger and older adults increased exploratory behaviour during planning-oriented motivational states, suggesting that this age-related exploitation bias does not reflect a fixed inability to engage exploratory processes. Instead, these findings, in conjunction with existing neuroimaging work, may suggest that goal states dynamically alter the relative weighting of valuation and executive control systems. Although the present thesis provides behavioural evidence demonstrating the influence of motivational states on explore-exploit decision making, the neural mechanisms through which these effects arise are unclear.

Taken together, neurocognitive and socioemotional theories of aging suggest that age-related changes in explore-exploit decision making arise from interactions among affective valuation, cognitive control, and motivational priorities. Building on the behavioural findings reported in this thesis, the proposed fMRI work will test whether planning-oriented motivational states shift the balance between frontoparietal control networks and default networks differentially in younger versus older adults. By examining how motivational context alters large-scale brain network dynamics underpinning explore-exploit decision making, this work aims to provide a mechanistic account of how motivation attenuates age-related exploitation biases.

Ecologically Valid Decision-Making Tasks

The second component of my doctoral research will extend the mechanistic work by developing ecologically valid approaches to studying explore-exploit decision making. This line of work aims to develop novel tasks that capture everyday decisions of greater personal relevance, thereby enhancing the real-world applicability of our findings. Although experimental tasks are essential for isolating the cognitive processes underlying exploration and exploitation, it remains unclear whether the mechanisms identified in laboratory settings generalize to the personally meaningful decisions individuals make in everyday life. While the current findings provide novel evidence linking motivation and explore-exploit decision making in older adulthood, future work is needed to investigate whether and how these influences on older adult decision-making manifest in more ecologically valid contexts. Building on the behavioural and neuroimaging work described above, this research will develop novel paradigms that incorporate contexts that better reflect the complexity and relevance of real-world behaviour.

Despite substantial advances in understanding explore-exploit decision making, much of the existing literature has relied on experimental paradigms that prioritize precision and control at the expense of ecological validity. Canonical task paradigms, such as the multi-armed bandit, isolate explore-exploit computations in highly constrained laboratory settings, allowing researchers to rigorously model decision processes with complex computational methods under controlled conditions. However, these tasks necessarily simplify the complexity of real-world decision making, which often require individuals to integrate uncertainty, emotional salience, competing goals, social consequences, and changing environmental demands. Consequently, it remains unclear the extent to which findings from laboratory settings generalize to real-world decisions.

This limitation extends beyond task structure to the nature of the rewards used to motivate behaviour. Many laboratory experiments rely on real or imagined monetary rewards or other

hypothetical scenarios (e.g., an art heist) that may not elicit behaviour that is representative of real-world decision making, where outcomes carry genuine personal, emotional, or social relevance. This distinction may be particularly relevant in older adulthood, where motivational priorities increasingly shift toward emotionally meaningful and personally relevant experiences. As a result, laboratory paradigms may underestimate the extent to which exploration and exploitation are shaped by broader social, emotional, and motivational processes. While the Art Museum Heist task used in the present thesis provides a somewhat more naturalistic framework than traditional reinforcement learning paradigms, it remains a hypothetical scenario that arguably most subjects would not personally relate to. Similarly, motivation in the present thesis was operationalized as a distinction between planning- and action-oriented goal states, consistent with existing models of motivated cognition. However, motivation is multifaceted and influenced by numerous interacting cognitive, affective, and social factors. Variables such as apathy (Le Heron et al., 2019; Steffens et al., 2022), mood (Treadway et al., 2012), curiosity (Hirsch et al., 2026), pleasure seeking or hedonic drive (Thomsen, 2015), and the personal relevance of decision contexts are all known to influence motivated behaviour and may modulate the balance between exploration and exploitation. Understanding how these broader motivational influences shape decision making will require paradigms that move beyond abstract rewards to incorporate personally meaningful contexts within an explore-exploit framework.

Accordingly, the second component of my doctoral research will develop novel paradigms that examine explore-exploit decision making in contexts that are personally relevant and representative of everyday life. By integrating more ecologically valid decision contexts with behavioural and neuroimaging approaches, this work will determine whether the motivational and neural mechanisms of explore-exploit decision making generalize to the decisions people make in their daily lives. Together with the proposed neuroimaging work, these studies will

provide a more comprehensive understanding of how motivational, cognitive, and affective processes interact to shape explore-exploit decision making across the adult lifespan.

CONCLUSION

The present thesis demonstrates that older adults exhibit an exploitation-bias during a naturalistic reinforcement-learning task. Importantly, the findings demonstrate that this bias is not fixed; rather, it is dynamically shaped by motivational context. Although older adults showed a greater tendency than younger adults to exploit known sources of reward, both age groups flexibly adapted their decision strategies in response to experimentally manipulated goal states. Specifically, adopting a planning-oriented goal state increased exploration and attenuated age differences in explore-exploit decision making relative to action-oriented goal states. These findings suggest that exploitation in older adulthood reflects not only age-related neurocognitive changes, but also adaptive shifts in motivational priorities that influence how individuals evaluate uncertainty and reward. More broadly, this work provides a novel framework for understanding explore-exploit decision making across the adult lifespan. Rather than viewing age-related exploitation as a fixed consequence of age-related cognitive decline, the present findings support the view that older adults are capable of shifting their decision strategies to fit the motivational context. Finally, this thesis establishes a foundation for future research investigating the neural mechanisms and real-world relevance of motivated explore-exploit decision making. My doctoral research program will extend the findings from the present thesis to an fMRI investigation of the large-scale brain networks that support the influence of motivational states on exploration and exploitation in younger and older adults. Complementary efforts to develop more ecologically valid paradigms will further determine whether the behavioural and neural mechanisms identified in this line of work will generalize to the personally meaningful decisions individuals make in

everyday life. Together, these lines of research have the potential to provide a more fulsome account of motivated decision making across the adult lifespan and to inform future interventions for promoting adaptive decision making and maintaining functional independence in later life.

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Appendix A: Sample task Instructions

Action-oriented Condition [Block 1]:

Imagine you are at the grand opening of a fine arts museum, and you are a master thief about to execute a heist. Right now, you are searching through the museum to find the most valuable art. Finding more valuable paintings will maximize your reward. Your goal is to steal as much valuable art as you can, before you run out of time and the guards catch you!

There are four doors leading to different rooms of the museum. Each turn, you will choose which door to open. You will see ONE painting from that room and learn its value. You will have 100 chances to steal the most valuable paintings. After you steal a painting, you will return to the hallway to avoid getting caught.

Watch out for the museum guard! Pay attention: If you see him, press [spacebar] quickly to avoid him. A green border will appear if you press [spacebar] fast enough. The task takes about 15 minutes to complete.

Now, it's time to steal some valuable paintings! Remember, you are a master thief in the middle of a heist. You want to steal as many high-value paintings as you can before time runs out, and don't get caught! The more valuable paintings you steal, the bigger your reward.

Planning-oriented Condition [Block 2]:

After the success of your first heist, you're ready for another! You are now at a new museum, and this time you're going to carefully PLAN the heist. This time, you want to explore the museum to find the most valuable paintings before you return to steal them in one week's time. Finding more valuable paintings will maximize your future reward.

There are four doors leading to different rooms of the museum. Each turn, you will choose which door to open. You will see ONE painting from that room and learn its value. You will discover the value of 100 paintings to decide which ones you will want to steal in one week. After you learn about a painting, you will return to the hallway to avoid looking suspicious.

Watch out for the museum guard! Pay attention: If you see him, press [spacebar] quickly to avoid him. A green border will appear if you press [spacebar] fast enough. The task takes about 15 minutes to complete.

Now, it's time to find some valuable paintings! Remember, you are a master thief planning a future heist. Learn about the high-value paintings in the museum so you can return to steal them in one week! The more valuable paintings you find, the bigger your future reward.