

UNIVERSITA' DEGLI STUDI "G. d'Annunzio"

Chieti-Pescara

SCUOLA SUPERIORE "G. d'Annunzio"

DOTTORATO DI RICERCA IN NEUROSCIENZE E IMAGING

CICLO XXXVIII

Temporal discounting as a risk factor and predictive marker of mental health: neurocognitive analysis using advanced and personalized treatment methods

Il temporal discounting come fattore di rischio e marker predittivo di salute mentale: analisi neurocognitive mediante metodi avanzati e personalizzati di trattamento

Dipartimento di Neuroscienze, Imaging e Scienze Cliniche

Settore Scientifico Disciplinare PSIC-01A/PSIC-01B

PhD Candidate

PhD Coordinator Federica Procida

Prof. Carlo Sestieri

Tutors

Prof. Carlo Sestieri

Prof.

Giorgia Committeri

Anni Accademici 2022/2025

A mia nonna,

Acknowledgments/Ringraziamenti

Although a PhD is often described as a rollercoaster, I can honestly say that these years have been among the most rewarding of my life. Not a single day has passed without feeling like a new adventure, and this is entirely thanks to the colleagues who inspired me and supported me, day after day.

My deepest gratitude goes to my supervisor, *Professor Carlo Sestieri*. He taught me everything he could, with a clarity and patience that shaped my growth as a researcher. His guidance has been a steady anchor throughout these years, and I am profoundly grateful for the trust he placed in me and for encouraging me, day after day, to push further and do more than I thought possible. I am equally grateful to my co-supervisor, *Professor Giorgia Committeri*, whose support and thoughtful guidance accompanied me throughout this journey. Whether in the most demanding phases of the work or in the quieter moments of reflection, she was always available, patient, and willing to engage in discussion, helping me clarify ideas and navigate complexity with calm and perspective. Working under their supervision has been a privilege that enriched me both professionally and personally.

My heartfelt thanks go to *Gianni*, a true pillar of the ITAB and a constant source of support throughout my PhD. Your calm, generosity, and endless patience — even in front of my wildest requests, like the infamous “40 MRI slots per week” — made an enormous difference.

I am also grateful to Annalisa and Stefano, whose trust, advice, and quiet support were always deeply meaningful.

My appreciation extends to the entire lab, for welcoming me even when I arrived knowing no one. The moments of collaboration, the support when it mattered, and the space to grow professionally have all been invaluable.

A special thanks goes to *Daniele, Darien*, and *Andrea*, the best technicians I could have hoped to work with. Your constant availability, the countless hours spent helping me with my experiments, and your expertise, patience, and good humor made even the most complicated days manageable. I promise I'll try not to bother you for a while... or at least I'll do my best.

I am grateful to my dear *Maggiu*, whose lightness and effortless approach to life have been a constant example of motivation, pride, and healthy competition. Even with your head sometimes in the clouds, you have been not only a colleague but a truly precious friend. My thanks also go to *Francesca*, for your support and for listening to me in the difficult moments; to *Davide*, whose consistency, determination, and immense heart have been a steady presence; and to *Andrea*, my dear principino, whose guidance and encouragement helped me more than he knows. I also want to acknowledge *Daniilo*, who put up with me every time I needed help with experiments and still managed to make me laugh on the

most stressful days, and *Federica T.*, whose thoughtfulness and generosity have made her an exceptional colleague and a true friend, a supportive presence throughout this entire experience.

My gratitude also goes to the “refertation group”, for all the time we spent together and for the small rituals that made even the busiest days feel lighter. A warm thank you to *Giulia R.*, for the moments we shared and the memories we collected along the way, Pescara isn’t that bad after all, is it? I am grateful to *Fabrizia*, who showed me her most hidden side and supported me even during the most demanding periods. A special mention goes to *Gabriella*, my swimming partner and one of the least optimistic people I know — which is precisely why our conversations were so precious. Thank you for the honesty, the confidence, and the reminders that we are never truly alone.

My appreciation extends to *Michela*, for the calm and positivity that define her — qualities I should really learn from. And of course, a heartfelt thank you to our favourite Spanish girl, *Raquel*. Your energy, your humor, and the warmth you brought into every moment made this journey brighter. My thanks go to *Lucie*, with her unmistakable French irony and our shared passion for thrillers; to *Sara*, who made me lose my patience more than once, but whose kindness is rare; and to *Giulia B.*, for the weekends and small adventures that made this experience richer and more human. A sincere thank you to *Emma*, whose advice always arrived at the right moment, and to *Domenico* and *Alessandro*, for their kindness and the passion they bring to their work, and for all the ‘anamneses’ you signed for us. A small gesture on your side, but a huge help on ours. Finally, thank you to *Litz*, *Manuela*, *Giordano*, and *Ester* for the time we shared and for your kindness throughout these years.

A warm thank you goes to *Fede Puls*, who welcomed me into her home almost four years ago and unknowingly gave life to a beautiful friendship. Our Fridays — a glass of gin, long conversations, and her attempts to convince me that some of my choices were questionable (you know me... stubborn as ever, I never changed them) — are memories I will always treasure. Her warmth, honesty, and the ease with which she opens her door, and her time have meant more than she realizes.

A special thank you to *Alice*, and to that day we met at the SfN Conference. From that moment on, the American adventure was no longer mine, but ours. Thank you for our walks through Manhattan and for the long conversations about the challenges we faced every day. Sharing them made everything lighter.

I am deeply grateful to *my family*, who supported me despite my choices and stood by me even when the path I chose was not the simplest to understand. Their patience, their trust, and the freedom they gave me to follow my ambitions have meant more than they know.

My lifelong friend *Marika* deserves a special place on these pages. Despite the distance, her constant presence accompanied me through every phase of this journey. Knowing I could always count on her, it made everything lighter and infinitely more human. I also want to thank *Veronica*, who has supported (and tolerated) me since the very first day of

our master's degree. The lightness she brought, especially through our trips, reminded me how important it is to breathe, laugh, and step outside the routine. Japan is waiting for us.

My gratitude extends to my friends 'di giù— *Piccola Vale, Andrea, Chiara, Vale Cob, and Federico*. Despite the distance and the different rhythms of our cities, we always managed to find a way to meet, to laugh, and to feel close again.

Finally, my deepest gratitude goes to *Dr. Karolina Lempert*, who welcomed me into her lab during my visiting period in NYC. Her guidance, support, and intellectual generosity made this experience profoundly enriching and shaped my trajectory in ways I will carry forward. And to *Gina and Peter*, thank you for welcoming me during my time there. Your warmth, conversations, and support when everyone else was far away meant more than I can express.

PREFACE

CHAPTER I

THE PHENOMENON OF TEMPORAL DISCOUNTING 1

MEASURING TEMPORAL DISCOUNTING..... 2

TEMPORAL DISCOUNTING PARADIGMS 2

CALCULATION OF DISCOUNT RATES 4

Discount rate (k) 4

Area under the curve 5

THE MALLEABILITY OF INTERTEMPORAL CHOICE

FRAMING EFFECT 7

INCIDENTAL AFFECT 8

EPISODIC FUTURE THINKING..... 9

NEURAL BASES OF TEMPORAL DISCOUNTING 10

FUNCTIONAL STUDIES 11

The Valuation (or Reward) Network..... 11

The Cognitive Control Network..... 12

The Prospection Network..... 13

STRUCTURAL STUDIES..... 16

LESION STUDIES 18

IMPULSIVE DECISION-MAKING 20

TEMPORAL DISCOUNTING AS A TRANSDIAGNOSTIC FACTOR AND MARKER OF ADDICTIVE BEHAVIOR..... 22

TEMPORAL DISCOUNTING AS TRAIT OR STATE..... 25

Delay Discounting as a Trait..... 25

Delay Discounting as a State..... 27

IMPLICATIONS FOR INTERVENTIONS AIMED AT REDUCING TEMPORAL DISCOUNTING 29

CHAPTER 2

STUDY 1 34

ASYMMETRY OF THE SULCAL PATTERN OF THE ANTERIOR CINGULATE CORTEX MODULATES DELAY DISCOUNTING 34

METHODS AND MATERIALS..... 36

Participants 36

Cognitive measures 36

MRI acquisition and pre-processing..... 37

Characterization of the sulcal pattern 38

<i>Statistical analysis</i>	39
RESULTS	40
DISCUSSION	43
CHAPTER 3	
CONCEPTUAL FRAMEWORK	53
STUDY 2	54
CHOOSING NOW OVER LATER: WHAT TEMPORAL DISCOUNTING REVEALS ABOUT ITALIAN UNIVERSITY STUDENTS AND ADDICTION RISK.....	54
METHODS AND MATERIALS.....	56
<i>Participants</i>	56
<i>Procedure</i>	57
<i>Data Analysis</i>	60
RESULTS	61
DISCUSSION	65
CHAPTER 4	
STUDY 3	73
MODULATING TEMPORAL DISCOUNTING AND ADDICTION RISK FACTORS AMONG ITALIAN UNIVERSITY STUDENTS THROUGH A MULTICOMPONENT INTERVENTION	73
METHODS AND MATERIALS.....	75
<i>Participants</i>	75
<i>Procedure</i>	76
<i>Data Analysis</i>	80
RESULTS	81
DISCUSSION	91
GENERAL DISCUSSION.....	98
REFERENCES.....	101

Preface

Every day, individuals make small decisions that guide the immediate flow of their activities, while only some influence the overall direction of their lives. Some decisions appear to have only short-term consequences, for example, “Should I prepare a quick meal at home or order food delivery tonight?”, while others carry implications that extend into the future, such as “Should I dedicate the evening to revising for an upcoming exam or spend time socializing with friends?”. Across the vast changes in human society since prehistoric times, the ability to make adaptive choices remains fundamental to survival and well-being (Loewenstein & Lerner, 2003). When individuals must decide between outcomes available at different points in time, for instance, enjoying a streaming series immediately versus investing the same time in practicing a skill that may yield career advancement later, they are engaging in a kind of choice that researchers define as “intertemporal”. Crucially, humans, and animals in general, typically show bias when making such choices, i.e., a tendency to favor smaller, sooner rewards over larger, later ones. This behavioral pattern is known in the literature as *temporal discounting* (Ainslie, 1992; Lempert & Phelps, 2016).

In Chapter 1 of this dissertation, the phenomenon of temporal discounting is introduced as a fundamental aspect of human decision-making. This section describes the paradigms employed to measure intertemporal choice, outlines methodological considerations that influence discount rates, and reviews theoretical models that describe how subjective value declines with delay. By situating temporal discounting within the broader framework of reward valuation and impulsivity, the thesis establishes the behavioral foundations necessary for understanding the relevance of this construct in both psychology and psychiatry. We also examine the neural substrates of temporal discounting introducing the major functional networks involved in valuation, cognitive control, and prospection, and reviews evidence from lesion, and structural studies. Furthermore, we outline temporal discounting through a psychopathological lens, outlining its role as a risk factor, a behavioral marker of impulsivity, and a potentially modifiable target for intervention aimed at reducing maladaptive discounting tendencies.

In Chapter 2, the thesis moves from these behavioral foundations to the neuroanatomical level, exploring how individual differences in the sulcal pattern of the anterior cingulate cortex relate to temporal discounting. By focusing on the morphology of the anterior cingulate cortex (ACC), a region centrally involved in cognitive control and consistently implicated in delay discounting, we examine whether its stable sulcal can

explain individual variability in intertemporal choice. Through this structural perspective, the chapter introduces a complementary dimension to the behavioral and cognitive mechanisms discussed earlier, situating delay discounting within a broader neurodevelopmental framework.

In the final part of the dissertation, we examine temporal discounting through a psychopathological lens, outlining its role as a potentially modifiable target for intervention aimed at reducing the temporal discounting. Through the Pr.I.M.E. project, designed to identify early signs of vulnerability and occasional substance use in university students, we investigate how targeted preventive efforts may influence intertemporal choice and support evidence-based strategies for emerging adults. Specifically, the study presented in Chapter 3 examines the psychological dimension of temporal discounting, investigating whether steeper discounting rates correspond to vulnerability-related profiles that may predispose young adults, such as university population, to maladaptive patterns of use. By focusing on such vulnerable population, this chapter explores how intertemporal decision-making intersects with emotional dysregulation, impulsivity, and psychological distress, positioning temporal discounting as a marker of emerging susceptibility.

Building on these findings, the study presented in Chapter 4 extends the focus to prevention by examining how temporal discounting can guide early intervention strategies. It describes the implementation of the Pr.I.M.E. program and assesses its capacity to strengthen regulatory mechanisms and reduce addiction-related risk factors in young adults.

Chapter I

The phenomenon of Temporal Discounting

Humans and animals are frequently required to make intertemporal decisions, choosing between actions whose outcomes occur at different points in time, with more desirable results often entailing greater effort or longer delays (Frederick et al., 2002). *Temporal discounting* or *delay discounting* refers to the systematic tendency for the subjective value of a reward to decrease as the delay to its receipt increases (Ainslie, 1975; Rachlin & Green, 1972). In other words, individuals prefer smaller–sooner over larger–later outcomes although this preference depends on reward magnitude, delay duration, and individual differences in discounting (McKerchar & Renda, 2012; Green & Myerson, 2004; Odum, 2011). (McKerchar & Renda, 2012). Within the Research Domain Criteria (RDoC) framework, this phenomenon is considered part of the Positive Valence Systems under the construct of reward valuation (U.S. Department of Health and Human Services, National Institutes of Health, National Institute of Mental Health, 2016).

Although temporal discounting is a robust and widely observed phenomenon, discount rates vary substantially across individuals (Peters & Büchel, 2011) and contexts, shifting across domains such as health, finance, and social decision-making (Lempert & Phelps, 2016). Experimentally, intertemporal preferences are typically assessed through paradigms in which individuals choose between smaller, immediate rewards and larger, delayed rewards. Steeper discounting reflects a diminished valuation of delayed outcomes and is widely regarded as a behavioral index of impulsivity (Takahashi, 2005). Indeed, individuals who discount more steeply are often described as unable to wait for delayed rewards, favoring immediate gratification over long-term benefits (Loewenstein et al., 2002; Takahashi et al., 2007). Elevated discount rates have also been consistently linked to maladaptive behaviors and psychiatric conditions, including substance use disorders, pathological gambling, obesity, attention-deficit/hyperactivity disorder, and mood disorders, underscoring their relevance for both clinical psychiatry and behavioral economics (Amlung et al., 2019).

Measuring Temporal Discounting

Temporal Discounting paradigms

Temporal (or delay) discounting tasks are designed to quantify intertemporal preferences by presenting participants with choices between rewards that vary in size, type and temporal delay. In a typical choice, one option involves a smaller reward that is available immediately or soon, whereas the alternative option involves a larger reward that can only be obtained only after a longer delay (Addis et al., 2009). When options vary along multiple dimensions, such as both amount and delay, decision difficulty increases. For instance, a participant might be asked to choose between receiving €30 today or €150 in five months, or between one candy bar now and ten in three weeks. By systematically manipulating reward magnitude and delay across trials, researchers can identify the so-called indifference point, at which the subjective value of the immediate option equals that of the delayed alternative. This measure represents the specific amount of an immediate reward that a person considers equally valuable to a larger, delayed reward (i.e. the choice situation is adjusted to find the point at which preference switches between the two alternatives). While there are animal models and task variations with different outcome types (e.g., food, drugs, sexual outcomes), temporal discounting in humans is mostly assessed using monetary outcomes (Hamilton et al., 2015; Odum et al., 2020).

Three primary classes of temporal discounting tasks are commonly used: titration, adjusting titration, and randomized choice (see Fig. 1). The titration tasks present a series of binary choices in which either the immediate or delayed reward is held constant while the other amount systematically increases or decreases across trials. This method allows for precise estimation of indifference points at each delay, though results may be influenced by presentation order or which reward is fixed (Sawicki & Bialek, 2016). In contrast, adjusting titration procedures dynamically modify one parameter (e.g., reward magnitude or delay) based on the participant's previous choice, enabling rapid convergence on the indifference point. While efficient, this approach yields individualized choice sets that vary across participants (Hardisty et al., 2013).

Finally, the randomized-choice tasks present single trials with randomly varied reward magnitudes and delays, allowing indifference points to be inferred from aggregate choice patterns. This method is less transparent to participants and widely adopted in the literature (e.g., Kirby et al., 1999), though careful stimulus selection of reward–delay pairs to adequately capture discounting gradients (Senecal et al., 2012).

While all discounting paradigms ask participants to make decisions about what they prefer, they can vary about what they prefer, they can vary in how choice is incentivized and implemented. For example, in incentive-compatible designs, one trial is randomly selected, and the corresponding outcome is delivered either immediately or after the specified delay (Kable & Glimcher, 2007; Lempert et al., 2015). This method encourages participants to respond in line with their true preferences. In contrast, “hypothetical tasks” do not involve actual rewards. Although discount rates derived from hypothetical and real-reward tasks are generally correlated, the use of hypothetical rewards in temporal discounting paradigms has prompted discussion, particularly regarding their ecological validity (Johnson & Bickel, 2002).

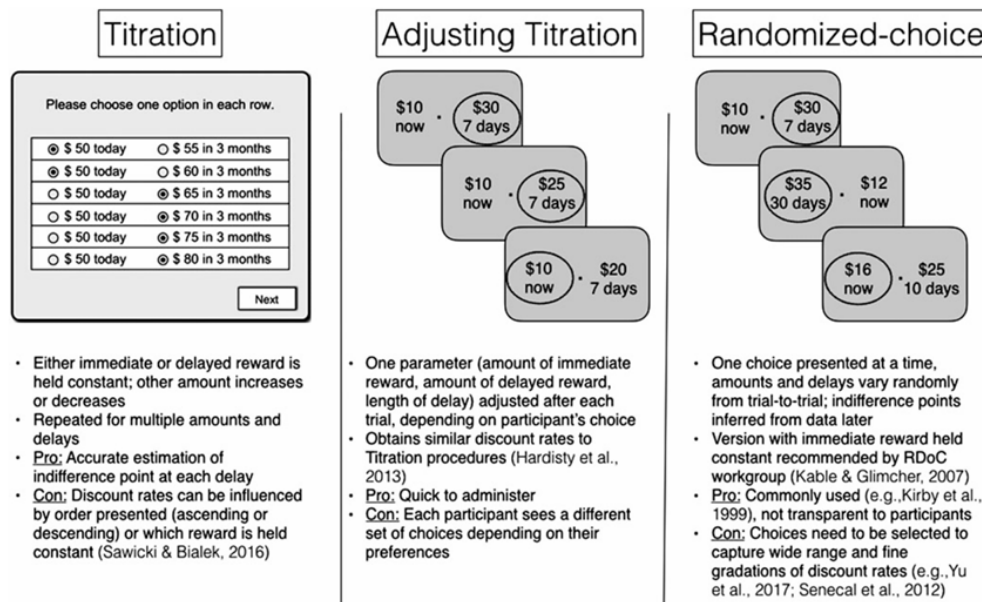


Figure 1. Graphical description of the three types of human delay discounting tasks—titration, adjusting titration, and randomized-choice (adapted from Lempert et al., 2016).

Moreover, temporal discounting tasks are also based on several assumptions, namely that participants treat outcomes as certain, immediately consumable, and independent of other contextual alternatives (Read, 2003). Within these paradigms, task parameters are systematically manipulated. In some procedures the smaller immediate option is progressively increased, a method referred to as Fixed Delayed Reward (FDR). In other paradigms, the larger delayed option is progressively decreased, known as Fixed Immediate Reward (FIR). Alternatively, delays and amounts can be adjusted dynamically according to the participants' choices. When the immediate and delayed rewards are

judged as equivalent, the choice reflects the indifference point (Reynolds & Schiffbauer, 2004) allowing researchers to generate discounting curves that capture subjective value over time and derive individual discounting rates (Tesch & Sanfey, 2008).

In addition to these approaches, some studies have employed intermediate paradigms that combine elements of different task structures (Calluso et al., 2015).

Calculation of discount rates

The quantification of delay discounting requires methods that capture how individuals assign subjective value to delayed outcomes. Several approaches have been proposed, ranging from simple descriptive indices to more complex parametric models (Doyle, 2013). The delay discount rate ((i.e., the rate at which the subjective value of a reward decays with delay) is typically quantified using two complementary approaches: the discounting parameter k , estimated via either hyperbolic or exponential models (Mazur, 1987; Rachlin et al., 1991; Green & Myerson, 2004; Fellows & Farah, 2005) and the area under the empirical discounting curve (AUC) (Myerson et al., 2001).

Discount rate (k)

Hyperbolic discounting refers to the fact that the effect of delay on value is not the same across the range of delays. At short delays, value is decreased proportionally more than at long delays (Mazur, 1987). For this reason, hyperbolic discounting has become the most widely used framework in psychology and psychiatry. The formula to calculate hyperbolic discounting is:

$$SV = \frac{A}{(1 + kD)}$$

where A is the amount of the reward, D is the delay to receiving it (for immediate rewards, $D=0$ and $SV=A$) and K is a free parameter that represents the discount rate (Mazur, 1987; Nevin and Rachlin, 1986). Steeper discounting (higher k) reflects a stronger preference for smaller–sooner rewards and is often interpreted as an indicator of impulsivity (Madden & Bickel, 2009). A distinctive feature of the hyperbolic model is that the rate of decline is steepest at short delays and becomes progressively shallower as outcomes are moved farther into the future (Kable & Glimcher, 2010).

On the other hand, exponential models assume a constant rate of decline over time, expressed as:

$$SV = e^{-kD}$$

(Ainslie, 1992; Mazur, 1987). In this formulation, delaying a reward by one day produces the same proportional reduction in value regardless of whether the delay occurs immediately or far in the future (Loewenstein et al., 2008; Kalenscher & Pennartz, 2008). Although mathematically elegant, exponential models fail to capture empirically observed preference reversals, such as choosing \$100 now over \$110 tomorrow but preferring \$110 in 31 days over \$100 in 30 days (Frederick et al., 2002). These time inconsistencies are better explained by hyperbolic models, which account for the disproportionate impact of proximal delays (Kirby & Marakovich, 1995; Johnson & Bickel, 2008). A graphical representation of both models is below (See Figure 2).

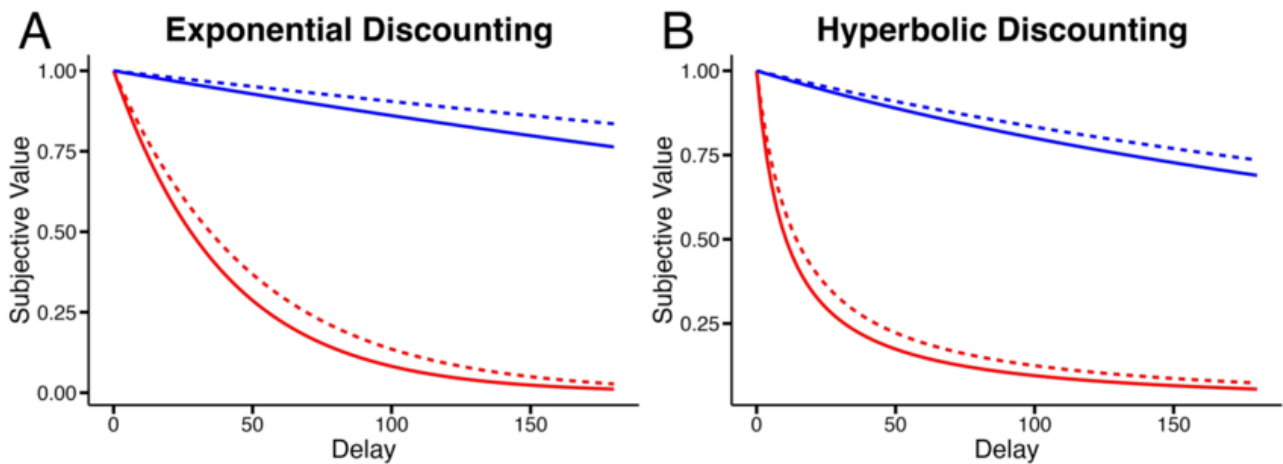


Figure 2. This figure illustrates A, exponential-and B, hyperbolic discounting curves with blue and red lines representing individuals with shallow and steep discounting rates, respectively. The solid and dashed lines within each color category highlight individual differences in discounting behavior across different contexts, such as varying environmental or psychological conditions (adapted from Wagner et al., 2022)

Area under the curve

A non-parametric measure is the area under the empirical discounting function. This approach requires no assumptions about the mathematical form of discounting, since both delay and subjective values are normalized. Since the area is calculated by the actual data points, unlike K, it does not depend on theoretical models regarding the shape of the discounting function (Myerson et al., 2001; Johnson and Bickel, 2008). The AUC is then computed using the trapezoidal rule, which approximates the area under the curve by summing the areas of trapezoids formed between successive data points. Each trapezoid is calculated as:

$$(x_2 - x_1) \frac{(y_1 + y_2)}{2}$$

where x_1 and x_2 represent adjacent delays and y_1 and y_2 are the corresponding subjective values (Myerson et al., 2001). The overall AUC is obtained by adding together all trapezoidal areas across the delay intervals. This index ranges from 0 to 1, with smaller values reflecting steeper discounting and therefore a stronger tendency to prefer smaller–immediate rewards over larger–delayed ones (Johnson & Bickel, 2008).

The malleability of Intertemporal Choice

As introduced in the preface, intertemporal choices are pervasive in everyday life and central to understanding human behavior. The observation that temporal discounting can be influenced by training programs indicates that temporal discounting, while considered a relatively stable, trait-like phenomenon (Miller et al., 2023; Odum, 2011a, 2011b), is nonetheless malleable (Scholten et al., 2019). Importantly, this malleability can be revealed by simple experimental manipulations (Koffarnus et al., 2013; Lempert & Phelps, 2016; Rung & Madden, 2018; Scholten et al., 2019).

According to Lempert and Phelps (2016), the context in which intertemporal decisions occur plays a crucial role, as such choices are susceptible to framing effects (i.e., how the scenario is presented; see Prospect Theory by Tversky & Kahneman, 1981) and incidental influences (i.e., pre-existing states such as affect) inducing systematic shifts in preferences. In this section, we present mechanisms by which these representational effects could occur.

Framing Effect

Framing refers to the context in which options are presented (Tversky & Kahneman, 1981). A meta-analysis by Kühberger (1998) showed that framing exerts robust influences on decision-making, identifying mechanisms such as reference points, outcome salience, and response mode. For example, identical outcomes framed as gains or losses elicit different choices, as illustrated by Tversky and Kahneman's disease outbreak scenario. In the domain of delay discounting, framing outcomes as gains or losses also alters preferences: delayed gains are typically discounted more steeply than delayed losses, a phenomenon known as gain–loss asymmetry or the sign effect.

Building on this line of research, Lempert and Phelps (2016) reviewed how framing manipulations shape intertemporal choice. They identified three key mechanisms: attention allocation, reference dependence, and time construal. For instance, attention can strongly shape how people make decisions. 'Delay' is typically viewed as a disadvantage of future reward. The size of that delayed reward is often a favorable feature because it tends to be larger than the immediate option. Shifting the focus away from reward magnitude and toward the delay itself is therefore expected to increase impulsive choices. Additionally, it is also possible to alter attention by changing the way that reward magnitudes are presented. One example of this manipulation is the 'decimal effect.' When rewards are framed as rounded numbers (e.g., €20.00 today vs. €15.00 in one week) rather than decimals (e.g., €12.44 today vs. €30.32 in one week), individuals tend to be

more impulsive (Fassbender C, et al. 2014). An explanation for this phenomenon is that greater cognitive effort is needed to interpret decimal values, which in turn directs the decision-makers focus on reward magnitudes and reduces attention to the delay.

Drawing attention to the opportunity costs of immediate rewards (the “hidden-zero effect”), or reframing delayed outcomes as investments, increases patience. This ‘explicit-zero’ condition (e.g., “€10 today and €0 later” vs. “€0 today and €12 later”) leads to reduced discounting, since seeing the default outcomes leads one to focus on the unpleasant future consequences of selecting the immediate reward (Radu, et al. 2011). Similarly, shifting the reference point, such as presenting the delayed reward as the default option, reduces impulsivity, consistent with loss aversion. Finally, another framing manipulation concerns how delays are described. The date/delay effect is a well-known frame that describes how the delay discounting is reduced when the delay until receipt of a reward is presented as a date (date condition, e.g., 30 November 2025) rather than in delay units (delay condition, e.g., in 91 days) (LeBoeuf, 2006; Read et al., 2004). For example, people tend to view an investment more favorably when its expected gain is framed as occurring on a specific date rather than after a delay described in years or months (Read et al., 2004). These findings reinforce the view that intertemporal preferences are not immutable traits but show a degree of context-dependency, and that framing provides a powerful tool to nudge individuals toward more advantageous long-term choices.

Incidental Affect

Incidental affect refers to the impact of emotions, moods, and stress on temporal discounting, even when these states are unrelated to the choice itself. Research on emotion–cognition interactions shows that both experiencing and regulating emotion can alter subsequent choices (Loewenstein & Lerner, 2003; Calluso et al., 2021). In the laboratory, affective states are typically induced through exposure to emotional stimuli, mood manipulations, or stress. Several studies indicate that viewing positive images, such as erotic material (Wilson & Daly, 2004; Van den Bergh et al., 2008), or desserts (Fedoroff, Polivy, & Herman, 1997), often increases impulsivity, leading individuals to favor immediate rewards. In contrast, myopic decision-making might also occur following incidental exposure to negative affective stimuli (Guan S, et al. 2015) though the evidence is inconsistent (Luo S, et al. 2014). The appraisal tendency framework (ATF) suggests that specific emotions elicit distinct cognitive and motivational tendencies that shape valuation

(Lerner & Keltner, 2000; Keltner & Lerner, 2010). Mood studies support this view: sadness increases impulsivity, possibly as a way of seeking immediate comfort (Lerner et al., 2004), while gratitude fosters patience by encouraging cooperation and future-oriented thinking (DeSteno et al., 2014). Stress represents another incidental state with mixed effects. Some studies report greater impulsivity under acute stress (Takahashi, 2004), others find no effect (Haushofer et al., 2013), and still others show outcomes depend on perceived stress levels (Lempert et al., 2012). Overall, incidental affect can meaningfully shift intertemporal preferences, but its effects are heterogeneous and contingent on the nature of the emotional state.

Episodic Future Thinking

Episodic future thinking (EFT) provides compelling evidence that prospection can foster more patient intertemporal choices. When individuals are prompted to imagine positive personal events in the future, prior to making a decision, they consistently display reduced discounting and select delayed rewards more often, even when the imagined scenario is unrelated to the reward itself (Peters & Büchel, 2010; Benoit, Gilbert, & Burgess, 2011; Lin & Epstein, 2014; Daniel, Stanton, & Epstein, 2013). By prompting individuals to recall emotionally rich, personally meaningful past events, this manipulation increases the affective vividness of future-oriented thought, thereby enhancing the subjective value of delayed outcomes and promoting greater preference for larger, later rewards (Lempert et al., 2017).

However, the precise mechanism driving this effect remains debated. Because most studies have used positive future events, it is unclear whether the effect arises from making the future more concrete (a change in time construal) or from enhancing positive affect associated with the imagined outcome. Supporting the concreteness hypothesis, some evidence shows that both neutral and positive future thinking reduce discounting (Lin & Epstein, 2014). Yet other work indicates that neutral future thinking has little effect, while negative future thinking increases impulsivity, suggesting that affective valence plays a critical role (Calluso et al., 2015). Another possibility is that engaging episodic memory systems, regardless of content, is sufficient to promote farsighted choice.

Thus, incidental affective states, such as emotions, moods, and stress, can shape intertemporal choice, potentially by shifting the reference point or by altering how attention is allocated to different choice attributes. In contrast, episodic future thinking appears to

Neural bases of Temporal Discounting

influence decision-making by modifying time construal, making future outcomes feel more concrete or proximal.

Neural bases of Temporal Discounting

Temporal discounting is a fundamental component of human decision-making and a key marker of vulnerability for several maladaptive behaviors (Amlung et al., 2019).

Despite its relevance, the neurocognitive architecture supporting discounting remains debated. Clarifying the neural basis of delay discounting has both practical implications (e.g., informing intervention strategies) and theoretical relevance (e.g., refining models of reward processing). Although traditional accounts distinguish between valuation and choice stages in decision-making (Peters & Büchel, 2011), emerging evidence suggests that these computations are embedded within the coordinated activity of multiple large-scale brain networks for valuation, cognitive and prospection.

Functional Studies

The Valuation (or Reward) Network

A central assumption in decision neuroscience and neuroeconomics is that the brain represents the value of environmental stimuli in an abstract, domain-general format. Such a representational scheme enables agents to compare qualitatively different reinforcers, such as food and money, on a common neural scale, thereby supporting flexible choice. Converging evidence implicates the ventral striatum (VS) and orbitofrontal cortex (OFC), particularly its ventromedial subdivision (vmPFC), as core components of this *valuation system* (Kable & Glimcher, 2007; Knutson et al., 2007; Chib et al., 2009; Hare et al., 2009) (Figure 3, panel A). These regions, tightly coupled with the mesolimbic dopamine system, encode the incentive value of both primary and secondary rewards and translate reward information into subjective value signals.

Alongside this unitary valuation framework, the “dual system” model has proposed that dopaminergically innervated valuation regions selectively encode immediate rewards (the β -system), whereas delayed rewards are represented in lateral prefrontal and parietal regions (the δ -system; McClure et al., 2004, 2007). Specifically, the model posits that intertemporal choice behavior is guided by (i) a “hot” visceral β -system processing immediate rewards, associated with activity in ventral striatum (vS), medial orbitofrontal cortex (mOFC), medial prefrontal cortex (mPFC) and posterior cingulate cortex (PCC), and (ii) a “cold” deliberative δ -system processing both immediate and delayed rewards and associated with activity in dorsolateral prefrontal cortex (dlPFC), ventrolateral prefrontal cortex (vlPFC), lateral orbitofrontal cortex (lOFC) and intraparietal cortex (McClure et al., 2004). However, subsequent work has shown that the vS, vmPFC, and PCC do not respond exclusively to immediate outcomes. These regions remain active even when all options are delayed by two weeks or more (McClure et al., 2004), and their responses reliably track the discounted subjective value of future rewards in the absence of any

immediate option (Kable & Glimcher, 2007, 2010; Peters & Büchel, 2009; Sripada et al., 2011).

A few years later, Kable & Glimcher (2007, 2010) proposed an alternative model, namely the *single valuation model*. This model, consistent with one-parameter behavioral accounts such as hyperbolic discounting, assumes that the subjective value of both immediate and delayed rewards is computed within a single, integrated valuation system. Converging neuroimaging evidence has shown that subjective value signals for choice options are encoded in regions including the ventral striatum (vS), ventromedial prefrontal cortex (vmPFC), and posterior cingulate cortex (PCC; Bartra et al., 2013). When contrasted with the dual-system formulation, most researchers nowadays prefer this single-valuation perspective (Peters & Büchel, 2011; Schüller et al., 2019), as hyperbolic models generally provide a better fit to fMRI data than quasi-hyperbolic alternatives (Kable & Glimcher, 2010). Neurophysiological studies further support the presence of value-related activity in the striatum (Samejima et al., 2005; Lau & Glimcher, 2008), although some accounts propose that VS responses may reflect prediction errors rather than value per se (Hare et al., 2008).

Finally, recent work suggests that the posterior cingulate cortex (PCC) may also contribute to delay-specific valuation, partially overlapping with regions identified by Kable and Glimcher (2007). However, PCC involvement is heterogeneous: some subregions encode value in a probability-specific manner, and several studies report no PCC value signals during delay discounting (Pine et al., 2009).

Altered valuation signals in this network have been documented in addiction: individuals with cocaine dependence or pathological gambling show reduced VS and vmPFC responses to monetary rewards (Goldstein et al., 2007; Reuter et al., 2005), and smokers exhibit attenuated striatal activity during reward anticipation (Rose et al., 2010), since diminished anticipatory value signals weaken the representation of delayed rewards and thereby contribute to steeper discounting.

The Cognitive Control Network

In the context of intertemporal choice, response conflict arises when individuals must choose between two options whose discounted subjective values are similar (McClure et al., 2007a). Not surprisingly, therefore, a second network frequently examined in the literature is the cognitive control network (Peters & Büchel, 2011; Schüller et al., 2019). This network includes regions implicated in conflict monitoring, strategic adjustment

(Peters & Büchel, 2011), and self-control, that is, the capacity to override immediately tempting options that may initially receive higher subjective value during early valuation processes (Figner et al., 2010; Schüller et al., 2019; see Figure 3, Panel A). Engagement of the cognitive control network is typically assumed to increase under conditions of high choice difficulty (Jimura et al., 2018; Marco-Pallarés et al., 2010; Pine et al., 2009), or more broadly when individuals select larger-later over smaller-sooner rewards (Wittmann et al., 2007; Ye & Wang, 2023). For example, activity in the anterior cingulate cortex (ACC) (Botvinick et al., 2004; van Veen et al., 2009) and in the lateral prefrontal cortex (PFC) (McClure et al., 2004; van Veen et al., 2009) is typically greater during difficult compared to easy intertemporal choices. In particular, while ACC activity also reflects increases in conflict-induced response times during delay discounting (van Veen et al., 2009), the dlPFC, in turn, plays a pivotal role in implementing control once conflict has been detected. Rather than encoding reward value directly, the dlPFC modulates valuation signals represented in the vmPFC. In situations where individuals exert self-control to override impulsive tendencies, dlPFC activity increases, exerting top-down influence on the valuation system and biasing choices toward delayed rewards (McClure et al., 2004; van Veen et al., 2009).

The Prospecction Network

A further perspective emphasizes the contribution of *episodic future thinking or prospecction*, suggesting that temporal discounting is shaped not only by valuation processes but also by the ability to mentally simulate future outcomes. Rather than reflecting a failure of impulse control, steep discounting may instead arise from a reduced ability to vividly simulate future events and evaluate their emotional and motivational significance. This theory emerged in the late 2000s, following influential evidence that individuals with hippocampal damage not only exhibited amnesia but also showed marked difficulties in imagining future events (Hassabis et al., 2007).

Concurrent neuroimaging work further demonstrated that the neural substrates supporting episodic memory retrieval and episodic future thinking substantially overlap (Schacter et al., 2007). Neuroimaging studies have identified a core network consistently engaged during episodic prospecction (Hassabis & Maguire, 2007; Schacter et al., 2007; Spreng et al., 2009). This network includes the medial temporal lobe (MTL), precuneus, and dorsomedial prefrontal cortex, regions that are active both when recalling episodic memories and when imagining future scenarios (Schacter et al., 2007) (Figure 3, panel A).

Because delay discounting requires simulating future outcomes (e.g., receiving rewards weeks or months later), engagement of this network is thought to reduce discounting by enhancing the vividness and salience of delayed consequences.

There are divergent hypotheses regarding the anatomical extent of the circuitry supporting episodic memory contributions to temporal decision-making: some accounts emphasize a predominantly MTL-centered system, whereas others propose a more distributed network that additionally encompasses lateral parietal regions and other association areas (e.g., Ranganath & Ritchey, 2012; Schacter et al., 2012). The medial temporal lobe (MTL) network described by Peters and Büchel (2011), which is largely consistent with the memory-based system proposed by Frost and McNaughton (2017), is more circumscribed compared to the prospection network. It comprises regions involved in representing past reward and delay experiences and in constructing future scenarios, such as the hippocampus and amygdala, with extensions into vmPFC, mOFC, and PCC, areas traditionally associated with valuation. Converging structural MRI findings further support the relevance of this network: MTL gray matter volume (Owens et al., 2017), hippocampal and parahippocampal white matter density (Yu, 2012), and white matter integrity in frontal and temporal tracts (Olson et al., 2009) all predict individual differences in delay discounting.

In this view, the prospection network complements the valuation and cognitive control systems. While the valuation regions compute the subjective worth of outcomes, the cognitive control regions modulate behavior in accordance with long-term goals, and the prospection network enriches the mental representation of the future, making delayed outcomes more vivid and thereby shifting intertemporal preferences (Peters and Büchel 2011).

Finally, several studies and theoretical models posit that intertemporal decisions unfold across both early and late processing stages, spanning sensory encoding and the generation or inhibition of motor responses (Frost & McNaughton, 2017; McClure et al., 2004). Early sensory processing engages the thalamus and primary sensory cortices, motor execution relies on premotor cortex, cerebellum, and basal ganglia, and the suppression of motor impulses recruits regions associated with cognitive control (Frost & McNaughton, 2017) (Figure 3, panel B).

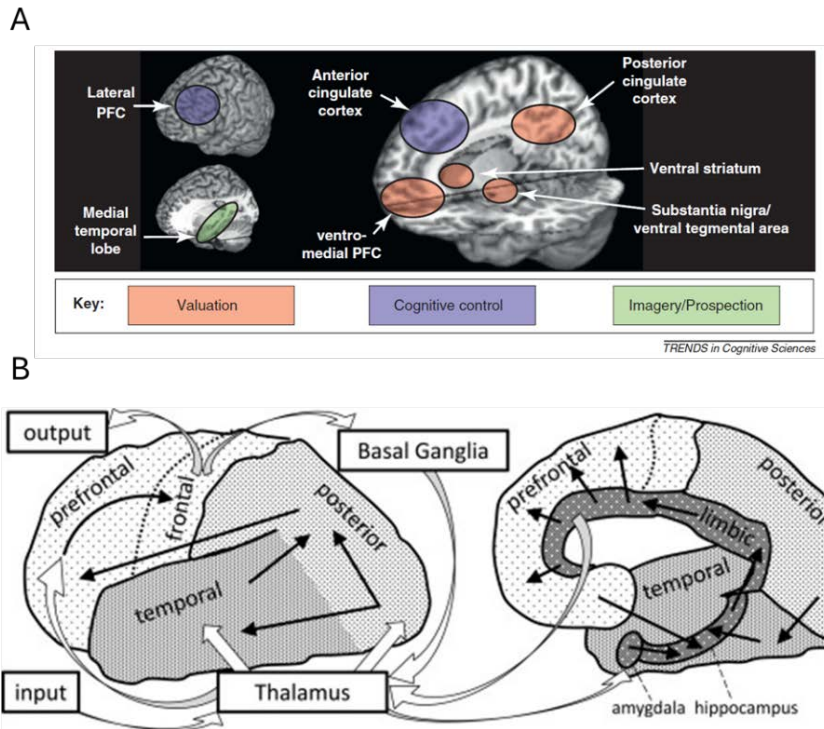


Figure 3. Panel A. Graphical representation of the three proposed neural networks involved in intertemporal decision-making, i.e., valuation (red), cognitive control (blue) and imagery/prospection (green) (Peters and Büchel, 2011). Panel B presents a suggestion of subcortical-cortical feedback loops involved in intertemporal choices. The left part of the figure is the lateral surface of the brain, and the right part is the medial part (Frost and McNaughton, 2017).

It is important to remark that the proposed networks are not fully distinct at the anatomical level, but instead involve partially overlapping regions, particularly within the prefrontal cortex (PFC). As a matter of fact, despite the different networks have often been conceptualized as being opposed to one another, and empirical findings provide mixed support for a crucial role of each network to varying degrees (Scheres et al., 2013), their substantial overlap suggests that intertemporal decisions may emerge from recurrent subcortical–cortical feedback loops that cut across network boundaries (Frost & McNaughton, 2017). Building on the available evidence, the review of the literature by Frost and McNaughton (2017) proposed a five-stage model of cognitive processing involved in intertemporal choice, linking each stage to corresponding neural activity and thereby integrating the various networks into a unified framework. These stages include object representation (sensory regions), memory processes (prospection-related areas), valuation (valuation regions), comparison of options (cognitive control regions involved in difficult choices), and motor response (premotor and motor areas) (Figure 3, panel B).

Structural studies

Structural neuroimaging provides a complementary perspective to functional work by capturing relatively stable anatomical features that may constrain or modulate the neural processes underlying intertemporal choice. Although functional studies have extensively characterized the valuation, cognitive control, and prospection networks involved in temporal discounting (Peters & Büchel, 2011), considerably less is known about the anatomical substrates that support individual differences in discounting behavior. A growing, but still limited, body of research has investigated the structural neural correlates of temporal discounting (TD), with most work concentrating on grey matter volume (GMV), cortical thickness (CT), and cortical surface area. Studies in healthy individuals consistently show that steeper discounting of delayed rewards is associated with reductions in several cortical metrics, including lower GMV in the inferolateral prefrontal cortex (PFC), as well as reduced GMV, CT, and surface area in the dorsolateral PFC (Bjork et al., 2009; Drobetz et al., 2014), and decreased GMV in the orbitofrontal cortex (OFC; Li et al., 2019). Subcortical alterations have also been documented, such as reduced volume in the bilateral ventral putamen and prefrontal subgyral regions, alongside increased parahippocampal volume in individuals showing heightened TD (Cho et al., 2013; Yu, 2012). At the cortical level, however, findings diverge, with several studies reporting that greater temporal discounting is associated with increased structural indices. For example, in contrast to Li et al. (2019), Cho et al. (2013) observed that increased GMV and CT in the orbitofrontal gyrus predicted steeper discounting. Additional findings associate higher temporal discounting with increased GMV in the bilateral anterior cingulate cortex (ACC; Li et al., 2019), medial frontal gyri, left middle cingulate (Cho et al., 2013), left middle frontal gyrus, and the right frontal pole (FP; Wang et al., 2016). Beyond this, elevated temporal discounting has also been linked to increased CT in the left lateral FP and to larger cortical surface area in the left FP, OFC, and mid-ACC (Drobetz et al., 2014). A few additional studies have further refined this picture. In the largest adult sample to date (N = 1,038), Owens et al. (2017) found that steeper discounting was associated with reduced GMV across 20 cortical regions, and that total cortical, but not subcortical, GMV predicted discounting behavior. This pattern suggests that temporal discounting reflects widespread cortical organization rather than localized abnormalities in isolated regions. Compelling evidence for the involvement of posterior cortical systems comes from studies of medial temporal lobe structures. More recently, variations in the bilateral ACC grey matter volume (Li et al., 2018) and right inferior frontal sulcus depth (McIntyre-Wood

et al., 2022) have been associated with inter-individual differences in discount rates. Lempert et al. (2020) reported that reduced entorhinal cortical thickness predicted steeper discounting in both healthy older adults and individuals with mild cognitive impairment. This relationship was partially mediated by episodic memory performance, and greater entorhinal thickness was associated with richer perceptual detail in autobiographical memories. However, despite this emerging pattern, the literature remains marked by substantial inconsistencies and methodological limitations. These quantitative measures are plastic and change over time as a result of physiological aging, learning, or the onset of certain diseases (Armstrong et al., 1995, Tudor et al., 2021). It is therefore difficult to determine whether anatomical changes preceded the development of TD or are a neuroplastic consequence of this phenomenon.

Given the distributed and integrative nature of the neural systems supporting temporal discounting, approaches that capture large-scale cortical organization may offer additional explanatory power. In this context, morphological measures, such as sulcal morphology (SM) that assess the morphology of the cortex by estimating the width and depth of several major sulci of the brain have emerged as promising complementary measures. Recent work suggests that sulcal-based measures can outperform traditional morphometric metrics in predicting behaviorally-relevant variability. In particular, qualitative alterations in sulcal patterns have been highlighted as sensitive indicators of structural brain integrity (Tudor et al., 2022). The first study of the present thesis, presented in the following chapter, was therefore aimed at analyzing a qualitative morphological feature, namely the cortical sulcus pattern that, compared to the aforementioned quantitative methods, is relatively stable over time (e.g., Cachia et al., 2018; Mangin et al., 2010). In particular, given the role of the ACC in executive/cognitive control (Alvarez et al, 2006) and its involvement in TD (Schüller et al., 2019), we hypothesize that stable morphological features of ACC influence individual differences in intertemporal choice behaviors.

Lesion studies

Complementing the correlational insights derived from functional neuroimaging, lesion studies provide crucial causal evidence on the neural mechanisms underlying intertemporal choice. One of the first systematic investigations in this domain was conducted by Fellows and Farah (2005), who compared the discounting behavior of individuals with ventromedial prefrontal cortex (vmPFC) lesions, patients with frontal lesions sparing the vmPFC, patients with non-frontal lesions, and healthy controls. While vmPFC patients exhibited a significantly foreshortened personal future time perspective relative to healthy controls, their temporal discounting rates did not differ from those observed in the other patient groups or controls. This dissociation suggested that a reduced subjective temporal horizon does not necessarily translate into steeper discounting, although the authors acknowledged that the task employed may have lacked sensitivity to detect subtle impairments in intertemporal valuation.

Subsequent work has refined this interpretation by highlighting a more specific role of orbitofrontal subregions in the valuation of delayed outcomes. In non-human primates, focal lesions to the medial orbitofrontal cortex (mOFC), but not to adjacent vmPFC regions, resulted in markedly steeper temporal discounting (Rudebeck et al., 2006), indicating that mOFC plays a critical role in evaluating rewards delivered at different delays (Noonan et al., 2010). Importantly, several vmPFC patients in the Fellows and Farah (2005) study had lesions that spared the mOFC, leaving open the possibility that the neural substrate critical for intertemporal valuation had not been fully compromised. However, direct causal evidence for the role of mOFC in human intertemporal choice was later provided by Sellitto and colleagues (2010). Across multiple delay discounting tasks involving both primary and secondary rewards, individuals with focal mOFC lesions showed a preference for immediate options and exhibited significantly steeper discounting than both healthy controls and brain-damaged controls. Lesion extent was positively associated with impatience, providing strong evidence that mOFC integrity is necessary for computing the subjective value of delayed outcomes.

Beyond valuation mechanisms, lesion and disruption studies have highlighted the contribution of additional regions involved in control and conflict resolution. Disruption of lateral prefrontal cortex (LPFC) selectively increases impatient choices when immediate and delayed rewards are in competition, without affecting valuation per se (Figner et al., 2010), suggesting a modulatory role over valuation regions, such as the mOFC. Similarly,

posterior parietal cortex has been implicated in difficult intertemporal decisions, particularly when the subjective values of the options are closely matched (Essex et al., 2012), pointing to the role of a broader frontoparietal network in deliberative choice.

Emerging evidence also indicates that damage to the medial temporal lobe (MTL) can influence intertemporal decision-making indirectly, through impairments in episodic memory and future simulation. Patients with MTL lesions show deficits in episodic future thinking and reduced ability to vividly represent future outcomes, which in turn diminishes the impact of imagined future rewards on choice behavior (Palombo et al., 2014). Nevertheless, while these studies provide compelling causal evidence regarding functional specialization, they offer limited insight into how interindividual variability in brain structure contributes to differences in temporal discounting, an issue that is particularly relevant for regions implicated in conflict monitoring and cost–benefit integration, such as the anterior cingulate cortex.

Impulsive decision-making

In the context of intertemporal choices, people often experience an internal conflict between an impulsive system oriented toward short-term reward and a reflective system capable of evaluating long-term outcomes. This conflict becomes particularly salient when individuals commit to a self-regulated course of action, such as quitting smoking, yet subsequently reverse that intention when an impulsive response prevails. These failures of self-control are commonly interpreted as manifestations of impulsivity, a multidimensional construct encompassing difficulties inhibiting maladaptive behaviors, a preference for immediate rewards, risk-taking, novelty seeking, impatience, and reduced capacity to sustain attention or goal-directed engagement (Evenden, 1999; Mitchell, 2004; Olmstead, 2006; Robbins et al., 2012).

Impulsivity can be conceptualized as a failure to appropriately integrate temporal information, particularly when immediate outcomes are weighted disproportionately relative to delayed ones. Classic theoretical contributions by Ainslie (1975) proposed that impulsive behavior arises from the hyperbolic nature of discounting, which renders immediate rewards disproportionately attractive and destabilizes long-term intentions. Similarly, Rachlin and Green (1972) conceptualized impulsivity as a breakdown of self-control emerging from the temporal structure of choice, while Logue (1988) integrated decades of research on delay of gratification into a unified account linking impulsive responding to temporal valuation. These foundational models established a strong conceptual link between impulsivity and the preference for immediacy, a link later reinforced by computational accounts of self-control (McClure et al., 2004). Despite this influential tradition, the extent to which delay discounting reflects self-control processes remains debated. Not all intertemporal choices require active inhibition: just as a non-smoker exerts no effort to refrain from cigarettes, an individual with a low discounting rate may automatically prefer the delayed reward without engaging regulatory mechanisms. This distinction has led several researchers to argue that discounting tasks alone may not fully capture the regulatory dimension of impulsive behavior (Duckworth & Steinberg, 2015; Lempert & Phelps, 2016).

The relevance of this framework becomes particularly evident in the study of psychopathology. Impulsive decision-making has been identified as a critical factor in the transition from controlled to compulsive substance use. For example, in addictive disorders (AD), impulsivity manifests through reduced ability to delay gratification (e.g., smoking for

immediate reward), heightened risk-taking for uncertain outcomes (e.g., continuing to gamble after a win), and diminished sensitivity to potential losses (e.g., academic or occupational impairment due to excessive alcohol consumption) (Goschke, 2014; Koob & Volkow, 2016). In the same view, converging evidence from a recent meta-analysis indicates that individuals with gambling disorder exhibit broad cognitive and impulsive impairments, including deficits in motor and attentional inhibition, discounting, and decision-making, suggesting a general predisposition toward premature, weakly regulated actions that may contribute to the onset and maintenance of the disorder (Ioannidis et al., 2019).

Finally, recent methodological advances have deepened our understanding of the dynamics underlying impulsive decision-making. Process-tracing studies using mouse-tracking reveal that motor trajectories often deviate toward the immediate reward even when individuals ultimately choose the delayed option, indicating that impulsive tendencies shape not only the final choice but also the unfolding decision process (Calluso et al., 2015, 2017). Individuals with steeper discount rates show stronger and less stable deviations, consistent with a broader vulnerability to premature responding. Neuroimaging evidence complements these findings, showing that such dynamics reflect heightened sensitivity to immediate reward signals and reduced engagement of control-related prefrontal regions (Calluso et al., 2019; 2020; Hare et al., 2009; Kable & Glimcher, 2007). Indeed, impulsive decision-making reflects a dynamic imbalance between neural systems involved in reward valuation and those supporting cognitive control. These findings resonate with transdiagnostic models of psychopathology, such as the RDoC framework, which conceptualize impulsive decision-making as a cross-cutting vulnerability spanning reward valuation, cognitive control, and arousal/regulation systems (Insel et al., 2010).

Temporal Discounting as a Transdiagnostic Factor and Marker of Addictive Behavior

For decades, psychiatry has been animated by the pursuit of neurocognitive mechanisms that transcend the confines of traditional diagnostic categories. Echoing this transdiagnostic ambition, the National Institute of Mental Health's Research Domain Criteria (RDoC) initiative endeavors to chart the fundamental dimensions of cognitive, perceptual, and social functioning that may illuminate novel therapeutic targets. Within this conceptual landscape, the behavioral-economic construct of temporal discounting, capturing the systematic devaluation of rewards as their receipt becomes temporally distant, has assumed a position of prominence (Lempert et al., 2019). Steeper discounting trajectories, typically indexed by a higher temporal discount rate and a lower area under the curve, are widely interpreted as signaling an impulsive preference for immediate gratification over deferred but potentially greater rewards (e.g., Mazur, 1987; Odum, 2011). Notably, elevated temporal discounting has been documented across a diverse array of psychiatric conditions, giving rise to the proposition that excessive devaluation of delayed outcomes constitutes a genuinely transdiagnostic process, one that may offer a unifying lens through which to discern shared mechanisms underlying heterogeneous forms of psychopathology (Amlung, 2019).

Previous narrative reviews by Bickel (2012) and Lempert (2019) have summarized evidence of steep discounting associated with numerous health conditions. Specifically, higher temporal discount rate has been observed in behavioral addictions (Amlung et al., 2017; Cheng et al., 2021; Weinsztok et al., 2021), substance use disorders (Amlung et al., 2017; MacKillop et al., 2011; Strickland et al., 2021), attention-deficit/hyperactivity disorder ADHD (Jackson & MacKillop, 2016; Marx et al., 2021; Mostert et al., 2015), depression (Amlung et al., 2019; Imhoff et al., 2014; Pulcu et al., 2014), bipolar disorder (Ahn et al., 2011; Amlung et al., 2019; Brown et al., 2018), borderline personality disorder (Amlung et al., 2019; Berenson et al., 2016; Paret et al., 2017) and bulimia nervosa (Amlung et al., 2019; Kekic et al., 2016; McClelland et al., 2016).

Nevertheless, emerging data suggests that some types of psychopathologies are linked to discount rates that are lower than those of healthy individuals. For instance, individuals with anorexia nervosa (AN) consume inadequate amounts of food, seemingly

foregoing the immediate reward of food consumption in favor of a potential future reward (further weight loss) (Amlung et al., 2019; McClelland et al., 2016; Steinglass et al., 2012). In a similar prospective, individuals with obsessive–compulsive personality disorder (OCPD) show personality traits of perfectionism and rigidity, as well as ritualized behaviors (Pinto et al., 2014), without the intrusive obsessions seen in obsessive–compulsive disorder (OCD). Therefore, the existing literature suggests that delay discounting lies on a continuum (see Figure 3 below in Lempert (2019)). Indexing the location of different disorders along this continuum may elucidate the degree to which delay discounting should be considered as a viable and necessary treatment target in the pursuit of ameliorating transdiagnostic symptoms.

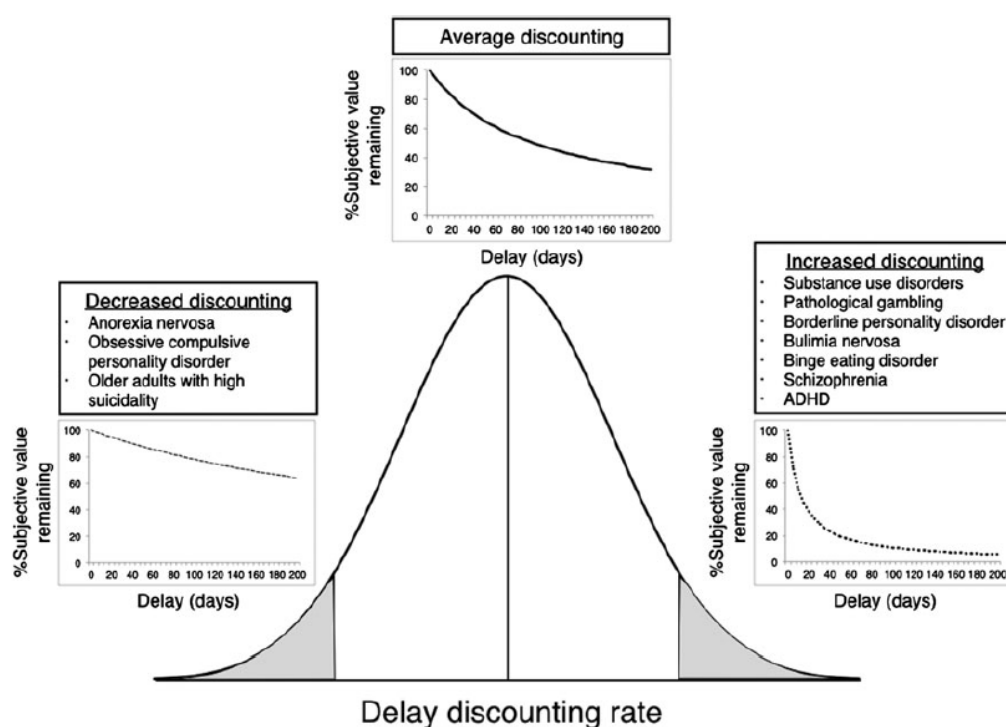


Figure 3. Hyperbolic delay discounting rates lie on a spectrum. Most individuals discount delayed rewards to some degree, but psychopathology has been associated with discounting delayed rewards too little (left) or too much (right) (Lempert et al., 2019).

Although many studies have examined how temporal discounting relates to different mental disorders, most have relied on traditional case–control comparisons. As a result, we still know relatively little about which underlying, cross-cutting psychological factors drive these associations. This gap likely reflects the limitations of current diagnostic systems, which group individuals by symptom clusters rather than by the processes that

cut across disorders. An alternative approach is to shift the focus away from diagnostic labels and instead investigate the specific psychological traits that co-occur with patterns of delay discounting across multiple conditions. For example, anorexia nervosa is classified as an eating disorder, yet it also shares features such as avoidance and persistent anxious preoccupations with disorders like obsessive–compulsive disorder (OCD) and social anxiety disorder (SAD). In a study comparing individuals with AN, OCD, SAD, and healthy controls, higher trait anxiety predicted a stronger preference for delayed rewards (Steinglass et al., 2017) suggesting that different traits may relate to temporal discounting in distinct ways: impulsivity may promote steeper discounting, whereas anxiety may be associated with more patient decision-making. Viewing psychopathology dimensionally may therefore clarify why results on delay discounting remain mixed in certain diagnostic groups, including autism spectrum disorders and major depressive disorder (Dombrovski et al., 2011; Carlisi et al., 2017).

However, delay discounting is not only relevant in clinical contexts, playing a significant role also in nonclinical situations. For example, it can impact welfare policy decisions and financial choices, where failing to consider future outcomes may lead to suboptimal decisions (Angeletos et al., 2003; Vanderveldt et al., 2016). Higher temporal discounting is associated with higher credit debts (Meier & Sprenger, 2010), less creditworthiness (Meier & Sprenger, 2012) and later uptake of welfare programs (Fang & Silverman, 2006). On the other hand, studies in the educational and work context found that people with higher discount rates have lower academic attainment (Freeney & O'Connell, 2010), put less effort into searching for a good job (Della Vigna & Paserman, 2005), have lower job satisfaction (de Ruijter et al., 2023) and experience lower wage growth (Munasinghe & Sicherman, 2005). Moreover, research on college students has shown that steeper delay discounting is linked not only to greater substance use but also to earlier initiation and a broader range of substances consumed (Kollins, 2003), suggesting that temporal discounting captures a core aspect of impulsive decision-making that may contribute to vulnerability to addictive behaviors even in non-clinical young adult samples. Based on these promises, a second study presented here, in Chapter 3 of the present thesis seeks to advance current knowledge by examining how temporal discounting relates to psychological risk factors implicated in vulnerability to addictive behaviors within a university student population.

Temporal Discounting as Trait or State

As a multicomponent construct, intertemporal choice and TD are sensitive to both state and trait influences (Odum and Baumann, 2010). That is, individual differences in discount rate can be attributable not only to traits (i.e. differences between subjects, such as genetic factors or personality), as just reported above, but also to internal state features (i.e. differences within the same subject, such as stress or hunger) and aspects of the situation, such as reward type (Kirby 2009; Peters and Büchel, 2011). A state variable influences behavior over a relatively short time frame, whereas a trait variable is a relatively stable pre-existing characteristic an individual brings to a situation. State variables shown to affect the degree of discounting include the type of outcome (e.g., Madden et al., 1997; Odum and Rainaud, 2003), the magnitude of an outcome (e.g., Green et al., 1997), and the context in which a choice is made (e.g., Dixon et al., 2006).

Several trait variables have been shown to affect the degree to which an outcome is discounted as well. For example, steeper discounting is associated with more fatalism (Johnson et al., 2010), less agreeableness (Miller et al., 2008) and less empathy (Kirby et al., 1999) as measured by personality scales. Similarly, certain psychiatric conditions, such as disinhibitory behavior problems and antisocial personality disorders (e.g., Bobova et al., 2009; Crean et al., 2000; Petry, 2002), as well as pathological gambling and drug abuse, are associated with elevated levels of delay discounting (see Petry and Madden, 2010 for review). It is interesting, however, that self-report measures of impulsivity have weak and often inconsistent relations to the degree of delay discounting across studies (e.g., Bobova et al., 2009; Janis and Nock, 2009; Perales et al., 2009; Smith and Hantula, 2008; see de Wit et al., 2007 for review). These inconsistencies may be partly explained by the fact that self-report scales measure multiple facets of impulsivity, including the tendency to act without thinking and the inability to withhold a pre-potent response, rather than aspects that are more specifically related to sensitivity to delayed outcomes.

Delay Discounting as a Trait

Despite well-documented associations between delay discounting and a range of personality-related characteristics, surprisingly little work has directly addressed whether discounting itself should be regarded as a personality trait (de Wit, 2008; Kirby, 2009). Personality traits are commonly defined as “relatively enduring patterns of thoughts,

feelings, and behaviors that reflect stable tendencies to respond in particular ways under specific circumstances” (Roberts, 2009). This definition naturally raises the question of whether an individual’s characteristic degree of temporal discounting constitutes a direct expression of such a dispositional tendency.

A first criterion for establishing a trait is temporal stability. In this respect, delay discounting demonstrates consistently strong test–retest reliability across a variety of tasks, reward magnitudes, and populations. Simpson and Vuchinich (2000), for example, reported exceptionally high reliability over a one-week interval using a hypothetical monetary choice task, and substantial stability has been observed even across a full year (Kirby, 2009). Comparable findings have been replicated in numerous studies employing different methodologies and samples (e.g., Baker et al., 2003; Beck & Triplett, 2009; Black & Rosen, 2011; Ohmura et al., 2006; Takahashi et al., 2007). However, although these results indicate that discounting is relatively stable over short and medium time spans, further research is needed to determine whether this stability extends across longer developmental periods.

A second criterion for defining a trait is cross-situational consistency: the tendency to respond in similar ways across different contexts, without requiring identical behavior in every circumstance (Roberts, 2009). In the domain of delay discounting, this criterion can be evaluated by examining whether individuals show similar discounting patterns across different types of outcomes. A substantial body of research demonstrates that individuals with opioid dependence, for instance, discount heroin more steeply than equivalent amounts of money (Madden et al., 1997), a pattern replicated across numerous substances including alcohol, cocaine, marijuana, and nicotine (e.g., Bickel et al., 1999; Coffey et al., 2003; Johnson et al., 2010; Petry, 2001). Importantly, this difference is not restricted to clinical populations: even individuals without problematic drinking discount alcohol more steeply than money (Odum & Rainaud, 2003). Similar gradients have been observed for a wide range of non-drug outcomes, including food, beverages, and various forms of entertainment (e.g., Estle et al., 2007; Odum & Baumann, 2007; Odum & Rainaud, 2003; Odum et al., 2006; Charlton & Fantino, 2008). These cross-commodity comparisons provide a valuable means of assessing whether discounting reflects a stable response tendency. If impatience functions as a trait, individuals who discount one type of reward steeply should also discount other rewards steeply, regardless of the specific commodity being evaluated or the contextual features surrounding the choice. This pattern of cross-outcome consistency would indicate that discounting reflects an underlying

dispositional tendency rather than a series of isolated, context-bound decisions. Overall, these findings indicate a meaningful degree of cross-situational consistency, supporting the view that discounting reflects a stable dispositional tendency.

Delay Discounting as a State

Another development stemming from Petry's (2001) work was the recognition that delay discounting offers a powerful lens for examining state influences on impulsive choice (Odum, 2011b). State influences refer to temporary shifts in discounting produced by situational variables, and one of the clearest demonstrations of this comes from comparing how different outcomes are discounted across different conditions. A large body of research shows that discounting rates vary systematically across commodities and fluctuate in response to transient physiological, emotional, and contextual conditions. Acute stress and negative affect, for example, reliably increase preference for immediate rewards (Field et al., 2006; Lempert et al., 2012), while states of deprivation, such as hunger, craving, or withdrawal, steeper discounting for relevant outcomes by enhancing the motivational salience of immediate reinforcement (Giordano et al., 2002; Amlung et al., 2011). Even subtle contextual manipulations, including framing, priming, or perceived resource scarcity, can modulate discounting (Kim & Zauberman, 2013; Haushofer & Fehr, 2014). State-dependent variability is also evident in the classical finding that money is discounted less steeply than primary or consumable rewards such as food, alcohol, and drugs (Madden et al., 1997; Estle et al., 2007). These differences reflect dynamic shifts in subjective value that depend on an individual's current motivational state: people with substance-use disorders discount their drug of choice more steeply than equivalent amounts of money, and similar patterns appear in non-clinical populations when the outcome aligns with immediate needs or desires (Odum & Rainaud, 2003).

Within this context, two hypotheses have been proposed to explain why addictive substances are discounted more steeply than money. The Withdrawal Hypothesis suggests that substances associated with a physical withdrawal syndrome are discounted more steeply because of the importance of avoid or alleviate withdrawal. However, this account cannot fully explain the evidence that addictive substances are discounted more steeply also when individuals know they would not experience withdrawal (Petry, 2001). This limitation has led to the Addiction Hypothesis, which posits that individuals who are susceptible to abusing a substance discount that substance more steeply than money regardless of their current withdrawal state. This perspective explains why people in

recovery from alcohol misuse continue to discount alcohol more steeply than monetary rewards, even in the absence of acute withdrawal. Together, these observations highlight that the steep discounting of addictive substances reflects not only enduring vulnerabilities but also state-dependent motivational processes that transiently amplify the value of immediate consumption.

To sum up, substantial evidence indicates that delay discounting is sensitive to both state and trait influences (see Odum and Baumann, 2010, for review). A state variable influences behavior over a relatively short time frame, whereas a trait variable is a relatively stable pre-existing characteristic an individual brings to a situation.

Implications for interventions aimed at reducing temporal discounting

Thus far, temporal discounting has been characterized as a core mechanism underlying intertemporal decision-making and a potential behavioral marker of vulnerability to maladaptive and addictive behaviors. Steep discounting reliably predicts poorer outcomes during substance-use treatment (Stanger et al., 2012; Washio et al., 2011), greater likelihood of relapse following treatment completion (MacKillop & Kahler, 2009; Sheffer et al., 2014), and higher relapse rates even among individuals who quit without formal intervention (Yoon et al., 2007). Given the potential role of temporal discounting in maladaptive behaviors, many efforts have been made to identify experimental manipulations that reduce temporal discounting. Indeed, certain laboratory manipulations in both healthy individuals and psychiatric populations can shift discount rates in predictable ways (MacKillop et al., 2011; Lempert and Phelps, 2016). For example, enhancing individuals' awareness of future outcomes, or increasing the subjective value they assign to those outcomes, tends to reduce temporal discounts (Bartels & Urminsky, 2015). One illustrative example comes from reframing choices to include explicit zeros (e.g., "\$10 today and \$0 in two weeks" versus "\$0 today and \$20 in two weeks"), a manipulation that reliably shifts preferences toward delayed rewards (Radu et al., 2011). By making the foregone future payoff more salient, this framing highlights the implicit costs of opting for the immediate reward. Similarly, instructing participants to reflect on such opportunity costs also leads to lower discount rates (Senecal et al., 2012).

Among the most robust approaches to reduce discounting is episodic future thinking (EFT), which refers to the mental simulation of events that may take place in one's personal future. It has been proposed that the capacity for episodic future thinking serves to make future outcomes more concrete to guide intertemporal decision-making (Boyer, 2008; Bulley et al., 2016). EFT reliably reduces discounting in healthy adults (Peters & Büchel, 2010; Benoit, Gilbert, & Burgess, 2011) and in clinical populations, including smokers (Daniel, Stanton, & Epstein, 2013) and individuals with obesity (Stein et al., 2016). Positive affective manipulations, such as recalling gratitude or nostalgic experiences, have similarly been associated with more patient intertemporal choices (DeSteno et al., 2014; Huang et al., 2016), although recent evidence suggests that positive memory recall alone may not reliably reduce discounting (Lempert et al., 2024).

Interventions targeting executive functions also show promise. Working memory and inhibitory control training have been found to attenuate impulsive choice, with individuals demonstrating increased preference for larger, delayed rewards following cognitive training (Bickel et al., 2011; Franco-Watkins et al., 2010). Bickel et al. (2011) showed that targeted working memory training can significantly reduce delay discounting among stimulant-dependent individuals. Participants who completed an intensive working memory program exhibited a marked increase in preference for larger, delayed rewards relative to an active control group, suggesting that strengthening executive resources enhances the capacity to value future outcomes. Alongside, Franco-Watkins, Pashler, and Rickard (2010) similarly found that cognitive training tasks engaging executive control processes can reduce temporal discounting in healthy adults, suggesting that strengthening the ability to maintain goal-relevant information supports more future-oriented choice behavior. Notably, Aranovich et al. (2016) observed that the magnitude of the cognitive-challenge effect, such as the temporary reduction in temporal discounting following engagement in a demanding cognitive task was inversely related to participants' baseline working memory performance. Individuals with higher working memory capacity showed little to no reduction in discounting, and in some cases even exhibited slight increases, following cognitive challenge, suggesting that greater baseline executive resources may buffer cognitive control processes against transient perturbations. This pattern indicates that the efficacy of acute cognitive engagement in modulating intertemporal choice may depend on the integrity of underlying working memory mechanisms.

Complementing this cognitive-training approach, mindfulness-based interventions offer a parallel pathway for reducing temporal discounting. Both brief mindfulness inductions and trait mindfulness are associated with lower discounting, likely through improved emotion regulation and reduced reactivity to immediate affective cues (Canali, 2021; Hendrickson & Rasmussen, 2013). Consistent with this pattern, clinical studies indicate that mindfulness-based emotion-regulation protocols can reduce discounting among individuals with addictive behaviors (Blackburn et al., 2021).

Altogether, the evidence reviewed in this chapter highlights temporal discounting as a multifaceted construct shaped by behavioral tendencies, contextual influences, and large-scale neural systems. By integrating perspectives from decision science, affective neuroscience, and psychopathology, temporal discounting emerges not only as a

fundamental mechanism of intertemporal choice but also as a promising marker of vulnerability for maladaptive behaviors. The following sections of the dissertation build on this foundation by examining how stable neuroanatomical features may contribute to individual variability in discounting (Study 1), how discounting tendencies relate to psychological vulnerability in emerging adults (Study 2), and how these insights can inform preventive, interventional strategies aimed at reducing addiction-related risk (Study 3). In this way, the theoretical principles outlined here serve as the conceptual anchor for the empirical and applied investigations that follow, allowing temporal discounting to be explored across complementary levels of analysis.

Chapter 2

STUDY 1

Asymmetry of the sulcal pattern of the Anterior Cingulate Cortex Modulates Delay Discounting

The broad overview of temporal discounting presented above highlights substantial inter-individual variability in the tendency to devalue delayed rewards, yet the neurobiological sources of this variability remain insufficiently understood. Functional neuroimaging studies have consistently implicated the valuation, prospection, and executive-control systems in intertemporal choice, with the anterior cingulate cortex (ACC) emerging as a key region for conflict monitoring, cognitive control, and the integration of value signals during decision-making (Botvinick et al., 2004; Kable & Glimcher, 2007; Peters & Büchel, 2011). More recently, structural neuroimaging studies have begun to investigate the anatomical underpinnings of DD by examining cortical thickness (Sadeh et al., 2023), grey matter volume (Wang et al., 2017), and white matter integrity (Han et al., 2018; Olson et al., 2009) related to the anterior cingulate cortex (ACC). Moreover, inter-individual differences in discount rates have been linked to variations in bilateral ACC grey matter volume (Li, Hu, & Liu, 2019) and to the depth of the right inferior frontal sulcus (McIntyre-Wood et al., 2022). However, structural investigations have largely focused on quantitative measures such as cortical thickness, grey matter volume, or white-matter integrity, features that are plastic and subject to change across development, learning, and disease, making it difficult to determine whether anatomical differences precede or follow the emergence of discounting tendencies.

To overcome these limitations, we analyzed a qualitative feature of the cortex, namely the sulcal pattern, which is established during fetal development and remains stable throughout life (Cachia et al., 2021). Unlike the aforementioned quantitative features, sulcal patterns are determined during fetal life (between 10 and 15 weeks for the ACC) and are already evident at birth, in the same way as is observed in human adulthood (Chi et al., 1977; Mangin et al., 2010; Zilles et al., 2013). Moreover, the morphological pattern does not change over time, as established by longitudinal studies (Cachia et al., 2016; Schwizer Ashkenazi et al., 2024; Tissier et al., 2018). In light of these peculiarities, in recent years the influence of sulcal patterns on cognition has drawn increasing attention

from several researchers who proposed the idea that certain morphological patterns may be statistically advantageous for cognitive development (Cachia et al., 2021; Santacroce et al., 2024; Tissier et al., 2018), serving as a sort of positive “neural fingerprint”. Several studies have investigated the anterior cingulate cortex (ACC) and its two morphological variants, defined by the presence (“double parallel pattern”) or absence (“single pattern”) of the paracingulate sulcus (PCS), which runs dorsal and parallel to the (always present) cingulate sulcus. In particular, the asymmetry of the ACC patterns (e.g., a double parallel pattern in one hemisphere and a single pattern in the other) has been repeatedly associated with better performance on cognitive control tasks both in adults (Fornito, 2004; Huster et al., 2009; Tissier et al., 2018) and children (Borst et al., 2014a; Cachia et al., 2014).

Given the role of the ACC in executive/cognitive control (Alvarez & Emory, 2006; Petersen & Posner, 2012) and its involvement in DD (Schüller et al., 2019; Seamans et al., 2024), we hypothesized that these stable morphological features might explain individual differences in intertemporal choice behavior. Building on this premise, our study aimed to examine the relationship between ACC sulcal morphology and delay discounting behavior in a large sample of healthy young adults (N=390) provided by the Human Connectome Project (HCP). Given the known association between the ACC sulcal pattern asymmetry and the efficiency of cognitive control, in addition to the involvement of the ACC in DD discounting reported in previous studies, we hypothesized that individuals with an asymmetric ACC sulcal pattern might have lower temporal discounting rates compared to those with a symmetric pattern (i.e. choose the immediate reward less). The specificity of this relationship was assessed by controlling for the effect of a different sulcus (i.e., the intraparietal sulcus, IPS) along with other cognitive measures (e.g., memory and language). Although our main objective was to study the morphology of the ACC sulcus as defined by the presence or absence of the paracingulate sulcus, the morphological variability of the cingulate sulcus itself has also been examined using morphometric and qualitative morphological descriptors, albeit in less depth and mainly in clinical populations (Li et al., 2021; Meredith et al., 2012). Accordingly, in addition to ACC/PCS-based pattern classification, we investigated whether the symmetry or asymmetry of the cingulate sulcus interruption was associated with delay discounting in our sample.

By focusing on stable, in utero-determined, morphological features, this research represents a first step to test whether steady structural configurations of the ACC provide a neural predisposition for the tendency to devalue future rewards across the lifespan.

Understanding this relationship may have important implications for interventions targeting cognitive control mechanisms in disorders characterized by impulsive decision-making.

This paper has been accepted for the publication in the *Brain Structure and Function* journal as: “Asymmetry of the sulcal pattern of the Anterior Cingulate Cortex Modulates Delay Discounting” by Federica Santacrocce*, Federica Procida*, Antonello Baldassarre, Arnaud Cachia, Carlo Sestieri, Giorgia Committeri.

Methods and Materials

Participants

Participants were extracted from the 1200 Subjects Release (S1200) of the Human Connectome Project (HCP) dataset, with the following inclusion criteria: age range: 26–30 years old; MRI field: 3T, DTI data (not analyzed for this study). Participants with quality control issues

(https://humanconnectome.org/storage/app/media/documentation/s1200/HCP_S1200_Release_Reference_Manual.pdf), major neurological diseases and psychiatric or medical disorders were excluded. A total of 390 participants (173 males, 44%) were included in the study. Participants gave informed consent, and all recruitment and acquisition methods were approved by the Washington University Institutional Review Board (IRB), following relevant guidelines and regulations.

Cognitive measures

The behavioral indices used in this study were derived from a Principal Component Analysis (PCA) performed by Santacrocce et al. (2024) on all cognitive measures available in the HCP database (18 behavioural measures/metrics derived from 12 different cognitive tasks within 8 general cognitive domains). In particular, as a measure of DD, we used the third factor of the PCA, which explained 8.9% of the total behavioural variance and captured two self-regulation/impulsivity tasks typically used to assess delay discounting (https://humanconnectome.org/storage/app/media/documentation/s1200/HCP_S1200_Release_Reference_Manual.pdf). In the two self-regulation/impulsivity tasks, DD was measured using the area under the curve (AUC) approach, which quantifies an individual's tendency to discount delayed rewards (Green & Myerson, 2004; Myerson et al., 2001). In particular, the AUC reflects the subjective decline in the value of delayed rewards over time, with smaller areas indicating greater discounting and larger areas indicating weaker

discounting. The task followed an adjustment titration paradigm (Estle et al., 2006) in which fixed reward delays were paired with dynamically adjusted reward amounts until an indifference point was reached, representing the delay at which a participant equated a smaller immediate reward with a larger delayed reward. Participants chose between a smaller immediate reward and a larger delayed reward across six delays (1 month, 6 months, 1 year, 3 years, 5 years, 10 years) and two reward amounts (\$200; \$40,000). Each condition consisted of five trials, with the final choice determining the indifference point. On the first trial, the immediate reward was set at 50% of the delayed amount and adjusted up or down based on the participant's choice. Subsequent adjustments followed a fixed proportion of the previous change, rapidly converging on the indifference point for each delay-reward pair. These points were then used to calculate the AUC for each reward level.

As a behavioural control measure to assess the specificity of the relationship between ACC morphology and DD, we used the first factor of the PCA, which explained 20.6% of the behavioural variance and captured performance on memory and language tasks.

MRI acquisition and pre-processing

The 3T anatomical MRI included in the HPC dataset corresponded to T1-weighted images acquired on Siemens 3T “Connectome Skyra” scanner using a 3D Magnetization Prepared Rapid Acquisition Gradient Echo (MPRAGE) sequence (TR = 2400 ms; TE = 2.14 ms; TI = 1000 ms; flip angle = 8°; FOV = 224 × 224 mm; voxel size = 0.7 mm isotropic). The MRIs were preprocessed using the standard FreeSurfer pipeline used in HCP (Glasser et al., 2016). T1 MRIs were volumetrically registered to the MNI152 space using nonlinear FNIRT followed by surface registration to Conte69 ‘164k_fs_LR’ mesh (Van Essen et al., 2012), with FreeSurfer fsaverage as an intermediate.

Based on each participant's MRI scan, a 3D model of the cortical surface was reconstructed using FreeSurfer 5.2. This 3D model included the segmentation of the white matter, the tessellation of the grey/white matter boundary, the inflation of the folded, tessellated surface, and the correction of topological defects.

Characterization of the sulcal pattern

Following the same approach developed in our previous work³⁶, the sulcal maps were superimposed on the corresponding highly inflated and pial surfaces for each participant to visualize the morphology of the ACC, using the Connectome Workbench visualization software. The sulcal pattern of the dorsal ACC was characterized according to Ono's classification⁵⁰ by visually inspecting each individual's 3D mesh-based reconstruction. All MRI data were anonymized, and the ACC sulcal pattern was classified by two raters (FS and FP). The inter-rater reliability yielded an agreement of 92,82% regarding the presence of the single vs. double-parallel ACC pattern for both the left and right hemispheres. Sulcal pattern labeling was performed blind to potential confounds such as participants' age, label in the contralateral hemisphere, and previously labeled IPS sulcal pattern. After that, all discrepant or doubtful cases (N=28, for each hemisphere) were re-examined by a third expert (GC). This process ensured a final agreed-upon label for every doubtful case, such that no commonly rated case remained unclear and no participant was excluded.

The ACC sulcal pattern was classified into two anatomical variants according to Ono's classification⁵⁰ ("single type" or "double parallel type"), based on the absence/presence of the paracingulate sulcus (PCS), respectively (see Figure 1 for representative examples). The PCS, when present, was located dorsally to the cingulate sulcus and ran parallel to it⁵¹. To disambiguate the confluence of the PCS with the superior rostral sulcus (SRS), we defined the anterior border of the PCS as the point where the sulcus extended posteriorly beyond an imaginary vertical line perpendicular to the axis connecting the anterior and posterior commissures (AC-PC)⁵². The PCS was only considered to be present if it extended at least 20 mm horizontally beyond this imaginary vertical line. The sulcal pattern was considered "symmetric" if it was the same in both hemispheres and "asymmetric" if it differed between the hemispheres. In addition, we characterized the variability of the cingulate sulcus (CS) with respect to sulcal interruptions. Details regarding this further morphological classification are reported in the Supplementary Materials.

The procedure for the characterization of the IPS, used as a control sulcus in the present study, has been described in detail in our previously published study³⁶. Briefly, IPS morphology can have two different sulcal patterns: the "interrupted pattern," when the course of IPS showed one or more interruptions by a cortical gyrus, and the "continuous pattern," when no interruptions were detected. Since our previous study already

demonstrated that neither the right nor the left hemisphere IPS pattern influenced DD, here we further control for the IPS symmetric/asymmetric pattern to ensure that the effect of cortical morphology on delay discounting is not generalized but specifically related to the ACC. Similar to the ACC, the symmetry/asymmetry IPS sulcal pattern was defined as “symmetric” if the sulcal pattern was identical in both hemispheres and “asymmetric” if it differed between the hemispheres.

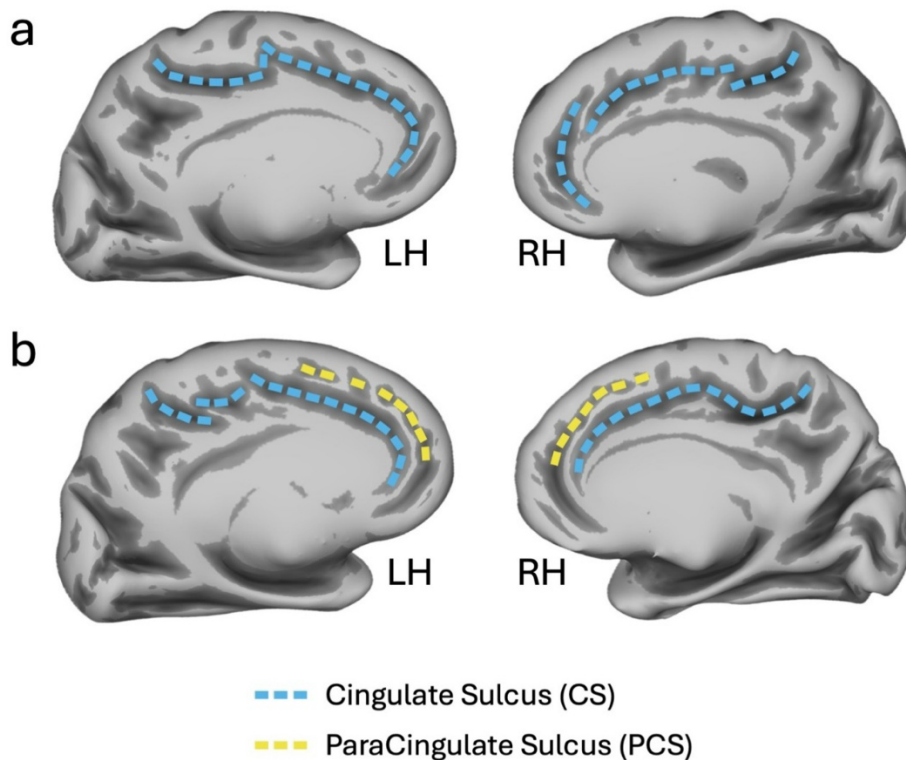


Figure 1. Sulcal pattern of the anterior cingulate cortex (ACC). a) Exemplars of single patterns in which only cingulate sulcus is present (sulci shown with cyan dashed lines). b) Exemplars of double-parallel patterns in which both cingulate (sulci shown with cyan dashed lines) and paracingulate (sulci shown with yellow dashed lines) sulci are present. LH left hemisphere, RH right hemisphere.

Statistical analysis

Based on the classification of the ACC pattern in each participant, an exact binomial test with exact Clopper-Pearson 95% CI was performed to examine the difference in

distribution between the “single” and “double parallel” patterns in the left and right hemispheres and between the symmetry and asymmetry distributions. To compare the distribution of the ACC pattern and its left-right asymmetry in our sample versus that obtained in previous studies with healthy adults^{35,52} and children^{35,39,40}, we performed a chi-square (χ^2) test with post-hoc pairwise comparisons, adjusted by Bonferroni correction, controlling for the sample size.

We then investigated the association between ACC individual morphological variability and DD rate using a Generalized Linear Model (GLM) including the ACC pattern symmetry/asymmetry and sex as categorical factors and the third factor of the PCA (delay discounting) as dependent variable. Sex was included in the analysis because of its effect on cortical morphology^{53,54}. Detailed analyses and results on the potential effect of the CS interruptions and their symmetry/asymmetry are reported in the Supplementary Materials.

To test the specificity of the ACC/DD relationship, we performed a similar GLM, adding the symmetrical/asymmetrical pattern of the IPS as further morphological variable and the first two factors of the PCA (memory and language, executive functions) as further behavioral variables. Specifically, the symmetrical/asymmetrical pattern of the ACC and the symmetrical/asymmetrical pattern of the IPS were included in the control GLM as fixed factors, and the first (memory and language), second (executive functions), and third (delay discounting) factors of the PCA as the dependent variables.

For completeness of analysis, we performed an additional single GLM entering all individual PCA metrics/tasks as dependent variables in relation to ACC morphology and sex as independent variables. The results are presented in Table S2 of the Supplementary Materials.

Results

Sulcal pattern distribution and comparison with previous studies

The manually labeled ACC patterns were classified by two raters (FS and FP) into two types based on the presence (double parallel type) or absence (single type) of the PCS. The inter-rater reliability yielded an agreement of 92.82% regarding the presence of the single vs. double-parallel ACC pattern for both the left and right hemispheres.

The ‘single’ type was found in 81.28% of the right hemispheres and 53.85% of the left. Our sample was nearly evenly divided between symmetrical and asymmetrical patterns, with 51.54% being symmetrical and 48.46% being asymmetrical.

A binomial test showed a significant difference in the number of “single” and “double parallel” ACC patterns in the right hemisphere ($p < 0.001$, 95% CI of 77.4%-85.1%), the “single” being more represented than the “double parallel” type. In contrast, there was no significant difference in the proportion of “single” and “double parallel” ACC patterns in the left hemisphere ($p = 0.14$, 95% CI of 49.0%-58.7%) and no significant difference between symmetric and asymmetric ACC ($p = 0.57$, 95% CI of 46.7%-56.4%). The ACC pattern distributions are shown in Figure 2.

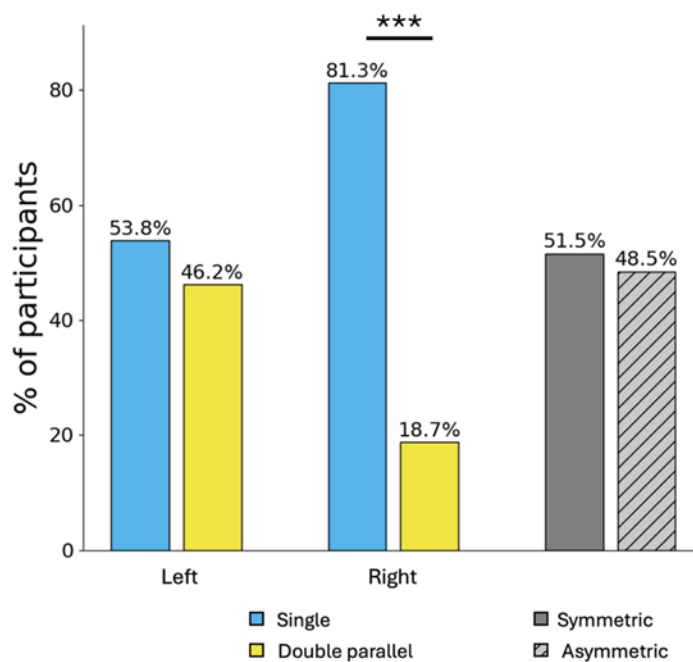


Figure 2. Sample distribution of the ACC sulcal pattern. Percentage of participants with single (in cyan) and double parallel (in yellow) patterns in both left and right hemispheres, and percentage of the same participants divided into symmetrical (dark grey) and asymmetrical (light grey with oblique lines) patterns. *** $p < 0.001$; sample size $n = 390$.

The chi-square (χ^2) analysis, controlling for the sample size, revealed a significant difference among the five studies regarding the frequency distribution of the left ($\chi^2 = 53.6998$, $df = 4$, $p < 0.001$) and right ($\chi^2 = 20.0947$, $df = 4$, $p < 0.001$) ACC pattern as well as of the ACC symmetry/asymmetry ($\chi^2 = 36.7340$, $df = 4$, $p < 0.001$) (see Figure 3 and Table 1 for details). Post-hoc pairwise comparisons showed that in the study by Tissier and colleagues³⁵, the frequency of the double pattern of the left ACC was higher than that observed in all other studies (all $p < 0.001$). For the right hemisphere, Tissier’s and Borst’s samples showed a more balanced distribution of the two patterns than in the present study

(both $p < 0.001$). Regarding the distribution of symmetry/asymmetry, Tissier's cohort showed a higher prevalence of the asymmetric pattern than all other studies (all $p < 0.001$). Details of post-hoc pairwise comparisons are reported in the Supplementary Table S1.

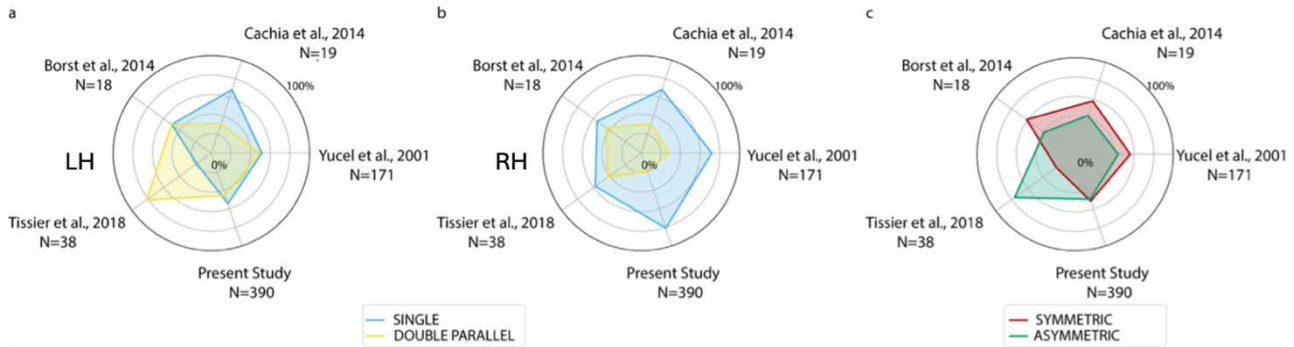


Figure 3. Comparison with previous studies. Comparison between the present and previous studies of ACC sulcal pattern sample distribution. The cyan lines represent the “single” pattern and the yellow lines the “double-parallel” pattern, in the a) left (LH) and b) right (RH) hemispheres. The red line represents the “symmetric” pattern and the green line the “asymmetric” pattern (c).

Relation between ACC symmetry/asymmetry and delay discounting

The relationship between the ACC symmetry/asymmetry and the DD rating was assessed using a Generalized Linear Model (GLM) including the ACC symmetry/asymmetry (“symmetric” vs “asymmetric”) and sex (“males” vs “females”) as categorical factors and the third factor of the PCA (reflecting the delay discounting measure) as the dependent variable.

This analysis revealed a main effect of the ACC sulcal pattern asymmetry ($\beta = 0.2117$, $df = 1$, $p = 0.036$), whereas no effect was found for sex ($\beta = -0.01510$, $df = 1$, $p = 0.137$). In particular, an asymmetric pattern of ACC was associated with a higher AUC, indicating a less steep discounting of delayed rewards (see Figure 4).

To test the specificity of the ACC effect on the DD measure, we 1) added a categorical factor related to the IPS asymmetry (“symmetric” vs. “asymmetric”) in the previous GLM and 2) also analyzed the first (memory and language) and the second (executive functions) factor of the PCA as a dependent variable. The analysis confirmed the main effect of ACC symmetry/asymmetry on DD ($\beta = 0.2059$, $df = 1$; $p = 0.042$), but no significant results were found for the two additional PCA factors (both $p > 0.05$). Again, an asymmetric pattern of the ACC was associated with a higher AUC. Conversely, the symmetry/asymmetry of the IPS pattern did not affect DD (see Figure 4), demonstrating a

morphological dissociation ($p = 0.519$). Finally, there was no significant effect of the IPS symmetry/asymmetry on the first ($\beta = -0.0254$, $df = 1$, $p = 0.809$) and second ($\beta = -0.1301$, $df = 1$, $p = 0.209$) factors of the PCA.

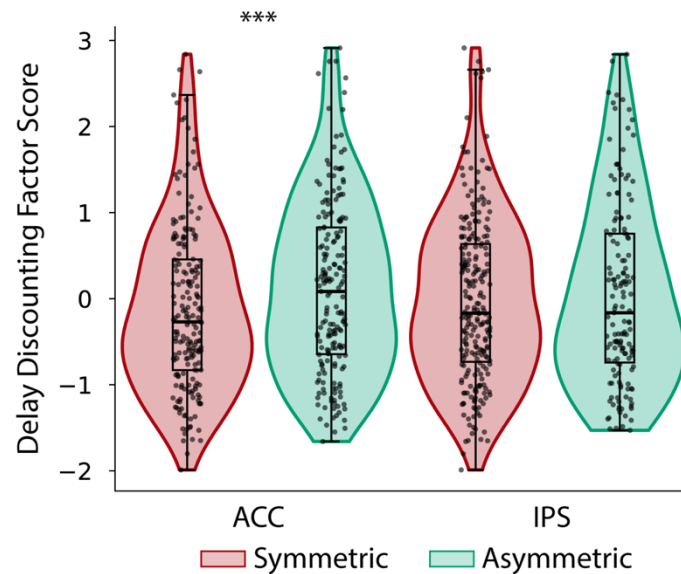


Figure 4. ACC symmetry/asymmetry pattern and Delay Discounting. Violin and box plot with individual data points represent the scores of the Delay Discounting Factor in participants with symmetric (red box) and asymmetric (green box) ACC (left boxes) and IPS (control sulcus, right boxes). Boxes indicate the interquartile Range (IQR, data points included between the first quartile, 25th percentile, and the third quartile, 75th percentile); horizontal black lines indicate the median (50th percentile). The whiskers go from the minimum to the lower quartile (the start of the box) and then from the upper quartile (the end of the box) to the maximum. *** $p < 0.05$; sample size $n = 390$.

Discussion

The present study provides the first evidence that a stable, in utero-determined morphological feature of the anterior cingulate cortex (ACC) is associated with interindividual differences in delay discounting (DD) behavior. Our results indicate that individuals with an asymmetric ACC sulcal pattern are less prone to discounting future rewards compared to those with a symmetric pattern, suggesting a greater ability to value delayed outcomes. This finding is possibly due to enhanced cognitive control mechanisms, consistent with previous evidence linking ACC asymmetry to better cognitive control (Fornito et al., 2004). Notably, this effect was not observed in relation to other cognitive domains, including memory and language, or morphological features (the symmetry of the interruption pattern of either the CS or the IPS).

Our findings are consistent with previous studies that highlight the ACC as a critical hub in the brain network of decision making, mediating conflict monitoring, effort allocation, and reward evaluation^{55,56}, all aspects that are central to discounting behavior. Such cognitive functions, which require the involvement of many high-level processes, need to be viewed from a network perspective. The main effect of ACC asymmetry on DD observed in the present study underscores the importance of inter-hemispheric communication, and particularly the critical role of structural brain asymmetries in shaping intertemporal decision-making. Specifically, our results show that individuals with an asymmetric ACC sulcal pattern exhibit a higher area under the curve (AUC) in DD tasks, indicating a more patient evaluation of delayed rewards compared to individuals with a symmetric ACC pattern. This suggests that the structural hemispheric asymmetry within the ACC may shape the development of cognitive control mechanisms, supporting the ability to prioritize long-term benefits over immediate gratification. Conversely, the presence of hemispheric symmetry may impose constraints on the development of efficient cognitive control mechanisms, potentially limiting the ability to delay gratification.

The presence of structural asymmetry in the ACC is likely to reflect intra-hemispheric specialization, reducing duplication and improving neural efficiency⁵⁷, as information transfer is more efficient between nearby areas within the same hemisphere than between distant regions across both hemispheres^{58,59}. The asymmetry of the ACC may foster the effective integration between reward valuation, e.g., through intra-hemispheric connections with the limbic system and vmPFC^{60,61}, and behavioral regulation, e.g., through intra-hemispheric connections with the dlPFC^{62,63}. This may explain why individuals with an asymmetric ACC sulcal pattern show a greater ability to resist impulsive choices efficiently and to evaluate delayed rewards more promptly, a cognitive advantage that may be linked to associations between cortical folding morphology and the brain's underlying structural connectivity^{64–66}. On the other hand, the lack of a significant relationship between ACC morphology and other cognitive measures not typically associated with the ACC (i.e., memory and language) reinforces the evidence that the effects of ACC sulci asymmetry is preferential for DD.

Indeed, when 'Executive Functions' were examined together with the 'Memory and Language' factor, the ACC–DD association remained the most prominent effect in our dataset. The lack of a corresponding association with the factor named "executive functions" (Factor 2) may appear unexpected. However, this result might be explained by the intrinsic heterogeneity of the executive domain, which aggregates partially dissociable

processes (e.g., inhibition, cognitive flexibility, planning). While we acknowledge that the behavioral battery of the HCP did not systematically cover the executive domain, the pattern of ACC may be only relevant for some, but not all, executive aspects and tasks. Consistent with this interpretation, previous studies have linked ACC sulcal patterns to Stroop Task and the Trail Making Test (TMT) in patients suffering from schizophrenia (e.g.^{35,67}), but not to other executive measures like working memory³⁹. Moreover, when considering individual tasks outside the PCA framework (see Table S2), we also observed an association between ACC symmetry/asymmetry and processing speed, a core ability strictly linked to executive functioning⁶⁸ and indeed included in the second “executive function” PCA factor³⁶. This indicates that the relationship between ACC morphology and cognition is not strictly limited to delay discounting at the single-task level. However, in the PCA-based analysis, the effect emerged only for the latent factor capturing delay discounting, suggesting that ACC symmetry/asymmetry may be more closely related to the shared variance underlying decision-making processes rather than to that shared by different executive processes.

Notably, we also found that the IPS pattern, a cortical region not directly involved in DD, did not affect delay discounting performance.. Interestingly, this finding supports a double dissociation framework, whereby the morphology of regions not involved in DD (such as IPS) fails to predict DD performance, but also the morphology of DD-related regions (e.g., ACC) does not predict unrelated cognitive functions (e.g., memory and language). Notably, few studies examining the relationship between morphology and cognition have controlled for either other cortical regions or cognitive domains: some studies have focused on the morphological control (e.g., Occipito-Temporal sulcus)³⁵, others on the cognitive control (e.g., verbal working memory)^{39,40}. This is the first study to simultaneously test both morphological and behavioral specificity in a single, large sample. To enhance the robustness of this emerging field, it will be essential for future research to investigate the bidirectional specificity of brain-behavior relationships, ensuring that particular structural configurations are more or less selectively mapped to distinct cognitive profiles.

The confirmation of such a relationship would also allow for extending the present findings to personalized clinical applications aimed at improving intertemporal decision-making. For example, non-invasive neuromodulation techniques that are widely used in the treatment of dysfunctional choice behavior (e.g., addiction and gambling disorders), such as transcranial magnetic stimulation (TMS), could be adapted differently according to

ACC morphology, potentially improving their ability to delay actuation. Indeed, several studies have found positive effects on delay discounting measures in patients suffering from addiction disorders through stimulation of the dlPFC^{69,70}. Due to its medial location, the ACC is not an obvious target for stimulation. However, through its functional connection to the dlPFC, the morphological pattern of the ACC could likely influence the outcome of such treatments. It would also be interesting to exploit alternative neuromodulation techniques, such as the transcranial ultrasound stimulation (TUS)⁷¹, which is more effective in targeting deep brain regions compared to TMS.

From an anatomical point of view, we observed that the distribution of the ACC single and double parallel patterns is balanced in the left hemisphere, consistent with previous studies (see Borst et. al., 2014, Cachia et. al., 2014, Yucel et. al., 2001)^{39,40,52}, except for Tissier et. al., 2018³⁵ which shows discordance with all other studies. In the right hemisphere, we observed that the single pattern is significantly more frequent than the double parallel pattern, contrary to what reported in previous studies (see Tissier et. al., 2018, Borst et. al., 2014)^{35,39}. Finally, the interstudy comparison revealed discrepancies in the distribution of the asymmetric ACC pattern between the study by Tissier et. al., 2018³⁵ and all other studies (see Borst et. al., 2014, Cachia et. al., 2014, Yucel et. al., 2001)^{39,40,52}, as well as between the study by Tissier et. al., 2018³⁹ and the present study. As shown in Figure 3, studies with smaller sample sizes tend to deviate more from the others, to varying degrees, as previously discussed.

We suggest that the small sample size may introduce more random variability into the results, leading to inter-studies discordance, particularly when comparing studies with limited cohorts to larger samples such as those used in our study (N=390) and in the study by Yucel et. al., 2001⁵² (N=171). It is indeed well established that detecting small genetic effects associated with complex traits, such as cortical morphology, requires large sample sizes⁷², particularly when examining these traits in relation to behavior⁷³. In addition to sample size, discrepancies across studies may also partly reflect methodological heterogeneity in sulcal labeling and reliability assessment (e.g., number of raters, reliability metrics, and adjudication strategies), which can introduce measurement noise and affect the reproducibility of structure-behaviour associations. These considerations underscore the importance of conducting studies with sufficiently large sample sizes to reliably capture stable interindividual variability in cortical morphology and to ensure the reproducibility of findings. In addition, from a methodological standpoint, efforts to improve reproducibility increasingly emphasize standardization of sulcal labeling and the development of

automated solutions aimed at limiting rater-dependent variability. Notably, recent self-supervised learning frameworks have shown encouraging potential for identifying ACC folding patterns, pointing to a more objective sulcal-pattern characterization⁷⁴.

Generally, from a purely qualitative point of view, as already noted³⁶, the right hemisphere seems to have a clearer morphology, making it easier to detect morphological patterns with respect to its left counterpart. This may partly account for the fewer discrepancies observed among the comparison studies in the right hemisphere. It would be interesting to investigate the possible causes of this inter-hemispheric difference, possibly due to genetic factors related to cortical development. The phenomenon known as the Yakovlevian torque, i.e., the greater frontal extension of the right hemisphere and occipital extension of the left hemisphere along the medial line⁷⁵, could be involved. In particular, the greater superficial extension of the right compared to the left frontal lobe may allow for less convoluted cortical folding and clearer sulcus morphological patterns. Furthermore, the notion that the right hemisphere develops earlier than the left and is therefore less influenced by the in-utero environment during fetal life^{76,77} supports the idea that its sulcal morphology stabilizes at an early stage, which may explain why it appears easier to define. However, further research is needed to clarify this aspect.

While this study provides valuable insights for understanding the impact of ACC structural morphology on DD, it also raises questions about the broader neural mechanisms underlying DD. Future research should investigate whether ACC asymmetry interacts with other structural and functional features, such as white matter integrity or neural connectivity, to influence decision-making. It would also be interesting to investigate whether the sulcal pattern of other regions involved in DD additionally contributes to the effect of the ACC sulcal morphology. Moreover, longitudinal studies could clarify whether ACC asymmetry drives the development of delay discounting behavior, particularly in the case of disease onset, and shed light on the causal pathways involved.

In summary, the present study highlights the critical role of cortical morphology, in particular the anterior cingulate cortex (ACC) sulcal asymmetry, in shaping individual differences in DD behavior. By demonstrating this sulcal morphological effect and its dissociation from unrelated cognitive domains or cortical regions, our findings suggest that stable anatomical features may serve as robust markers of impulsivity. The structural asymmetry of the ACC, likely reflecting interhemispheric specialization, not only advances our understanding of decision-making but also opens new avenues for personalized approaches to cognitive enhancement and clinical intervention. Sulcal patterns can be

regarded as a 'fossil trace' of early brain development, influencing later cognitive and functional adaptations. As such, they may act as potential neuroprotective or risk factors.

	Study	Pattern	N (%)	chi-square
--	-------	---------	-------	------------

This perspective enriches our interpretation of sulcal morphology as not just a static anatomical feature but as a persistent signature of developmental and functional optimization. These 'fossilized' features offer a unique window into the neural substrates of behavior and provide a foundation for future research aimed at disentangling the complex interplay between brain structure, function, and cognition.

Table 1. Frequency distribution of left and right ACC pattern and ACC symmetry/asymmetry pattern in the present and previous studies.

Left ACC	Yücel et. al., 2001 (N=171)	Single	88 (51%)	$\chi^2=53.7585$ df = 4 p < 0.001
		Double-parallel	83 (49%)	
	Cachia et al., 2014 (N=19)	Single	13 (68%)	
		Double-parallel	6 (32 %)	
	Borst et al., 2014 (N=18)	Single	9 (50%)	
		Double-parallel	9 (50%)	
	Tissier et. al., 2018 (N=38)	Single	7 (18%)	
		Double-parallel	31 (82%)	
Right ACC	Yücel et. al., 2001 (N=171)	Single	123 (72%)	$\chi^2=20.0947$ df = 4 p < 0.001
		Double-parallel	48 (28%)	
	Cachia et al., 2014 (N=19)	Single	13 (68%)	
		Double-parallel	6 (32%)	
	Borst et al., 2014 (N=18)	Single	10 (56%)	
		Double-parallel	8 (44%)	
	Tissier et. al., 2018 (N=38)	Single	22 (58%)	
		Double-parallel	16 (42%)	
Symmetry/asymmetry ACC	Yücel et. al., 2001 (N=171)	Symmetric	96 (56%)	$\chi^2=36.7060$ df = 4 p < 0.001
		Asymmetric	75 (44%)	
	Cachia et al., 2014 (N=19)	Symmetric	11 (58%)	
		Asymmetric	8 (42%)	
	Borst et al., 2014 (N=18)	Symmetric	11 (61%)	
		Asymmetric	7 (39%)	
	Tissier et. al., 2018 (N=38)	Symmetric	9 (24%)	
		Asymmetric	29 (76%)	
	Present study (N=390)	Symmetric	201 (51%)	
		Asymmetric	189 (49%)	

Chapter 3

Conceptual Framework

Given the central role of temporal discounting in shaping impulsive choice and vulnerability to substance use, prevention models that explicitly target the cognitive and emotional processes underlying steep discounting are particularly relevant for university settings. The Pr.I.M.E. project (Prevenire con Insight, Motivazione, Emozione) is a national prevention initiative designed to address early vulnerability to substance use among university students, a population characterized by low-risk perception, minimization of harm, and limited propensity to seek treatment. The Pr.I.M.E. project aims “to reduce the time of access to care, through the early identification of conditions of vulnerability and occasional substance use in the university population,” while validating an intervention model that can be transferred to other national contexts. The initiative is implemented through a public–public partnership funded by the Department for Anti-Drug Policies of the Presidency of the Council of Ministers of Italy and led by ASL Roma 1 in collaboration with the University “G. d’Annunzio” of Chieti-Pescara and “La Sapienza” University of Rome. It adopts a multi-component, evidence-based approach that combines participatory design, peer-to-peer engagement, and structured research activities. The project includes large-scale online screening, individual assessments involving psychological, neuropsychological, and a series of experiential group-based interventions aimed at strengthening emotional regulation, impulse control, insight processes, and coping strategies. The preventive model is articulated across several work packages, ranging from awareness campaigns to laboratory-based experiential sessions, motivational groups, and facilitated access to specialized services for students presenting risk factors.

A distinctive feature of Pr.I.M.E is its focus on cognitive-emotional mechanisms that contribute to vulnerability in emerging adulthood. By targeting executive functions, emotional insight, and motivational processes, the project seeks to address the psychological dimensions that may underlie delayed help-seeking and persistent engagement in risky behaviors. This emphasis aligns with contemporary models of addiction that highlight the role of impaired decision-making, reduced future-oriented thinking, and heightened sensitivity to immediate rewards. In other words, the Pr.I.M.E. project is aimed at containing the risk of addiction by enhancing executive functions, insight processes, risk awareness in the university population. Within this framework, the following studies investigate how temporal discounting relates to vulnerability-related

psychological processes in university students (Study 2) and whether a multicomponent preventive program can modulate the cognitive and emotional mechanisms that sustain impulsive decision-making (Study 3).

STUDY 2

Choosing Now over Later: What Temporal Discounting Reveals about Italian University Students and Addiction Risk

Considering recent evidence pointing to the increased rate of mental health problems in academic contexts (Schwaller, 2024), university students represent a target population for investigating vulnerability to maladaptive decision-making and addictive behaviors. During the university years, high delay discounting has been associated with procrastination, reduced self-control, and increased vulnerability to stressors commonly encountered in academic life (Schouwenburg & Groenewoud, 2001; Dewitte & Schouwenburg, 2002; Bertrams & Englert, 2013). Research on college students has shown that higher delay discounting is associated not only with greater substance use but also with earlier initiation and a wider range of substances consumed (Kollins, 2003). These findings suggest that temporal discounting captures a core dimension of impulsive decision-making that may contribute to vulnerability to addictive behaviors even in the non-clinical population of young adults.

However, evidence in student samples also indicates that distinct forms of impulsive decision-making may be differentially related to addictive behaviors. For instance, although Holt and colleagues (2001, 2003) found no differences in temporal discounting between gambling and non-gambling students, they reported steeper probability discounting among gamblers, suggesting that distinct decision-making processes may underlie different forms of addiction. Consistently, Dennhardt and Murphy (2011) showed that elevated delay discounting, presence of depressive symptoms and low distress tolerance, predicted more severe alcohol-related problems in college students. Together, these findings highlight the importance of considering delay discounting within a broader context of psychological risk factors.

Personality traits and executive functioning appear to play a central role in shaping intertemporal decision-making during university years. Students scoring high on neuroticism report higher levels of impulsive behavior (Whiteside & Lynam, 2001) and procrastination (Lee et al., 2006), whereas conscientiousness is associated with greater self-regulation and lower procrastination (Lee et al., 2006). Moreover, executive functioning has been directly linked to delay discounting: Weatherly and Ferraro (2011) found that university students with low executive functions exhibited steeper discounting across different outcome domains. These findings are particularly relevant given that the transition to adulthood is characterized by increased psychological demands and stressors, including academic and parental pressure, financial concerns, uncertainty about the future, and the increasing of responsibilities (Arnett, 2000; Beiter et al., 2015; Wood et al., 2018). Such challenges may exacerbate vulnerabilities in cognitive control and decision-making, increasing the risk for maladaptive behaviors.

Despite extensive evidence linking delay discounting to addiction and related psychological processes, limited research has examined how temporal discounting is associated with addictive behavioral tendencies and personality traits in non-clinical university populations, particularly within the Italian context. While both temporal discounting and addiction-related behaviors are well documented in the literature, less is known about how these constructs interact with personality dimensions, as assessed through the Big Five, and subclinical addictive tendencies, as measured by the Addictive Behavior Questionnaire (ABQ), in Italian university students. The present study aimed to address this gap by investigating the relationship between temporal discounting and a range of psychological risk factors associated with the development and maintenance of addictive behaviors in this population.

This study was conducted within the framework of the aforementioned Pr.I.M.E. project (Prevenire con Insight, Motivazione, Emozione), which aims to reduce the risk of addiction by enhancing executive functions, insight processes, risk awareness related to substance use, and coping strategies through experiential group-based activities. However, the present work focuses specifically on the screening phase of the project, examining behavioral and cognitive risk factors related to substance use, with particular emphasis on delay discounting. By isolating these dimensions, the study contributes to the broader Pr.I.M.E. framework by clarifying which cognitive processes may serve as early indicators of vulnerability prior to the implementation of preventive interventions.

This manuscript has been submitted to the *Journal of Affective Disorders* as "Choosing Now over Later: What Temporal Discounting Reveals about Italian University Students and Addiction Risk" by Federica Procida, Lorenzo Mattioni, Fabrizio Mascitti, Michela La Stella, Francesca Favieri, Renata Tambelli, Anna Maria Speranza, Giovanni Martinotti, Selene Regio, Giuseppe Ducci, Adele Di Stefano, and Giorgia Committeri.

Methods and Materials

Participants

181 volunteer university students participated in the study. Two participants could not be included in the statistical analysis since they showed no choice variability in the intertemporal choice task (only now responses), precluding the estimation of the decision indices, four participants were excluded from the analyses, as their classification as 'other' as their gender did not allow for the assignment to a specific percentile, and one presented an outlier rate on the second scale of the Body Perception Questionnaire (BPQ). The final sample included 175 participants (115 F, 60 M), aged 18-33 (mean: 23.5 ds: ± 3.02).

All participants were recruited from the University "G. d'Annunzio" of Chieti-Pescara and from La Sapienza University of Rome (Italy), through participant referral and classroom presentations in different degree courses.

General socio-demographic information was collected for each participant through the biographical fact sheet of the Addictive Behavior Questionnaire (ABQ, Caretti et al., 2016, see below) (Table 1). All participants classified as employed or as postgraduates (i.e., individuals who had completed an undergraduate degree and were enrolled in advanced training programs such as specialization schools) were nonetheless actively enrolled as students at the time of participation.

Table 1.

Sociodemographic information about the final sample.

	N = 175
Sex	
Female	115 (65.71%)
Male	60 (34.29%)
Relationship status	
Single	164 (93.71%)
In a relationship	3 (1.71%)
Cohabitation	7 (4.00%)
Divorced	0 (0 %)

Widower	1	(0.57%)
Education Level		
Diploma	64	(36.57%)
Bachelor's degree	87	(49.71%)
Master's degree	16	(9.14%)
Postgraduate Qualification	8	(4.57%)
Professional Occupation		
Employed	27	(15.43%)
Student	120	(68.57%)
Unemployed	15	(8.57%)
Self-employed	4	(2.29%)
Other	9	(5.14%)
Religious Orientation		
Catholic	65	(37.14%)
Atheist	78	(44.57%)
Buddhist	1	(0.57%)
Other	31	(17.71%)
Sport Activity		
Yes	103	(58.86%)
No	72	(41.14%)

Procedure

Each participant underwent a psychopathological and psychological assessment first, followed by an intertemporal choice task, by using the available, standardized Italian versions of all instruments. All questionnaires and the intertemporal choice task were administered in electronic format through the Qualtrics platform and in presence of an experienced clinician (except for 15 participants).

Psychopathological and psychological assessment

All participants were submitted to a psychopathological and psychological evaluation including the following self-assessment questionnaires:

- Addictive Behavior Questionnaire (ABQ, Caretti et al., 2016) is a 49-item questionnaire for categorical/dimensional assessment of addiction disorders. The instrument contains (i) a biographical form, (ii) a severity risk survey about substance, alcohol, gambling and internet use (section a: severity index; section b: obsessive-impulsive-compulsive spectrum), and (iii) (iii) a diagnostic section that supports the identification and characterization of different forms of addiction (substance use, gambling, and internet-related disorders) across the various stages of assessment and intervention. It consists of two instruments: The Severity Index (SI) and the Seven Domains Addiction Scale (7DAS). The SI is used to assess the

current severity of addiction in four main areas: (1) psychoactive substances; (2) alcohol; (3) gambling; (4) Internet. Each area is composed of two sections: section A for the assessment of addictive behavior; and section B for the assessment of seven domains of psychopathology that are relevant to the understanding and treatment of addictive behaviors. The Seven Domains Addiction Scale (7DAS) included in section B measures seven different domains of mental and behavioral functioning that have been considered, according to clinical experience and research findings, as risk factors for the development and maintenance of addictive behaviors (7 Domains Addiction Scale, 7DAS). Each domain is investigated through 7 questions about the frequency of experiences rated on a scale from 0 (never) to 5 (always): D1, Separation anxiety, for the evaluation of difficulties to safely create and/or enjoy an attachment relationships (insecure attachment); D2, Affect dysregulation, for the evaluation of the difficulty to identify, differentiate, modulate, and communicate emotions; D3, Somatoform and psychological dissociation, for the evaluation of symptoms of altered state of consciousness and strangeness toward oneself, one's own body and others; D4, Childhood traumatic experiences, for the evaluation of traumatized mental states related to experiences of emotional neglect or abuse during childhood; D5, Impulse Dyscontrol, for the assessment of the difficulty to resist an impulse, an impelling desire or behavior, despite the potential negative consequences of one's actions; D6, Compulsive behavior and ritualization, for the evaluation of the tendency to compulsively implement repetitive and ritualized behaviors, even when they are dangerous for one's own health or well-being; D7, Obsessive thoughts, for the evaluation of obsessional, recurrent, persistent and repetitive thinking and difficulty to make a decision.

- Difficulties in Emotion Regulation Scale (DERS, Sighinolfi, et al., 2010) is a 36-item questionnaire that aims to assess emotional dysregulation using six subscales: non-acceptance of negative emotions (Non-Acceptance), difficulties engaging in goal-directed behaviors when distressed (Goals), belief that there is little that one can do to regulate emotions effectively (Strategies), difficulties controlling impulsive behaviors when distressed (Impulse), lack of emotional awareness (Awareness) and lack of emotional clarity (Clarity). Each item is rated on a scale from 1 (almost never) to 5 (almost always). The total DERS score is calculated from the sum of all

six subscales, resulting in a score range of 36 to 180. Higher scores suggest more difficulties in emotion regulation.

- Toronto Alexithymia Scale (TAS-20, Bressi, et al., 1996) is a 20-item questionnaire that measures difficulty in identifying and describing emotions. The TAS-20 has 3 subscales: (i) Difficulty Describing Feelings subscale is used to measure difficulty describing emotions; (ii) Difficulty Identifying Feeling subscale is used to measure difficulty identifying emotions; (iii) Externally Oriented Thinking subscale. Items are rated using a 5-point Likert scale. Score higher than 51 are indicators of alexithymia.
- Kessler Psychological Distress Scale (K10, Carrà, et al., 2011) is a 10-items questionnaire. The scale uses a five-value response option for each question (from 1 =none of the time to 5= all of the time). The maximum score is therefore 50, indicating severe distress, and the minimum score is 10, indicating no distress.
- Body Perception Questionnaire (BPQ-SF, Poli, et al., 2021) aims to measure body awareness and autonomic reactivity. Items ask participants to rate on a 5-point scale (from 1 = never to 5 = always) the frequency with which they feel aware of bodily sensations (body awareness) and the frequency with which they experience supradiaphragmatic reactivity and subdiaphragmatic reactivity.
- Big Five Questionnaire (BFQ-2, Caprara, et al., 2008) was designed to assess the constellation of traits defined by the Five Factor Theory of Personality: extraversion (E), indicating a confident and enthusiastic approach to interpersonal relations; agreeableness (A) or friendliness, the orientation towards altruism and taking care of the other; conscientiousness (C), the tendency to be precise, accurate and persevering; emotional stability or neuroticism (ES), the orientation to control of emotional states and impulses; and intellect or openness to experience (OE), the openness to new ideas, to the values of others and their feeling.

Intertemporal choice task

Participants chose between a hypothetical amount of money to be received immediately and a hypothetical amount of money to be received after some specified delay. There were six possible delays, each presented five times: 2 days, 2 weeks, 1 month, 3 months, 6 months, and 1 year. The order of blocks of choices for each delay was randomized. Within each block (five choices), the delayed amount was always EUR 40,

while the amount of the immediate reward was adjusted based on the participant's choices using a staircase procedure that converged on the amount of the immediate reward that was equal, in terms of subjective value, to the delayed reward. The first choice was always between a delayed amount of EUR 40 and an immediate amount of EUR 20. If the participant chose the immediate reward, then the amount of the immediate reward was decreased on the next trial; if the subject chose the delayed reward, then the amount of the immediate reward was increased on the next trial (figure 1), using a titration procedure that converges on the amount of the immediate reward that has equivalent subjective value as the delayed reward (Sellitto et al., 2010). This procedure was repeated until the subject made five choices for each delay, after which a new series of five choices with a different delay began for a total of 30 choices (Garofalo et al., 2022). The task lasted approximately 10 minutes.

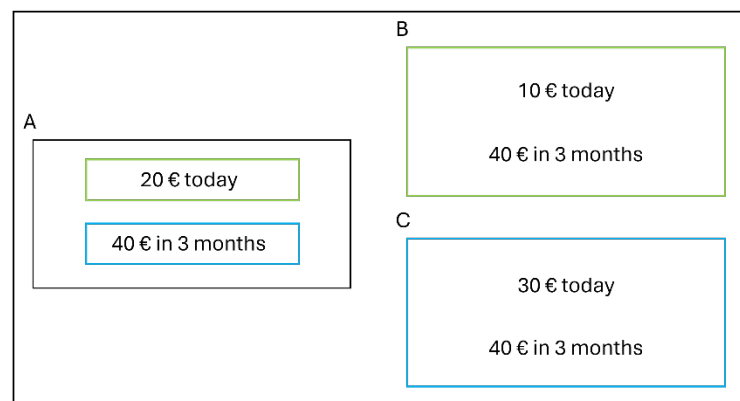


Figure1. Graphical representation of the delay discounting (DD) task. The task was adapted from Garofalo (2002) and modified to accommodate the graphical capabilities of Qualtrics. In each trial, participants chose between a smaller amount of money delivered immediately (top option in panel A) and a larger amount delivered after a delay (bottom option in panel A). If the participant chose the immediate reward (green rectangle), then the amount of the immediate reward was decreased on the next trial (top option in panel B.); if the subject chose the delayed reward (blue rectangle), then the amount of the immediate reward was increased on the next trial (bottom option in panel C).

Data Analysis

To quantify individual's temporal discounting rate, we fit the choices to the hyperbolic model (Green and Myerson, 2004; Kable and Glimcher, 2007; Mazur, 1987). We determined the best-fitting discount parameter k in each condition:

$$SV = \frac{1}{(1 + kD)}$$

Where SV_{del} is the subjective value of the delayed reward, A is the amount of the delayed reward, D is the delay and K is the parameter that represents the participant's discount rate (higher k values correspond to more impatience). Hyperbolic function was fitted to the data, separately, to determine the K constant of the best fitting delay discounting function using a nonlinear least-squares algorithm in R studio. SV represents the subjective value (expressed as a fraction of the delayed amount) and D the delay (in days). The larger the value of k , the steeper the discounting function, the more participants were inclined to choose small immediate rewards over larger delayed rewards. Following log-transformation k constants were normally distributed, and therefore comparisons were performed using parametric statistical tests when appropriate. The analysis of K value was conducted using R scripts adapted from those originally developed by Garofalo et al. (2022) (<https://osf.io/65bg7/>).

The association between the individual scores on these tests and the discounting rate (k) was assessed using independent Spearman's correlations since the distribution of scores of these tests was not normally distributed (Shapiro $< .001$). All the statistical analyses were implemented in Jamovi 2.7.4.

Results

Intertemporal Choice Task

For hyperbolic k scores, the bigger the value, the higher the delay discounting (Sellitto et al., 2010). Thus, k scores falling below the 10th percentile indicate extremely low performance, while k scores falling above the 90th percentile indicate extremely high performance. For instance, any female with 9 to 13 years of education scoring lower than -7.57 should be considered as presenting an extremely low delay discounting; similarly, any female with 9 to 13 years of education scoring higher than 2.73 on the hyperbolic k should be considered as presenting an extremely high delay discounting (see Garofalo et al., 2022).

As expected, the k parameter reflecting the discount rate showed large inter-subject variability, with estimates that varied from a minimum of -9.92 to a maximum of 2.90 (mean = -5.00 ; standard deviation = 2.70). Values are in line with those observed in the Italian standardization (Garofalo et al., 2022), where average hyperbolic k was -4.35 for females

and -4,13 for males of equivalent education level. Table 2 shows the distribution of k scores according to the percentiles provided by the same standardization.

Table 2.

Overall view of discounting rate stratification according to the percentile equivalent for 175 participants (excluding the four participants with “Other” gender). K scores falling below the 10th percentile indicate extremely low performance (i.e. low discounter), while K scores falling above the 90th percentile indicate extremely high performance (i.e. high discounter) (see Garofalo *et al.*, 2022).

Hyperbolic K		
	Female	Male
High discounter (>90 th)	24 (20.9%)	14 (23.3%)
Medium discounter (>10 th <90 th)	78 (67.8%)	38 (63.3%)
Low discounter (<10 th)	13 (11.3%)	8 (13.3%)
Tot	115	60

Relationship between discounting rate and psychological factors

As shown in Figure 2 and Table 3, we observed significant positive correlations (95% confidence intervals computed for all significant correlations) between delay discounting and domains 3 [Somatoform and psychological dissociation (Spearman' rho = 0.18, p = 0.017)] and 6 [Compulsive behaviors and ritualization (Spearman's rho = 0.147, p = 0.052)] of the ABQ questionnaire (Figure 2A and 2B). We also found a significant positive correlation between the K value and the awareness subscale of the DERS test (Spearman's rho = 0.168, p = 0.027) (Figure 2C).

A further significant positive correlation was detected between the k parameter and TAS-20 total (Spearman's rho = 0.200, p = 0.008) as well as two TAS-20 subscales, the difficulty identifying feelings (Spearman's rho = 0.172, p = 0.023) and the externally oriented thinking (Spearman's rho = 0.231, p = 0.002) (Figure 2D-E). Given the exploratory nature of these analyses, uncorrected p-values are reported.

No significant correlations were found between the K rates and K-10, BPQ and personality traits, as measured by the Big Five Questionnaire (BFQ) (Table 3).

These results indicate that participants who are more impulsive in their decision-making, preferring immediate gratification over delayed benefits, also show higher levels of somatoform and dissociative symptoms, as well as more frequent and intense obsessive thoughts. At the same time, they show higher lack of emotional awareness, struggling to

Choosing Now over Later: What Temporal Discounting Reveals about Italian University Students and Addiction Risk

recognize their own emotions and focusing on external details rather than internal emotional states. Average values for each test are reported in Table 4.

Figure 2. Correlations between the delay discounting parameter K hyperbolic and psychological measures (Domain 3-ABQ, Domain 6-ABQ, DERS-Awareness, TAS-20, Difficulty Identifying Feelings, Externally Oriented Thinking). Points represent individual data; dashed lines indicate linear fits.

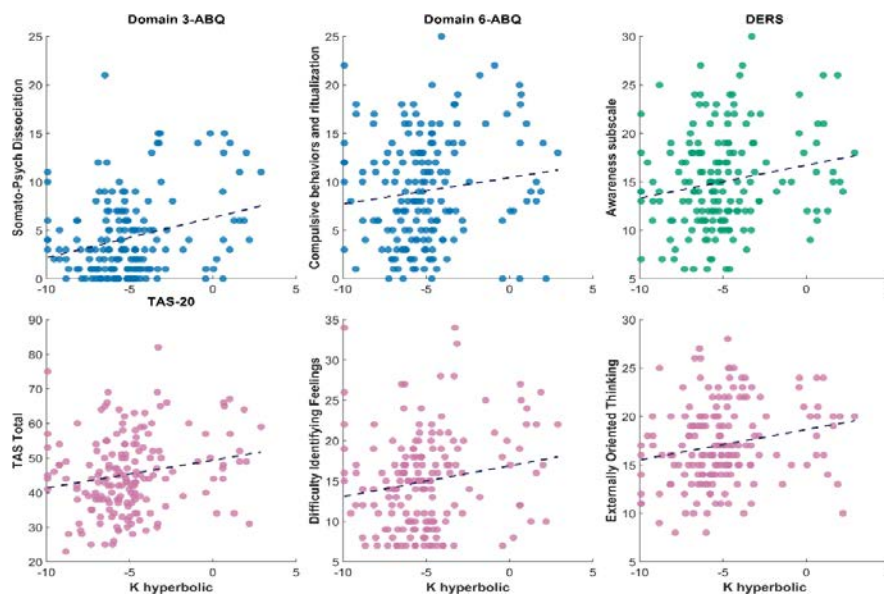


Table 3.

Correlation coefficients between the delay discounting rate (k parameter) and study variables. Statistically significant correlations are shown in red.

Variable	Spearman's rho	p-value
A Severity Index – Substance use	0.193	0.246
B Severity Index – Obsessions/impulses/compulsions substance use	0.005	0.977
A Severity Index – Alcohol	-0.009	0.925
B Severity Index – Obsessions/impulses/compulsions alcohol	0.040	0.691
A Severity Index – Gambling	0.342	0.408
B Severity Index – Obsessions/impulses/compulsions gambling	0.396	0.379

Choosing Now over Later: What Temporal Discounting Reveals about Italian University Students and Addiction Risk

A Severity Index – Internet	-0.033	0.690
B Severity Index – Obsessions/impulses/compulsions internet	-0.016	0.855
Domain 1 – Separation anxiety	-0.012	0.872
Domain 2 – Affective dysregulation	0.127	0.093
Domain 3 – Somatoform and psychological dissociation	0.180	0.017
Domain 4 – Traumatic childhood experiences	0.053	0.483
Domain 5 – Impulse Dyscontrol	0.037	0.623
Domain 6 – Compulsive behaviors and ritualization	0.147	0.052
Domain 7 – Obsessive thoughts	0.126	0.096
DERS – total	0.103	0.176
Nonacceptance	0.085	0.265
Goals	0.021	0.787
Impulse	0.123	0.104
Strategies	0.027	0.726
Awareness	0.168	0.027
Clarity	0.126	0.096
K10 – total	0.036	0.632
TAS-20 total	0.200	0.008
Difficulty identifying feelings	0.172	0.023
Difficulty describing feelings	0.047	0.538
Externally oriented thinking	0.231	0.002
Body awareness	-0.090	0.239
Supradiaphragmatic reactivity	0.114	0.134
Body awareness/Subdiaphragmatic reactivity	0.022	0.768
Agreeableness	-0.094	0.215
Conscientiousness	0.067	0.379
Emotional stability	-0.098	0.197
Extraversion	-0.079	0.299
Openness	-0.079	0.298

Table 4.

Mean and standard deviation for each questionnaire on the total sample (N=175).

Addictive Behavior Questionnaire (ABQ)	(mean ± sd)
Severity Index (SI)	

Choosing Now over Later: What Temporal Discounting Reveals about Italian University Students and Addiction Risk

A-Addictive Behaviors-substance use	(4.58 ± 2.98)
B-Obsessions-Impulses-Compulsions	(7.61 ± 5.49)
A-Addictive Behaviors-alcohol	(3.48 ± 1.93)
B-Obsessions-Impulses-Compulsions	(4.42 ± 3.20)
A-Addictive Behaviors-gambling	(12.71 ± 12.40)
B-Obsessions-Impulses-Compulsions	(4.16 ± 2.53)
A-Addictive Behaviors-internet	(6.80 ± 4.70)
B-Obsessions-Impulses-Compulsions	(6.11 ± 5.10)
7-Domain (7DAS)	
D1-Separation Anxiety	(13.04 ± 6.89)
D2-Affective Dysregulation	(12.58 ± 5.08)
D3- Somatoform and Psychological Dissociation	(4.23 ± 4.16)
D4-Childhood Traumatic Experiences	(6.65 ± 6.32)
D5-Impulse Dyscontrol	(11.03 ± 5.03)
D6-Compulsive Behaviors and Ritualization	(9.07 ± 5.60)
D7-Obsessive Thoughts	(13.87 ± 6.51)
Difficulties in Emotion Regulation Scale (DERS)	(88.75 ± 25.81)
Non-acceptance	(13.81 ± 6.23)
Goals	(15.22 ± 5.09)
Impulse	(12.64 ± 5.06)
Strategies	(19.45 ± 7.77)
Awareness	(15.02 ± 4.99)
Clarity	(12.63 ± 4.31)
Kessler Psychological Distress Scale-10 (K10)	(21.94 ± 8.16)
Toronto Alexithymia Scale-20 (TAS)	(45.36 ± 11.14)
Difficulty identifying feelings	(14.98 ± 5.86)
Difficulty describing feelings	(13.29 ± 4.70)
Externally oriented thinking	(17.09 ± 4.17)
Body Perception Questionnaire (BPQ)	
Body awareness	(13.97 ± 4.34)
Supradiaphragmatic reactivity	(10.06 ± 2.50)
Body awareness/Subdiaphragmatic reactivity	(12.34 ± 3.54)
Big-Five Questionnaire (BFQ)	
Agreeableness	(6.35 ± 1.70)
Conscientiousness	(7.04 ± 1.90)
Emotional stability	(5.49 ± 2.05)
Extraversion	(6.10 ± 1.99)
Openness	(7.53 ± 1.87)

Discussion

The present study contributes to the understanding of vulnerability to addictive behaviors in university students, a population that has received comparatively limited attention despite being exposed to academic, social, and developmental stressors. Previous research has indicated that university students may be at increased risk for non-prescribed substance use—including illegal drugs (e.g., cannabis, ketamine, cocaine) and the non-medical use of prescription medications (e.g., analgesics, sedatives, tranquilizers, stimulants)—and may experience poorer outcomes in psychological treatment compared to employed young adults, likely due to student-specific pressures

and instability (Bennett & Holloway, 2014; El Ansari et al., 2015; Barnett et al., 2022; Schwaller et al., 2024; Favieri et al., 2023). Within this context, investigating psychological and decision-making factors associated with vulnerability represents an important step toward the prevention of risky or addictive behaviors and the early identification of individuals who may be particularly vulnerable to developing them.

Beyond confirming the association between temporal discounting and impulsive decision-making, the present findings highlight a set of psychological dimensions that may co-occur with steeper delay discounting in university students. Using a standardized delay discounting task alongside a comprehensive psychological assessment, we observed that higher discount rates showed a significant association with two specific domains of the Addictive Behavior Questionnaire (ABQ). These findings suggest that temporal discounting in this population may reflect a broader pattern of affective and behavioral dysregulation rather than impulsivity alone. This interpretation is consistent with previous research linking steeper delay discounting to maladaptive and inflexible behavioral patterns (Lange & Eggert, 2015; Reynolds et al., 2006).

In particular, the association between steeper discounting and somatoform and dissociative symptoms aligns with evidence indicating that individuals characterized by somatization or dissociation often seek immediate relief from distressing bodily or emotional states. Such behaviors may reflect a preference for short-term alleviation of discomfort over longer-term adaptive strategies. Previous studies reported somatization and dissociation in individuals with substance use disorders linking them to emotion regulation difficulties and trauma-related processes (Hasin & Katz, 2007; Kirmayer & Taillefer, 1997; Favieri et al., 2025). In this framework, higher temporal discounting may reflect reduced engagement with future-oriented representations of the self, potentially impairing the valuation of delayed outcomes. Rather than implying a causal pathway, these findings suggest that dissociative tendencies and steep discounting may represent interconnected manifestations of vulnerability within a broader affective-cognitive profile.

Similarly, the association between temporal discounting and Compulsive Behaviors and Ritualization points to a potential link between steep discounting and rigid, repetitive behavioral strategies aimed at reducing immediate distress or uncertainty. Compulsive behaviors are often characterized by short-term relief at the expense of long-term flexibility and adaptive functioning. This pattern is consistent with evidence that individuals with

obsessive-compulsive tendencies may display altered intertemporal decision-making, prioritizing immediate reduction of discomfort over delayed benefits (Steinglass et al., 2016; Story et al., 2015). From this perspective, steeper discounting may be associated with a reliance on habitual or ritualized responses, which can contribute to maladaptive behavioral cycles (Boyer & Liénard, 2006). Importantly, these findings support the view that temporal discounting may capture compulsive as well as impulsive dimensions of behavior.

Taken together, the observed associations suggest that vulnerability to addictive behaviors should be considered in a complex frame including emotional, cognitive, and behavioral dysregulation. During intertemporal decision-making, anticipated rewards are known to elicit physiological and visceral responses, which may be particularly salient in individuals with emotional dysregulation. Consistent with the somatosensory amplification hypothesis, increased bodily responses to anticipated outcomes may bias individuals toward immediate rewards (Nakao et al., 2002; Nyklíček & Vingerhoets, 2000; Wise & Mann, 1994; Scarpazza et al., 2017). In line with previous findings, greater difficulties in emotion regulation have been associated with steeper delay discounting (Scheres et al., 2013). However, the extent to which delay discounting directly reflects self-control processes remains debated, as not all intertemporal choices necessarily involve deliberate regulatory effort (Lempert et al., 2019).

In this context, the present findings are consistent with integrative models of addiction that emphasize the interplay between impulsivity, compulsivity, emotional dysregulation, dissociation, and obsessive tendencies (Caretti et al., 2018). Many individuals with problematic substance use or behavioral addictions report intrusive thoughts and repetitive behavioral patterns that may serve either to obtain immediate gratification or to alleviate emotional distress. The associations observed in this study suggest that temporal discounting may index decision-making styles that are embedded within this broader network of psychological processes. A further relevant finding concerns the association between temporal discounting and alexithymia. Alexithymia, characterized by difficulties in identifying and describing emotions, has been linked to heightened awareness of bodily signals and increased interoceptive sensitivity (Brower et al., 2021). Previous research indicates that individuals with higher levels of alexithymia tend to display greater impatience in intertemporal choice tasks, particularly when immediate rewards are salient (Scarpazza et al., 2017). This tendency may be related to increased physiological arousal

elicited by immediate rewards, which enhances their subjective value relative to delayed outcomes (Laibson, 1997; Lempert et al., 2015, 2016). Neuroimaging studies further suggest that alexithymia is associated with altered processing of visceral and emotional signals, potentially biasing decision-making toward immediate options (Kano & Fukudo, 2013; Moriguchi & Komaki, 2013). The association with the Externally Oriented Thinking (EOT) subscale of the TAS-20 further supports this interpretation. Individuals with high EOT may have difficulty simulating future emotional states, relying instead on concrete and immediately accessible information when making decisions (Taylor and Bagby, 2004). As a result, future outcomes that require emotional forecasting or internal reflection may be undervalued, favoring choices that provide immediate and tangible rewards. Although this relationship remains underexplored, it represents a promising avenue for future research on the emotional mechanisms underlying intertemporal decision-making.

In contrast to these findings, no significant associations were observed between temporal discounting and personality traits as assessed by the Big Five. While traits such as low conscientiousness and high neuroticism have been theoretically linked to poorer self-regulation and greater affective reactivity (Barrick et al., 2001; Conner & Abraham, 2001; Goldberg et al., 1998; Paunonen, 2003), the absence of such relationships in the present study suggests that temporal discounting may not simply reflect stable personality dispositions. Consistent with previous research reporting weak and inconsistent correlations between delay discounting and self-report measures of impulsivity (de Wit et al., 2007; Reynolds et al., 2006; Calluso et al., 2015), these findings support the view that temporal discounting represents a distinct behavioral construct rather than a direct proxy for personality traits.

Finally, temporal discounting was not associated with substance-use variables, as the study did not include clinical, subclinical, or recreational measures of substance use or addiction severity. This pattern is expected given the non-clinical nature of the sample, which showed generally low substance use levels and limited variability in addiction related symptoms. Under these conditions, detecting strong associations with clinical outcomes is inherently difficult. Nonetheless, the links observed with psychological vulnerability factors suggest that temporal discounting may still capture early, subclinical risk processes relevant to substance use vulnerability in non-clinical populations.

Despite the interesting preliminary insight emerging from this study, several limitations should be acknowledged. A first limitation concerns the cross-sectional and correlational nature of the design. Although this approach allowed us to capture an initial snapshot of the associations between personality traits, impulsivity, and intertemporal choice within a single session, it does not permit causal conclusions about the direction of these relationships. A second limitation relates to the relatively modest sample size. While recruitment constraints made this sample feasible for an in-person assessment, the limited statistical power may have reduced sensitivity to more subtle associations, particularly those involving personality traits. While a third limitation involves the exclusive use of self-report questionnaires to assess psychological constructs. These measures are widely used and standardized yet remain vulnerable to reporting biases and may not fully capture dispositional tendencies beyond participants' subjective accounts. Finally, the delay discounting task relied on hypothetical monetary rewards. This choice is common and methodologically validated, but hypothetical decisions may not entirely reflect the motivational dynamics of real-world intertemporal choices, potentially limiting ecological validity.

Despite these limitations, the present study contributes to a growing body of research suggesting that vulnerability to addictive behaviors in university students may be better understood through the interaction of affective, cognitive, and behavioral processes rather than through impulsivity alone. By identifying associations between temporal discounting and dissociative, compulsive, and emotional processing dimensions, this work highlights potential targets for future research and prevention efforts aimed at reducing addiction risk in vulnerable student populations, particularly within the Italian context. These insights align with prevention-oriented approaches such as those of the Pr.I.M.E. project, which emphasizes the importance of early identification of cognitive and emotional vulnerability markers to inform competence- enhancing interventions. Integrating these dimensions into screening and preventive programs may help refining risk detection and developing tailored strategies for strengthening executive functions, emotional awareness, and adaptive decision- making in emerging adults.

Chapter 4

STUDY 3

Modulating Temporal Discounting and Addiction Risk Factors among Italian University Students through a Multicomponent Intervention

The pattern of vulnerability identified in the previous chapter underscores the need for preventive approaches capable of addressing the early manifestations of risk in emerging adults. Within this perspective, the observation that steeper discounting behavior aligns with psychological fragility, maladaptive coping, and occasional substance use suggests that intertemporal decision-making may serve not only as a marker of vulnerability but also as a strategic entry point for intervention. Indeed, even if temporal discounting shows a degree of trait-like stability, growing evidence indicates that it also reflects a state-dependent process that can shift with fluctuations in emotional regulation, cognitive control, and the capacity to represent future outcomes. In our previous study, we found that steeper discounting was specifically associated with reduced emotional awareness, greater difficulty in identifying one's own feelings, and a more externally oriented cognitive style, a profile that reflects impaired access to internal emotional states and aligns with established evidence linking alexithymic traits to impulsive choice (Procida et al., submitted).

Following the rationale underlying the Pr.I.M.E. initiative, which was conceived as a multicomponent program designed to detect early signs of maladaptive tendencies and promote healthier decision-making trajectories, the present study focused on psychological characteristics identified in prior literature as potential risks or protective factors for maladaptive behaviors, to clarify their contribution to addiction vulnerability among Italian university students. More specifically, the current study examined whether these dimensions function as meaningful intervention targets and whether the PR.i.M.E framework can reliably capture early indicators of addiction risk in this population. In doing so, the study contributes to validating an intervention framework designed to act on these core mechanisms and to assess whether the targeted constructs behave in line with the model's theoretical assumptions.

In recent years, universities have increasingly recognized the need to strengthen mental health services (Priestley et al., 2021; Vallianatos et al., 2019), although many students continue to rely on external healthcare systems (Barnett et al., 2021; Eisenberg

et al., 2018). Across Europe, several initiatives have been developed to address substance-related problems and behavioral addictions among university students. The UK, for example, has implemented university-level drug and alcohol policies and student support services, Ireland's Healthy Campus initiative integrates health promotion and addiction prevention into campus life, and Norway's "SHoT" study systematically monitors student well-being to inform policy. In Italy, prevention efforts have expanded through national programs such as PROBEN—based on the I COPPE framework (Prilleltensky et al., 2015; Esposito et al., 2022)—and through university-based initiatives including Units Health and a range of counseling services addressing substance use, behavioral addictions, and emotional regulation. Additionally, the University of Macerata (Italy) participated in the "#Lifeaddicted – Never Drive When You Are High" project, which involved educators and socio-health professionals working both in schools and in nightlife settings to engage young people and raise awareness about drug-related road accidents. The initiative also offered dedicated training courses for students (Marchenews, 2023). A similar commitment is shared by the University of Pavia, where counseling services are designed to help students identify their difficulties and navigate available treatment options. The university also offers group-based skills-training programs grounded in Dialectical Behavior Therapy (DBT) to strengthen emotion-regulation abilities and self-efficacy, alongside mindfulness groups aimed at reducing psychological and physical distress through the cultivation of awareness and personal resources. Overall, the European landscape reflects an increasingly articulated set of preventive efforts, where the promotion of general well-being and targeted actions addressing specific risks are progressively integrated into a unified approach. Yet, Italy still lacks research-intervention programs specifically tailored to university populations, underscoring the need for integrated approaches that combine scientific inquiry with transformative action.

The intervention component of the present study responded to this gap by implementing a structured series of experiential workshops targeting psychological mechanisms implicated in early addiction vulnerability. Consistent with the Pr.I.M.E. framework mentioned above, the intervention unfolded across two sequential modules, such as the first module focused on *Emotions and Desire*, followed by a second module targeting *Motivation for Change*, delivered in small groups to foster engagement and leverage group-based regulatory processes. Each session blended psychoeducation with mindfulness-based and contemplative practices, body-awareness exercises, and respiratory and emotional-regulation techniques. This multicomponent structure was

STUDY 3

designed to strengthen emotional clarity, enhance interoceptive and body-based awareness, and to support cognitive and executive control through mind–body integration.

The workshop structure was intentionally shaped to support cognitive control and cultivate future-oriented episodic thinking, domains identified as closely intertwined with impulsive choice patterns in the study 2 of the present thesis. This approach aligns with a view of temporal discounting as a state-like construct that can be modulated through targeted strategies such as episodic future thinking, emotion-regulation techniques, and cognitive-control enhancement. By addressing these interconnected mechanisms simultaneously, the program adopts a comprehensive preventive stance aimed at reducing impulsivity and fostering more future-oriented decision-making in emerging adults.

In line with this rationale, we expected participants of the experimental group to show improvements in the targeted psychological dimensions, while the control group should not exhibit comparable changes. A manuscript describing the study is currently in preparation.

Methods and Materials

Participants

A total of 109 university students took part in this study. All individuals were part of the Study 2 cohort and were recruited on a voluntary basis at the University “G. d’Annunzio” of Chieti-Pescara (Italy).

The experimental group consisted of individuals who, in accordance with the study protocol, agreed to complete both the initial screening assessment and a subsequent laboratory session, yielding 54 participants (42 women). After the experimental group was established, a control group of 55 participants (44 women) was selected. Control participants were matched to the experimental group on age and gender. Three participants were excluded because they could not be classified as high or low discounters according to the sex-specific percentiles proposed by Garofalo et al. (2022). The final sample consisted of 106 participants (age 19-33). Of these, 52 were included in the experimental group (42 women, mean age = 23.6, SD = 2.83) and 54 in the control group (44 women; mean age = 23.4, SD = 1.74) (see Table 1).

Table 1.

Sociodemographic information about the two final samples.

STUDY 3

	Experimental Group (N=52)	Control group (N=54)
Sex		
Female	42 (8.80%)	44 (81.48%)
Male	10 (19.20%)	10 (18.52%)
Relationship status		
Single	49 (94.23%)	54 (10.00%)
In a relationship	1 (1.92%)	-
Cohabitation	2 (3.85%)	-
Divorced	-	-
Widower	-	-
Education level		
Diploma	19 (36.54%)	16 (29.63%)
Bachelor's degree	25 (48.08%)	32 (59.26%)
Master's degree	6 (11.54%)	6 (11.11%)
Postgraduate qualification	2 (3.85%)	0 (.00%)
Professional occupation		
Employer	14 (26.92%)	4 (7.41%)
Student	35 (67.31%)	39 (72.22%)
Unemployed	3 (5.77%)	1 (1.85%)
Self-employed	-	3 (5.56%)
Other	-	7 (12.96%)
Religious orientation		
Catholic	16 (3.77%)	20 (37.04%)
Atheist	23 (5.77%)	29 (53.70%)
Buddhist	1 (1.92%)	1 (1.85%)
Other	12 (23.08%)	5 (9.26%)
Sport activity		
Yes	28 (53.85%)	28 (51.85%)
No	24 (46.15%)	26 (48.15%)

Procedure

Participants initially underwent a psychopathological and psychological assessment and subsequently completed an intertemporal choice task, administered with the standardized Italian versions of all instruments.

All questionnaires and the intertemporal choice task were administered electronically via the Qualtrics platform and in the presence of an experienced clinician, with the exception of 15 participants who completed the procedure remotely (see Procida et al., submitted). Every measure was administered at two time points: during the baseline phase (pre-test, t0) and again during the final assessment phase (post-test, t1).

The interval between the two assessments was either approximately 8 weeks or 4 weeks, depending on the workshop schedule. During this period, participants in the

STUDY 3

experimental group attended a structured series of experiential workshops delivered by clinicians from ASL Roma 1 at the University “G. d’Annunzio” of Chieti-Pescara, while participants in the control group received no intervention, in early feasibility work. In addition, participants in the experimental group took part in an individual feedback session at the end of the test phase, during which a clinician reviewed and discussed the results of the initial assessment with them (see below for further details).

First phase: Pre-test Psychopathological and psychological assessment (t0)

All participants were submitted to a psychopathological and psychological evaluation including self-assessment psychological questionnaires and an intertemporal choice task as in our previous study (see Study 2 in Chapter 3).

Second phase: Assessment feedback session

As part of the intervention, each participant of the Experimental group completed an individual feedback interview with the clinician responsible for supervising the screening phase. During this session, the scores of the previously administered tests were presented and discussed in detail. Providing participants with structured feedback based on standardized assessments is considered an effective procedure for increasing self-awareness in preventive contexts, and in this study the feedback session offered students a clear restitution of their personal strengths and vulnerabilities related to early risk factors. Consistent with extensive empirical evidence, feedback derived from statistical or actuarial methods tends to outperform subjective evaluations in helping people recognize patterns of risk and protection (Ægisdóttir et al., 2006; Grove, 2005).

Third phase: Experiential Labs

Participants in the experimental group took part in a series of experiential workshops. Students who chose to participate attended the “Emotion and Desire” and “Motivation for Change” labs, each lasting 2 hours, delivered either across eight sessions over a 2-month period or four longer sessions over a 1-month period effectively balancing the total duration of the two-month sessions.

The experiential intervention delivered to the experimental group was structured around evidence-based practices designed to strengthen emotional self-regulation, cognitive control, and stress-management capacities. Across eight two-hour sessions,

STUDY 3

students engaged in a set of practices targeting core mechanisms of emotional awareness, attentional stability, and inhibitory regulation—domains consistently linked to prefrontal functioning and adaptive behavioral modulation. The program introduced the emotional process as a multidimensional system integrating subcortical circuitry, physiological activation, conscious representations, and expressive components, and guided participants in observing automatic thoughts and mind wandering to increase metacognitive insight into implicit cognitive dynamics (Smallwood & Schooler, 2015). Breath-focused attention with counting was used to enhance sustained attention and internal self-control, while mindfulness-based stabilization practices supported autonomic regulation and stress reduction, processes associated with neuroplastic changes in prefrontal regions implicated in executive regulation (Zeidan et al., 2010; Hölzel et al., 2011).

Building on these foundations, the intervention incorporated cognitive and behavioral strategies for emotion regulation, such as reappraisal, distraction, and somatic relaxation, supported by prefrontal engagement (Gross, 2002; Morawetz et al., 2016). Body-scan practices were employed to cultivate non-judgmental interoceptive awareness and reduce anxiety and stress (Allen et al., 2012; Kral et al., 2018), while diaphragmatic breathing targeted parasympathetic activation, contributing to reductions in cortisol and blood pressure and fostering psychophysiological calm (Ma et al., 2017). The program also addressed the role of emotions in stress reactivity and their impact on higher-order cognition, integrating progressive muscle relaxation to counteract sympathetic arousal and promote deep relaxation (Jacobson, 1929; Sapolsky, 2004; Arnsten, 2009). Language-based strategies were introduced to support cognitive-emotional regulation, including the use of the validated Geneva Emotion Wheel to facilitate fine-grained labeling of emotional states and their associated thoughts and bodily sensations (Scherer et al., 2013). Emotion personification exercises further promoted psychological distancing and attenuation of emotional intensity (Chen et al., 2020). The intervention also examined the neuropsychological mechanisms of desire, with particular attention to dopaminergic pathways involved in reward anticipation and motivation, highlighting how psychoactive substances and maladaptive behaviors can dysregulate these systems and foster compulsive desire (Schultz, 1997; Berridge & Robinson, 1998; Wise, 2004). Mindfulness-based observation of desires without automatic enactment, gratitude journaling, and the recall of pleasant experiences were used to activate reward circuits and strengthen resilience (Emmons & McCullough, 2003; Benson, 1996).

STUDY 3

Throughout the program, mindfulness was conceptualized as intentional, non-judgmental awareness of the present moment, a process known to reduce craving, impulsive responding, and relapse risk (Tang et al., 2015). Practices such as the STOP technique were used to interrupt automatic cognitive-emotional reactions (Rahl et al., 2017), while perceptual anchoring on breath or environmental sounds supported attentional control and cognitive reorientation. Finally, the intervention addressed theory of mind and empathy as components of self-regulation, emphasizing mentalization as a capacity essential for managing impulsive behaviors and understanding others' mental states (Frith & Frith, 2006). Loving-Kindness Meditation, compassion meditation, and self-compassion letter writing were incorporated to cultivate benevolence, emotional clarity, and self-directed care, processes shown to enhance positive emotional regulation (Klimecki et al., 2014; Neff & Germer, 2013; Hutcherson et al., 2008).

The underlying assumption is that participation in the experiential workshops would lead to positive changes in key psychological variables assessed during the initial screening, such as a reduction in temporal discounting and/or improvements in emotion-regulation capacities. In contrast, the control group did not receive any intervention. Four weeks of treatment are the minimum number for taking part in the treatment.

Fourth phase (post-test, t1): Post-test Psychopathological and psychological assessment (t1)

After the 8- or 4-week interval, participants of both the Experimental and the Control group completed the post-test assessment. During this second assessment, only the K-10, DERS, BPQ-SF, and the Temporal Discounting task were re-administered. These measures assess psychological processes that are expected to change over the relatively short interval between assessments, such as distress, emotion regulation, somatic reactivity, and impulsive decision-making. In contrast, the ABQ, BFQ-2, and TAS-20 capture more stable cognitive beliefs, personality traits, and dispositional characteristics, which are not typically sensitive to short-term fluctuations and were therefore not repeated at the post-test.

Data Analysis

To estimate individual discounting tendencies, choices were fitted with a standard hyperbolic function (Green & Myerson, 2004; Kable & Glimcher, 2007; Mazur, 1987), yielding a discount parameter k indexing the steepness of temporal devaluation. The model was implemented using nonlinear least-squares estimation in R, and k values were log-transformed prior to statistical analyses to approximate normality. Higher k values reflect steeper discounting, indicating a stronger preference for immediate over delayed rewards. Following log-transformation, k values were normally distributed, allowing the use of parametric statistical tests when appropriate. The analysis was conducted using R scripts adapted from Garofalo et al. (2022; <https://osf.io/65bg7/>).

Descriptive statistics included means and standard deviations for numerical variables—especially those obtained from standardized questionnaires—and frequencies and percentages for categorical variables related to sociodemographic characteristics and addiction-related habits. All statistical analyses were performed in Jamovi 2.7.4.

Moreover, Spearman correlations were performed to examine associations among the pre-test measures (t_0), including indices of addictive behaviors, temporal discounting, emotion regulation, alexithymia, psychological distress, personality traits, and body perception. Specifically, correlations were examined between the Severity Indices (SI) of the Addiction Behavior Questionnaire (ABQ; substance use, gambling, internet use, and alcohol use; obsessive–compulsive–impulsive and addictive behaviors) and the seven ABQ domains (separation anxiety, affective dysregulation, somatoform and psychological dissociation, childhood traumatic experiences, impulse dyscontrol, compulsive behaviors and ritualization, and obsessive thoughts). The same ABQ measures were also correlated with the DERS and its subscales, the hyperbolic discounting parameter (k) derived from the Temporal Discounting task, the TAS-20, the K-10, the Big Five Questionnaire (BFQ), and the Body Perception Questionnaire (BPQ) variables. To note, correlational analyses involving the variables SI-gambling and OC-gambling were not conducted due to insufficient valid observations. Both variables indeed showed missing values for all the participants out of two ($N = 106$), resulting in an inadequate effective sample size for reliable estimation of correlation coefficients.

To assess intervention effects, a mixed-design ANOVA was performed with Group (experimental vs. control) as the between-subjects' factor and Time (pre-test vs. post-test) as the within-subjects' factor, followed by Bonferroni post hoc test.

STUDY 3

In addition, to assess whether changes in one variable were associated with changes in another we performed a spearman's rho correlations for the change scores (delta; pret-est - post-test) of the DERS, the hyperbolic k value of Temporal Discounting, the K- 10, and the BPQ.

Results

Addiction risk and psychological variables

Independent samples t- tests conducted at baseline (t_0) revealed several group differences, five of which remained significant after controlling for multiple comparisons using the False Discovery Rate (FDR). The strongest effects emerged within the 7DAS domains, specifically for separation anxiety (Dom1: $t(104) = -3.38$, $p = .001$, $d = -0.66$) and childhood traumatic experiences (Dom4: $t(104) = -3.68$, $p < .001$, $d = -0.71$). Additional FDR- corrected differences within the 7DAS included impulse dyscontrol (Dom5: $t(104) = -2.49$, $p = .015$, $d = -0.48$) and obsessive thoughts (Dom7: $t(104) = -2.49$, $p = .014$, $d = -0.48$). A further significant effect was observed for alcohol- related obsessive–compulsive features (ABQ- Alcohol B: $t(76) = 2.65$, $p = .010$, $d = 0.50$) and ABQ-Internet A : $t($. In contrast, indices of problematic internet use, affective dysregulation, somatoform dissociation, compulsive behaviors, and substance- related addictive tendencies did not survive FDR correction. Measures of temporal discounting (TD), emotion- regulation difficulties (DERS), alexithymia (TAS- 20), body awareness (BPQ), and personality traits (BFQ) also showed highly comparable profiles across groups. Overall, despite a small cluster of differences concentrated in trauma- related and impulse- regulation domains, the two groups were sufficiently homogeneous at baseline for the purposes of the study (see Table 2), although potential self- selection effects cannot be excluded (but see discussion for possible self-selection bias).

Table 2.

Means and standard deviations of the scores obtained at pre-test (t_0) by both groups. Asterisks denote statistically significant effects at the baseline.

Measure	Experimental Group (Pre)	Control Group (Pre)	p_{FDR}
Severity Index (SI)			
A – Addictive behaviors (substances)	6.08 ± 2.74	4.3 ± 3.68	0.2166
B – Obsessions–impulsions–compulsions	10.33 ± 5.84	5.4 ± 6.58	0.1333
A – Addictive behaviors (alcohol)	3.75 ± 1.93	3.27 ± 1.61	0.2166
B – Obsessions–impulsions–compulsions*	3.94 ± 3.51	2.27 ± 1.92	0.0433
A – Addictive behaviors (internet)*	4.60 ± 2.57	3.48 ± 2.38	0.0117

STUDY 3

B – Obsessions–impulsions–compulsions	6.37 ± 4.63	4.6 ± 5.25	0.1333
7-Domain (7DAS)			
D1 – Separation anxiety*	14.88 ± 6.78	10.68 ± 5.98	0.0117
D2 – Affective dysregulation*	13.58 ± 5.12	11.37 ± 5.12	0.0627
D3 – Somatoform and psychological dissociation	4.75 ± 4.61	3.35 ± 3.73	0.1333
D4 – Childhood traumatic experiences*	8.83 ± 6.85	4.42 ± 5.41	0.0117
D5 – Impulse dyscontrol*	11.83 ± 5.14	9.48 ± 4.57	0.455
D6 – Compulsive behaviors and ritualization	9.77 ± 5.96	8.24 ± 5.19	0.2166
D7 – Obsessive thoughts*	15.35 ± 6.30	12.29 ± 6.28	0.0455
DEERS Total	92.5 ± 27.14	85.13 ± 25.33	0.3020
Nonacceptance	14.69 ± 6.24	13.05 ± 5.95	0.3020
Goals	15.92 ± 4.85	14.5 ± 5.43	0.3020
Impulse	12.94 ± 5.17	12.44 ± 5.43	0.6300
Strategies	19.71 ± 7.76	18.24 ± 7.28	0.5295
Awareness	15.96 ± 5.42	15.55 ± 5.42	0.7010
Clarity*	13.27 ± 4.29	11.33 ± 3.76	0.1575
K-10 Psychological Distress	23.52 ± 8.50	20.05 ± 7.82	0.2170
Toronto Alexithymia Scale-20 (TAS)	45.98 ± 12.08	44.70 ± 12.08	0.5880
Difficulty identifying feelings	15.36 ± 6.34	13.74 ± 5.50	0.3020
Difficulty describing feelings	14.38 ± 5.03	12.81 ± 5.16	0.2900
Externally oriented thinking	16.23 ± 3.93	18.15 ± 4.24	0.1890
Body Perception Questionnaire (BPQ)			
Body awareness	14.17 ± 4.19	14.24 ± 5.76	0.9380
Supradiaphragmatic reactivity	9.94 ± 2.23	9.29 ± 1.58	0.2200
Subdiaphragmatic reactivity	12.07 ± 3.81	12.13 ± 3.74	0.9430
Agreeableness*	6.98 ± 1.55	6.26 ± 1.78	0.2170
Big-Five Questionnaire (BFQ)			
Conscientiousness	7.03 ± 1.82	7.33 ± 2.19	0.5295
Emotional Stability	5.60 ± 1.83	5.29 ± 2.30	0.5295
Extraversion	5.94 ± 1.72	6.11 ± 2.34	0.7010
Openness	7.90 ± 1.64	6.94 ± 2.29	0.1575
Delay Discounting	-5.45 ± 2.84	-5.34 ± 2.32	0.2800

Correlations Between the ABQ Severity Indices, the Seven Domains, and Psychological Factors

For what concerns the pattern of association between addiction-related (substance, alcohol, internet) severity indices (measured in terms of addictive behaviors and obsessions–impulsions–compulsions) and risk factors for addiction development and maintenance, table 3 shows widespread significant correlations that generally sustain the multidimensional model by Caretti et al. (2018), according to which higher severity levels co-occur with greater impulsivity and poor behavioral control, compulsive and obsessive–conflictual tendencies, somatoform and psychological dissociation, trauma-related affective dysregulation, and insecure attachment features.

STUDY 3

Substance-related addictive behaviors showed a selective pattern, positively correlating only with Domain 4 ($r = .508$, $p = .016$), Domain 5 ($r = .442$, $p = .039$), and Domain 6 ($r = .553$, $p = .008$), and negatively with Conscientiousness ($r = -.558$, $p = .007$).

Alcohol-related severity showed a broader profile. The SI for alcohol-related addictive behaviors correlated with Domain 2, reflecting affective dysregulation ($r = .327$, $p = .003$), with Domain 3, reflecting somatoform and psychological dissociation ($r = .241$, $p = .034$), and with Domains 5, 6, and 7 (r s = .364, .293, and .454; p s = .001, .009, and $< .001$). The SI for alcohol-related obsessions–impulsions–compulsions correlated with Domain 1, reflecting separation anxiety ($r = .238$, $p = .036$), with Domain 2 ($r = .285$, $p = .011$), and with Domains 5, 6, and 7 (r s = .423, .313, and .407; p s $< .001$, .005, and .003). Both indices were associated with emotion dysregulation, such as addictive behaviors correlated with the DERS total score ($r = .496$, $p < .001$) and with all subscales except Awareness (all p s $< .001$), whereas obsessions–impulsions–compulsions correlated with Nonacceptance ($r = .323$, $p = .004$), Goals ($r = .375$, $p < .001$), Impulse ($r = .368$, $p < .001$), Strategies ($r = .214$, $p = .016$), and Clarity ($r = .369$, $p < .001$).

Alcohol-related addictive behaviors also correlated with psychological distress ($r = .405$, $p < .001$), alexithymia ($r = .275$, $p = .015$), lower Emotional Stability ($r = -.326$, $p = .004$), and higher Openness ($r = .316$, $p = .005$), whereas alcohol-related obsessions–impulsions–compulsions correlated with psychological distress ($r = .334$, $p = .003$), alexithymia ($r = .240$, $p = .034$), lower Emotional Stability ($r = -.227$, $p = .045$), and higher Openness ($r = .262$, $p = .021$).

Internet-related severity showed the most pervasive pattern. Both the SI for internet-related addictive behaviors and the SI for internet-related obsessions–impulsions–compulsions correlated with all risk domains (r s = .315–.449, all p s $< .01$). Internet-related addictive behaviors correlated with the DERS total score ($r = .343$, $p < .001$) and with all subscales, including Nonacceptance ($r = .228$, $p = .028$), Goals ($r = .400$, $p < .001$), Impulse ($r = .303$, $p = .003$), Strategies ($r = .298$, $p = .004$), Awareness ($r = .204$, $p = .049$), and Clarity ($r = .237$, $p = .022$). The obsessions–impulsions–compulsions index correlated with Goals ($r = .338$, $p < .001$), Impulse ($r = .267$, $p = .010$), Strategies ($r = .261$, $p = .011$), and Clarity ($r = .218$, $p = .036$). Internet-related addictive behaviors were also associated with psychological distress ($r = .382$, $p < .001$), alexithymia ($r = .296$, $p = .004$), lower Emotional Stability ($r = -.233$, $p = .025$), and higher supradiaphragmatic reactivity (all p s $< .001$), whereas internet-related obsessions–impulsions–compulsions correlated with

STUDY 3

psychological distress ($r = .428$, $p < .001$), alexithymia ($r = .278$, $p = .007$), and supradiaphragmatic reactivity (all $ps < .001$).

Finally, gambling-related severity showed a pattern similar to internet-related addiction: the SI for gambling-related addictive behaviors correlated with all DERS subscales (all $ps < .01$), whereas the SI for gambling-related obsessions–impulsions–compulsions correlated with all subscales except Nonacceptance and Awareness ($ps > .09$), and both indices correlated with psychological distress ($rs = .382$ and $.428$, both $ps < .001$).

Neither index was associated with temporal discounting (all $ps > .05$).

A complete overview of these associations is presented in Table 3, which reports correlations with the ABQ cognitive domains, and in Table 4, which summarizes correlations with the psychological measures.

Table 3.

Correlations between the ABQ addiction severity and cognitive domains.

SI-AC = Severity Index; SI-OC = obsessions–impulsions–compulsion.

	D1-Separation Anxiety	D2-Affective Dysregulation	D3-Somatoform and Psychological Dissociation	D4-Childhood Traumatic Experiences	D5-Impulse Dyscontrol	D6-Compulsive Behaviors and Ritualization	D7-Obsessive Thoughts
SI-AB substance	$r=.079$ $p = .726$	$r = .126$ $p = .575$	$r = .190$ $p = .398$	$r = .508^*$ $p = .016$	$r=.442^*$ $p = .039$	$\rho=.553^*$ $p = .008$	$r = .240$ $p = .282$
SI-OC substance	$r = .118$ $p = .600$	$r = .247$ $p = .267$	$r = .235$ $p = .292$	$r = .209$ $p = .350$	$r=.310^*$ $p = .161$	$r = .409$ $p = .058$	$r = .227$ $p = .309$
SI-AB alcohol	$r=.210$ $p=.065$	$r=.327^*$ $p=.003$	$r=.241^*$ $p=.034$	$r=-.016$ $p=.891$	$r=.364^*$ $p=.001$	$r=.293^*$ $p=.009$	$r=.454^*$ $p<.001$
SI-OC alcohol	$r=.238^*$ $p=.036$	$r=.285^*$ $p=.011$	$r=.217$ $p=.056$	$r=.078$ $p=.496$	$r=.423^*$ $p<.001$	$r=.313^*$ $p=.005$	$r=.407^*$ $p=.003$
SI-AB internet	$r=.388^*$ $p<.001$	$r=.401^*$ $p<.001$	$r=.360^*$ $p<.001$	$r=.250^*$ $p=.016$	$r=.509^*$ $p<.001$	$r=.276^*$ $p=.007$	$r=.413^*$ $p<.001$
SI-OC internet	$r=.434^*$ $p<.001$	$r=.388^*$ $p<.001$	$r=.416^*$ $p<.001$	$r=.315^*$ $p=.002$	$r=.450^*$ $p<.001$	$r=.345^*$ $p<.001$	$r=.449^*$ $p<.001$

Table 4. *Correlations between addiction severity and psychological measures.* SI-AC = Severity Index; SI-OC = obsessions–impulsions–compulsion.

	SI-AB substance	SI-OC substance	SI-AB alcohol	SI-OC alcohol	SI-AB internet	SI-OC internet
DERS						
DERS	$r = .245$	$r = .322$	$r = .496^*$	$r=.381^*$	$r=.343^*$	$r=.288^*$

STUDY 3

total	p = .272	p = .145	p <.001	p <.001	p <.001	p=.005
Nonacceptance	r=.309 p = .162	r=.367 p = .093	r = .483* p <.001	r = .323* p = .004	r = .228* p=.028	r=.173 p=.097
Goals	r = .161 p = .474	r = .350 p = .111	r = .392* p <.001	r = .375* p <.001	r = .400* p <.001	r=.338* p <.001
Impulse	r = .160 p = .477	r = .273 p = .220	r = .512* p <.001	r = .368* p <.001	r = .303* p=.003	r= .267* p=.010
Strategies	r = .244 p = .274	r = .348 p = .112	r = .416* p <.001	r = .214* p = .016	r = .298* p=.004	r=.261* p=.011
Awareness	r = .087 p = .702	r = .185 p = .410	r = .127 p = .267	r = .116 p = .310	r = .204* p=.049	r=.124 p=.236
Clarity	r = .308 p = .163	r = .361 p = .099	r = .447* p <.001	r = .369* p <.001	r = .237* p=.022	r= .218* p=.036
K-10						
K-10 total	r = .163 p = .468	r = .197 p = .379	r = .405* p <.001	r = .334* p = .003	r = .382* p <.001	r=.428* p <.001
TAS-20						
TAS-20 total	r = - .014 p = .950	r = - .047 p = .834	r = .275* p = .015	r = .240* p = .034	r = .296* p=.004	r=.278* p=.007
Difficulty Identifying feelings	r=.108 p=.770	r=.066 p=.634	r=.406* p<.001	r=.317* p=.005	r=.329* p=.001	r=.337* p<.001
Difficulty describing feelings	r=-.012 p=.958	r=-.088 p=.697	r= .199 p=.080	r=.171 p=.134	r=.314* p=.002	r=.244* p=.018
Externally oriented thinking	r=-.258 p=.246	r=-.119 p=.597	r=-.040 p=.726	r=-.008 p=.943	r=.042 p=.688	r=.107 p=.305
BFQ-2						
Agreeableness	r = -.308 p = .163	r = -.143 p = .524	r = -.070 p = .544	r = .004 p = .969	r=.134 p=.201	r=-.132 p=.205
Conscientiousness	r = - .558* p = .007	r = - .138 p = .540	r = - .081 p = .478	r = .098 p = .393	r=-.102 p= .332	r = - .108 p = .303
Emotional Stability	r = - .012 p = .957	r = - .034 p = .882	r=-.326* p = .004	r=-.227* p = .045	r=-.233* p = .025	r = - .194 p = .063
Extraversion	r = - .032 p = .887	r = - .049 p = .827	r = - .070 p = .543	r = - .001 p = .994	r = - .065 p = .537	r = - .195 p = .061
Openness	r = .247 p = .268	r = .243 p = .275	r = .316* p = .005	r = .262* p = .021	r = .060 p = .571	r = .058 p = .581
(BPQ)						
Body awareness	r = .005 p = .982	r = -.171 p = .446	r = -.001 p = .991	r = .111 p = .332	r = .044 p = .678	r = -.060 p = .565
Supradiaphragmatic reactivity	r = .326 p = .139	r = .337 p = .126	r = .202 p = .076	r = .168 p = .142	r = .375* p <.001	r = .494* p<.001
Body awareness/Sub diaphragmatic reactivity	r = .206 p = .358	r = -.021 p = .925	r = -.014 p = .902	r = .077 p = .500	r = .083 p = .429	r = .145 p = .167
TD						
Hyperbolic K	r = .039	r = .298	r = .006	r = -.032	r = .044	r = .058

STUDY 3

| $p = .864$ | $p = .178$ | $p = .961$ | $p = .780$ | $p = .678$ | $p = .581$

Respect to the ABQ domains of addiction risks (D1–Separation Anxiety, D2–Affective Dysregulation, D3–Somatoform and Psychological Dissociation, D4–Childhood Traumatic Experiences, D5–Impulse Dyscontrol, D6–Compulsive Behaviors and Ritualization, D7–Obsessive Thoughts), all psychological measures showed significant associations, although with different patterns of strength and consistency.

As reported in Table 5, the ABQ domains showed moderate- to- strong correlations with the DERS total score ($r_s = .43-.74$, all $p_s < .001$), with the strongest associations emerging for Affective Dysregulation, Impulse Dyscontrol, and Obsessive Thoughts. A comparable pattern was observed across most DERS subscales—non- acceptance, goals, impulse, strategies, and clarity—whereas the awareness subscale showed weaker and less consistent associations.

The ABQ domains were also positively and strongly associated with psychological distress measured through the K- 10 ($r_s = .32-.75$, all $p_s < .001$). With respect to alexithymia, the ABQ domains showed significant correlations with the TAS- 20 total score, particularly for Affective Dysregulation, Somatoform and Psychological Dissociation, Impulse Dyscontrol, and Obsessive Thoughts. Among the TAS- 20 subscales, Difficulties Identifying Feelings and Difficulties Describing Feelings showed consistent moderate- to- strong correlations, whereas Externally Oriented Thinking was not significantly associated with any ABQ domain.

Regarding personality traits, the ABQ domains were generally negatively associated with agreeableness, conscientiousness, emotional stability, and extraversion, with emotional stability showing the strongest and most consistent inverse correlations across domains. In contrast, openness was positively associated with Childhood Traumatic Experiences, Impulse Dyscontrol, Compulsive Behaviors and Ritualization, and Obsessive Thoughts.

With respect to body perception, the ABQ domains were positively associated with supradiaphragmatic reactivity measured through the BPQ, whereas body awareness and subdiaphragmatic reactivity did not show significant associations.

Finally, the ABQ domains showed small but significant correlations with hyperbolic discounting parameters derived from the Temporal Discounting task, particularly for Somatoform and Psychological Dissociation, Compulsive Behaviors and Ritualization, and

STUDY 3

Obsessive Thoughts, while no significant associations emerged for the remaining domains.

Table 5.

Correlations between each domain and neuropsychological measures.

	D1- Separation Anxiety	D2- Affective Dysregulation	D3- Somatoform and Psychological Dissociation	D4- Childhood Traumatic Experiences	D5- Impulse Dyscontrol	D6- Compulsive Behaviors and Ritualization	D7- Obsessive Thoughts
DERS							
DERS total	$r = .637^*$ $p < .001$	$r = .737^*$ $p < .001$	$r = .472^*$ $p < .001$	$r = .173^*$ $p < .001$	$r = .634^*$ $p < .001$	$r = .433^*$ $p < .001$	$r = .679^*$ $p < .001$
Non acceptance	$r = .432^*$ $p < .001$	$r = .520^*$ $p < .001$	$r = .391^*$ $p < .001$	$r = .175^*$ $p = .004$	$r = .443^*$ $p < .001$	$r = .277^*$ $p = .004$	$r = .481^*$ $p < .001$
Goals	$r = .510^*$ $p < .001$	$r = .611^*$ $p < .001$	$r = .392^*$ $p < .001$	$r = .204^*$ $p < .001$	$r = .647^*$ $p < .001$	$r = .480^*$ $p < .001$	$r = .660^*$ $p < .001$
Impulse	$r = .509^*$ $p < .001$	$r = .608^*$ $p < .001$	$r = .489^*$ $p < .001$	$r = .201^*$ $p < .001$	$r = .548^*$ $p < .001$	$r = .526^*$ $p < .001$	$r = .676^*$ $p < .001$
Strategies	$r = .604^*$ $p < .001$	$r = .615^*$ $p < .001$	$r = .422^*$ $p < .001$	$r = .195^*$ $p < .001$	$r = .548^*$ $p < .001$	$r = .399^*$ $p < .001$	$r = .667^*$ $p < .001$
Awareness	$r = .407^*$ $p < .001$	$r = .482^*$ $p < .001$	$r = .204^*$ $p = .036$	$r = -.136$ $p = .163$	$r = .328^*$ $p < .001$	$r = .074$ $p = .499$	$r = .214^*$ $p = .028$
Clarity	$r = .514^*$ $p < .001$	$r = .723^*$ $p < .001$	$r = .439^*$ $p < .001$	$r = .160$ $p = .102$	$r = .523^*$ $p = .022$	$r = .309^*$ $p = .001$	$r = .556^*$ $p < .001$
K-10							
Total	$r = .614^*$ $p < .001$	$r = .750^*$ $p < .001$	$r = .535^*$ $p < .001$	$r = .318^*$ $p < .001$	$r = .636^*$ $p < .001$	$r = .540^*$ $p < .001$	$r = .736^*$ $p < .001$
TAS-20							
Total	$r = .538^*$ $p < .001$	$r = .751^*$ $p < .001$	$r = .528^*$ $p < .001$	$r = .158$ $p = .107$	$r = .530^*$ $p < .001$	$r = .385^*$ $p < .001$	$r = .548^*$ $p < .001$
Difficulty Identifying feelings	$r = .512^*$ $p < .001$	$r = .768^*$ $p < .001$	$r = .607^*$ $p < .001$	$r = .300^*$ $p = .002$	$r = .656^*$ $p < .001$	$r = .523^*$ $p < .001$	$r = .666^*$ $p < .001$
Difficulty describing feelings	$r = .565^*$ $p < .001$	$r = .657^*$ $p < .001$	$r = .433^*$ $p < .001$	$r = .212^*$ $p = .029$	$r = .485^*$ $p < .001$	$r = .276^*$ $p < .001$	$r = .498^*$ $p < .001$
Externally oriented thinking	$r = .125$ $p = .202$	$r = .239^*$ $p = .014$	$r = .114$ $p = .243$	$r = -.127$ $p = .196$	$r = .020$ $p = .838$	$r = .011$ $p = .907$	$r = .015$ $p = .877$
BFQ-2							
Agreeableness	$r = -.237^*$ $p = .015$	$r = -.276^*$ $p = .004$	$r = -.019$ $p = .848$	$r = -.067$ $p = .494$	$r = -.284^*$ $p = .003$	$r = -.120$ $p = .220$	$r = -.148$ $p = .130$
Conscientiousness	$r = -.279^*$ $p = .007$	$r = -.247^*$ $p = .011$	$r = -.093$ $p = .343$	$r = .094$ $p = .335$	$r = -.307^*$ $p = .001$	$r = -.065$ $p = .507$	$r = -.062$ $p = .527$
Emotional Stability	$r = -.422^*$ $p < .001$	$r = -.509^*$ $p < .001$	$r = -.227^*$ $p = .020$	$r = -.112$ $p = .253$	$r = -.468^*$ $p < .001$	$r = -.328^*$ $p < .001$	$r = -.505^*$ $p < .001$
Extraversion	$r = -.292^*$ $p = .002$	$r = -.353^*$ $p < .001$	$r = .021$ $p = .833$	$r = .023$ $p = .817$	$r = -.220^*$ $p = .023$	$r = .050$ $p = .608$	$r = -.178$ $p = .068$
Openness	$r = .237^*$ $p = .014$	$r = .117$ $p = .232$	$r = .076$ $p = .440$	$r = .276^*$ $p = .004$	$r = .217^*$ $p = .025$	$r = .280^*$ $p = .004$	$r = .282^*$ $p = .003$
BPQ							
Body awareness	$r = -.045$ $p = .645$	$r = -.092$ $p = .349$	$r = .036$ $p = .718$	$r = .134$ $p = .171$	$r = .011$ $p = .862$	$r = .015$ $p = .880$	$r = .021$ $p = .829$
Supradiaphragm	$r = .481^*$	$r = .539^*$	$r = .528^*$	$r = .381^*$	$r = .549^*$	$r = .446^*$	$r = .467^*$

STUDY 3

atic reactivity	p<.001	p<.001	p<.001	p<.001	p <.001	p<.001	p<.001
Body awareness/Sub diaphragmatic reactivity	r = .092 p=.348	r = .049 p=.615	r = .136 p=.166	r = .138 p=.158	r = .051 p =.604	r = .144 p =.140	r = .157 p=.108
TD							
Hyperbolic K	r = .011 p = .911	r = .149 p = .128	r = .222* p = .022	r = .087 p = .377	r = .102 p = .298	r = .276* p = .004	r = .232* p = .017

Outcome Changes Across the Pre-test – Post-test Interval

To examine changes in psychological measures across time and groups, we conducted a mixed-design ANOVA on log-transformed hyperbolic discounting parameters (k), following standard practice to correct for the typical positive skew and non-normal distribution of raw k values. The analysis revealed a significant Time $\times$ Group interaction, [F (1, 104) = 9.22, p = .003], indicating that changes in discounting behavior over time differed between groups. A significant main effect of Time also emerged, [F (1, 104) = 7.80, p = .006], whereas the main effect of Group was not significant (all ps > .05). Post hoc comparisons showed that participants in the experimental group exhibited a significant decrease in k values over time, reflecting reduced temporal discounting, t (104) = 4.08, p < .001. (Figure 1A)

A similar pattern emerged for difficulties in emotion regulation (DERS). The ANOVA revealed a main effect of Time [F (1, 104) = 9.63, p = .002] and a significant Time $\times$ Group interaction, [F (1, 104) = 15.85, p < .001]. Post hoc comparisons indicated that the decrease from pre-test to post-test was significant only in the experimental group, t (104) = 4.96, p < .001 (Figure 1B).

For psychological distress (K10), we observed no significant main effects of Time or Group (all ps > .05), but only a significant interaction effect, [F (1, 104) = 7.62, p = .007], with Bonferroni-corrected post hoc comparisons did not yield significant pairwise differences.

Finally, a similar result was shown for body awareness, which revealed only a significant interaction effect [F (1, 104) = 9.996, p = .002]. Post-hoc analyses indicated a significant increase from pre-test to post-test in the experimental group [t (104) = -2.90, p = .027], whereas no significant change was observed in the control group (Figure 1C). Average values for each test at pre(t0) and post-test (t1) are reported in Table 6.

STUDY 3

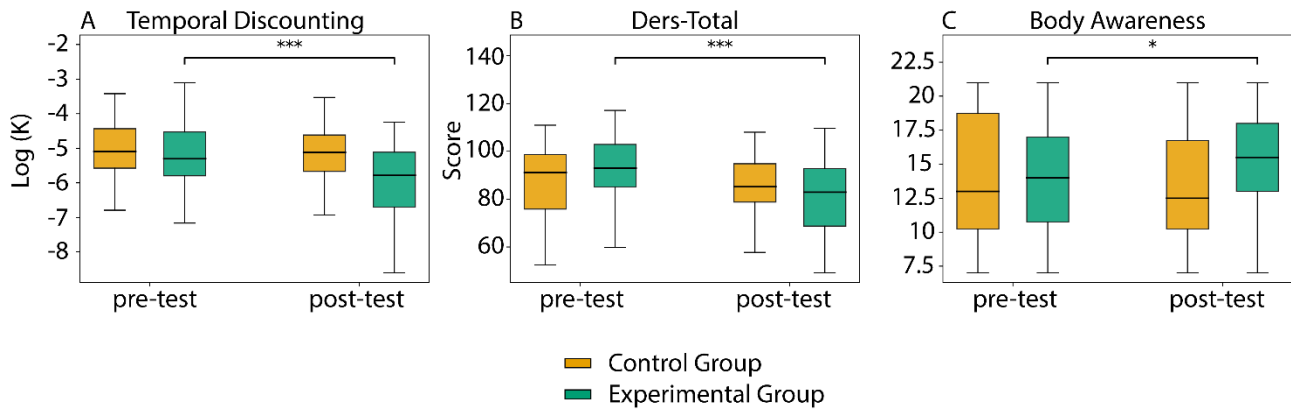


Figure 1. Box plots show the distribution of scores for the control (orange) and experimental (green) groups at pre-test and post-test for (A) temporal discounting (log k), (B) DERS total score and (C) Body Awareness. Boxes represent the interquartile range with median values indicated by horizontal lines; whiskers denote the data range (** $p < .001$).

Table 6.

Mean and standard deviation for each questionnaire and each measurement (pre-test and post-test) on the two groups

Pre-Test (T0)	Control group (mean $\pm$ SD)	Experimental group (mean $\pm$ SD)
Addictive Behavior Questionnaire (ABQ)		
Severity Index (SI)		
A-Addictive Behaviors-substance use	4.30 $\pm$ 3.68	6.08 $\pm$ 2.75
B-Obsessions-Impulses-Compulsions	5.40 $\pm$ 6.59	10.33 $\pm$ 5.84
A-Addictive Behaviors-alcohol	3.27 $\pm$ 1.61	3.76 $\pm$ 1.94
B-Obsessions-Impulses-Compulsions	2.27 $\pm$ 1.92	3.95 $\pm$ 3.52
A-Addictive Behaviors-gambling	3.00 $\pm$ 3.46	-
B-Obsessions-Impulses-Compulsions	8.33 $\pm$ 6.81	-
A-Addictive Behaviors-internet	3.49 $\pm$ 2.39	4.60 $\pm$ 2.57
B-Obsessions-Impulses-Compulsions	4.60 $\pm$ 5.26	6.38 $\pm$ 4.62
7-Domain (7DAS)		
D1-Separation Anxiety	10.07 $\pm$ 5.98	14.90 $\pm$ 6.78
D2-Affective Dysregulation	11.40 $\pm$ 5.12	13.60 $\pm$ 5.12
D3- Somatoform and Psychological Dissociation	3.35 $\pm$ 3.73	4.75 $\pm$ 4.61
D4-Childhood Traumatic Experiences	4.43 $\pm$ 5.41	8.83 $\pm$ 6.85
D5-Impulse Dyscontrol	9.48 $\pm$ 4.57	11.83 $\pm$ 5.14
D6-Compulsive Behaviors and Ritualization	8.24 $\pm$ 5.19	9.77 $\pm$ 5.96
D7-Obsessive Thoughts	12.30 $\pm$ 6.28	15.35 $\pm$ 6.31
Difficulties in Emotion Regulation Scale (DERS)		
Total score	85.10 $\pm$ 25.3	92.5 $\pm$ 27.1
Non-acceptance	13.10 $\pm$ 5.95	14.7 $\pm$ 6.15
Goals	14.5 $\pm$ 5.43	15.9 $\pm$ 4.82
Impulse	12.4 $\pm$ 5.43	12.9 $\pm$ 5.17
Strategies	18.2 $\pm$ 7.28	19.7 $\pm$ 7.77
Awareness	15.6 $\pm$ 5.42	16.0 $\pm$ 5.42

STUDY 3

Clarity	11.3 ± 3.76	13.3 ± 4.29
Kessler Psychological Distress Scale (K10)		
Total score	20.1 ± 7.82	23.5 ± 8.5
Toronto Alexithymia Scale-20 (TAS)		
Total score	44.7±12.1	46.0±12.1
Difficulty identifying feelings	13.70 ± 5.51	15.40 ± 6.34
Difficulty describing feelings	12.80± 5.17	14.38 ± 5.03
Externally oriented thinking	18.19 ± 4.25	16.23 ± 3.93
Body Perception Questionnaire (BPQ)		
Body awareness	14.27 ± 4.77	14.27 ± 4.19
Supradiaphragmatic reactivity	9.30 ± 1.59	9.94 ± 2.24
Body awareness/Subdiaphragmatic reactivity	12.08 ± 3.74	12.08 ± 3.81
Big-Five Questionnaire (BFQ)		
Agreeableness	6.26 ± 1.78	6.98 ± 1.55
Conscientiousness	7.33 ± 2.20	7.04 ± 1.83
Emotional stability	5.30 ± 2.30	5.60 ± 1.99
Extraversion	6.11 ± 2.34	5.94 ± 1.72
Openness	6.94 ± 2.29	7.90 ± 1.64
Delay discounting task - Hyperbolic K	-5.34 ± 2.32	-4.45 ± 2.84

Post-test (T1)	Control group (mean ± SD)	Experimental group (mean ± SD)
Difficulties in Emotion Regulation Scale (DERS)		
Total Score	86.52 ± 23.72	81.31 ± 23.17
Nonacceptance	14.10 ± 5.97	12.96 ± 5.28
Goals	14.11 ± 4.82	14.42 ± 4.52
Impulse	13.20 ± 4.82	11.87 ± 4.01
Strategies	18.53 ± 6.34	17.44 ± 5.61
Awareness	14.80 ± 5.45	13.40 ± 4.89
Clarity	11.20 ± 3.42	11.19 ± 3.68
Kessler Psychological Distress Scale (K10)		
Total Score	21.41 ± 7.87	21.81 ± 7.22
Body Perception Questionnaire (BPQ)		
Body awareness	13.40 ± 4.38	15.69 ± 3.63
Supradiaphragmatic reactivity	9.85 ± 2.33	10.77 ± 2.79
Body awareness/Subdiaphragmatic reactivity	12.46 ± 3.53	12.98 ± 3.02
Delay discounting task - Hyperbolic K	-5.31 ± 2.76	-5.61 ± 2.07

Relationships Between Delta Scores Across Measures

The correlation analysis conducted on the change scores (Δ ; post- test minus pre- test) of the hyperbolic k value of Temporal Discounting, the DERS, the K- 10, and the BPQ revealed a significant positive association between the DERS delta and the K- 10 delta ($r = .364$, $p < .001$), as well as between the Body Awareness delta and the Subdiaphragmatic Reactivity delta ($r = .450$, $p < .001$). All other correlations were not statistically significant ($p > .05$) (Table 7).

STUDY 3

Table 7.

Correlations Between Changes (Δ) in Study Variables

Measure 1	Measure 2	r	p
Δ Temporal Discounting	Δ DERS	r = 0.086	p = 0.374
	Δ K-10	r = 0.046	p = 0.636
	Δ Body Awareness	r = -0.164	p = 0.089
	Δ Supradiaphragmatic Reactivity	r = 0.049	p = 0.612
	Δ Body Awareness / Subdiaphragmatic Reactivity	r = 0.022	p = 0.817
Δ DERS	Δ K-10	r = 0.364	p < .001
	Δ Body Awareness	r = -0.185	p = 0.054
	Δ Supradiaphragmatic Reactivity	r = 0.109	p = 0.261
	Δ Body Awareness / Subdiaphragmatic Reactivity	r = -0.135	p = 0.161
Δ K-10	Δ Body Awareness	r = -0.067	p = 0.491
	Δ Supradiaphragmatic Reactivity	r = 0.107	p = 0.269
	Δ Body Awareness / Subdiaphragmatic Reactivity	r = -0.034	p = 0.723
Δ Body Awareness	Δ Supradiaphragmatic Reactivity	r = 0.057	p = 0.553
	Δ Body Awareness / Subdiaphragmatic Reactivity	r = 0.450	p < .001
Δ Supradiaphragmatic Reactivity	Δ Body Awareness / Subdiaphragmatic Reactivity	r = 0.094	p = 0.331

Discussion

University life represents a critical developmental transition, offering important opportunities for learning and personal growth while simultaneously posing substantial challenges to students' psychological well-being (Arnett, 2000; Beiter et al., 2015; Wood et al., 2018). Within the university context, factors such as high perceived academic demands, limited control over academic outcomes, and insufficient peer support have been associated with increased levels of anxiety and depressive symptoms (Chambel & Curral, 2005; Capone et al., 2020). These vulnerabilities are particularly pronounced among students who rely on maladaptive coping strategies when facing prolonged stress. Given that university attendance often coincides with the developmental period of emerging adulthood, sustained exposure to these stressors may increase the risk of psychological distress and the emergence of maladaptive or risk behaviors (Bedewy & Gabriel, 2015; Capone et al., 2020; Pfeiffer, 2001).

STUDY 3

Within this frame, the present study increases the understanding of addiction vulnerability among Italian university students by integrating psychodynamic, developmental, and neurocognitive perspectives. The pattern of associations observed across emotional, cognitive, and personality domains suggests that addictive tendencies in this population are not isolated behavioral phenomena but rather manifestations of broader regulatory fragilities. This interpretation is consistent with the integrated model of addiction proposed by Caretti et al. (2018), which conceptualizes addictive behaviors, whether substance-related or behavioral, as maladaptive attempts to regulate overwhelming internal states, often rooted in early relational trauma, dissociative tendencies, and impaired affective modulation.

Multifactorial Vulnerability in Addictive Behaviors

The overall pattern of correlations points to a multifactorial etiological model of addiction in which psychological vulnerabilities, neurocognitive mechanisms, and dispositional traits jointly shape students' susceptibility to different forms of addictive behavior. Substance-related severity showed only selective associations, primarily with impulse dyscontrol and compulsive–ritualized tendencies, consistent with neurobiological accounts linking substance involvement to impaired prefrontal inhibitory control and the transition from impulsive to compulsive consumption (Everitt & Robbins, 2016; Volkow et al., 2019). In contrast, alcohol-related severity displayed a far broader constellation of associations, encompassing affective dysregulation, obsessive ideation, emotion-regulation difficulties, psychological distress, and alexithymic traits, suggesting that alcohol may function as a maladaptive strategy for alleviating negative affect or managing overwhelming internal states (Estévez et al., 2017). These patterns were mirrored in personality correlates, with lower emotional stability and higher openness predicting greater alcohol-related risk, in line with evidence linking novelty seeking and emotional reactivity to binge-drinking tendencies. The most pervasive associations emerged for problematic internet use, which was strongly linked to all ABQ domains as well as to deficits in emotion regulation, elevated distress, alexithymia, and reduced emotional stability. This profile supports the view that internet use may serve as a broad dysfunctional coping strategy for individuals with diverse regulatory fragilities, offering immediate affective relief while reinforcing compulsive engagement through reward-based and habit-driven mechanisms (Brand et al., 2019).

STUDY 3

Our findings also support a conceptualization of addiction that views maladaptive behaviors not merely as impulsive acts, but as complex responses shaped by emotional and relational dysregulation. The involvement of alexithymia further suggests that for some students, emotional experience may be encoded primarily at a somatic or pre-reflective level, limiting access to symbolic processing and increasing vulnerability to maladaptive coping strategies. This interpretation is consistent with research showing that alexithymic individuals are more likely to engage in addictive behaviors as a means of down-regulating undifferentiated arousal (Lane et al., 2015; Thorberg et al., 2011). This aligns with the framework proposed by Caretti et al. (2018), which suggests that addictive behaviors arise from the interplay of impulsivity, compulsivity, obsessiveness, emotional dysregulation, dissociation, and insecure attachment. Indeed, many individuals with problematic substance use or behavioral addictions report obsessive preoccupation with addictive stimuli, which can lead to impulsive or compulsive enactment (Caretti et al., 2018).. Moreover, these results are in line with our previous study (Procida et., submitted) that revealed how these interconnected vulnerabilities may contribute to the development and persistence of addictive behaviors and risk factors in young university students.

Personality and impulsivity as dispositional risk factors

While alexithymia captures an emotional–cognitive susceptibility that biases individuals toward immediate rewards, the profile emerging from broad personality traits diverges from this account. The findings also highlight the contribution of dispositional traits to addiction vulnerability. Low conscientiousness and low emotional stability were associated with higher addiction severity, consistent with evidence that these traits reflect enduring tendencies toward impulsivity, affective instability, and poor self-control (Andreassen et al., 2013; Kotov et al., 2010). These personality dimensions may amplify the impact of situational stressors by reducing the capacity to maintain goal-directed behavior or inhibit maladaptive impulses. Importantly, the associations between temporal discounting and the ABQ domains of somatoform/psychological dissociation (D3), compulsive behaviors and ritualization (D6), and obsessive thoughts (D7) suggest that steep discounting reflects a broader vulnerability toward immediacy-driven regulation rather than addiction severity per se. Individuals with somatoform or dissociative tendencies often rely on rapid strategies to alleviate internal discomfort, consistent with evidence that somatization and dissociation are linked to a preference for short-term relief and difficulties representing future outcomes (Hasin & Katz, 2007; Kirmayer & Taillefer,

1997; Holmes et al., 2005). Likewise, the associations with impulsive, compulsive, and obsessive domains indicate that high discounting aligns with urgency-driven action and habitual responding: compulsive rituals and intrusive thoughts generate acute tension that individuals attempt to neutralize immediately, mirroring the prioritization of short-term outcomes observed in altered intertemporal decision-making among obsessive-compulsive profiles (Steinglass et al., 2016; Story et al., 2015). From this perspective, temporal discounting may index a core cognitive-affective bias toward immediate relief, fostering reliance on dissociative, impulsive, or ritualized responses and providing a substrate that can potentiate—but does not directly determine—addictive vulnerability (Bickel et al., 2014).

The effects of the Pr.I.M.E. intervention

Beyond identifying vulnerability markers, the present study provides preliminary evidence that the Pr.I.M.E. experiential workshops can produce meaningful improvements in psychological processes implicated in addiction risk. Participants in the intervention group exhibited reductions in emotional dysregulation, psychological distress, and somatic reactivity, as well as changes in temporal discounting, whereas no comparable improvements were observed in the control group. These findings suggest that the intervention successfully targeted core regulatory mechanisms, consistent with its theoretical foundations. When interpreting the effectiveness of the intervention, it is important to consider the baseline differences that emerged between the two groups on several ABQ domains. Participants in the experimental group showed higher initial scores in critical areas such as childhood traumatic experiences, separation anxiety, and, most notably, affective dysregulation and impulse dyscontrol (as measured by the ABQ rather than the DERS). This pattern suggests that the experiential workshops were implemented with a subgroup characterized by greater psychological vulnerability. It is plausible that these students possessed a stronger intrinsic motivation to engage in the intervention, which may have contributed to a self-selection process favoring individuals with more pronounced regulatory difficulties.

The reduction in DERS scores is particularly noteworthy, given that emotion-regulation difficulties emerged as one of the strongest correlates of addiction vulnerability. The experiential workshops incorporated mindfulness practices, breath awareness, body-scan exercises, and emotion-labeling strategies, techniques known to enhance regulatory capacity by increasing interoceptive awareness, reducing autonomic arousal, and

STUDY 3

promoting non-reactive attention to internal states (Hölzel et al., 2011; Tang et al., 2015). Improvements in psychological distress, as measured through the K-10 test, further indicate that the intervention may buffer students against stress-related triggers of maladaptive coping, a particularly relevant outcome given the high prevalence of distress in university populations (Auerbach et al., 2016; Sheldon et al., 2021). Furthermore, reductions in emotional dysregulation were moderately associated with reductions in psychological distress, indicating that improvements in the capacity to modulate emotional states co-occurred with a broader decrease in subjective suffering. This finding is consistent with theoretical accounts positioning emotion regulation as a central mechanism through which stress and maladaptive coping tendencies are mitigated (Gross, 2015; Sinha, 2008). In other words, students who became more capable of managing emotional arousal also experienced relief from the psychological burden that often fuels maladaptive behaviors, reinforcing the idea that affective regulation is a pivotal leverage point in preventive interventions.

The decrease in supradiaphragmatic reactivity suggests enhanced autonomic regulation, consistent with evidence that mindfulness-based practices reduce sympathetic activation and promote parasympathetic balance (Ma et al., 2017). From a polyvagal perspective, this pattern may reflect a more efficient engagement of the ventral vagal complex, which regulates supradiaphragmatic structures such as the heart, lungs, pharynx, and larynx and supports states of calm, social engagement, and flexible emotional responding (Porges, 2007, 2009). According to the Polyvagal Theory, indeed, difficulties in emotion regulation can shift the autonomic system toward defensive states characterized by heightened sympathetic arousal and reduced vagal tone, leading to physiological hyperactivation that is experienced as stress. Thus, reductions in supradiaphragmatic reactivity may indicate a restored capacity to modulate autonomic responses and maintain a more adaptive balance between arousal and regulation.

Although changes in temporal discounting were modest, they indicate that experiential practices may also influence cognitive aspects of impulsivity, shifting preferences toward larger, delayed rewards—a choice typically regarded as less impulsive, more mature and adaptive, and indicative of greater self-control (Hendrickson & Rasmussen, 2017). As such, a preference for small, immediate rewards is also a well-established predictor of conduct problems and a significant risk factor for the development of substance misuse, drug use, and addictive behaviors. From a broader theoretical perspective, self-control can be understood as the capacity to maintain a

STUDY 3

preference for long-term, higher-value goals even when smaller, immediately available rewards are present. In this sense, self-control reflects the ability to attenuate temporal discounting, the natural tendency to devalue future outcomes and to experience a diminished motivational pull toward delayed gratifications that all individuals, to some extent, exhibit (Canali 2020).

The fact that temporal discounting changed despite its lack of baseline associations suggests that cognitive impulsivity may be more malleable than previously assumed, even if it is not a primary vulnerability marker in this population (Lempert and Phelps, 2016). In this sense, the malleability of temporal discounting may reflect broader shifts in self-regulatory functioning induced by the intervention, rather than direct effects on reward valuation per se. This interpretation aligns with dual-process models suggesting that discounting can be modulated by interventions that strengthen executive control or reduce affective reactivity, particularly during emerging adulthood when these systems retain substantial plasticity (Bechara, 2005; Steinberg, 2010).

Overall, the findings support a mechanism-focused approach to addiction prevention in university settings. Rather than targeting specific behaviors, interventions may be more effective when they strengthen underlying regulatory capacities—emotion regulation, interoceptive awareness, distress tolerance, and impulse control. The Pr.I.M.E. program appears to operate precisely on these mechanisms, and the observed improvements suggest that even brief, experiential workshops can produce measurable psychological change. This is particularly relevant given the high prevalence of distress and maladaptive coping strategies among university students and the limited availability of campus-based mental health services (Eisenberg et al., 2018; Priestley et al., 2021).

Limitations

Although this study provides meaningful insights into the university experience of Italian students and identifies several variables associated with addictive behaviors and addiction risk, the findings should be interpreted with caution. The relatively small and demographically unbalanced sample limits the generalizability of the results; in particular, the predominance of female participants constrained the examination of gender-related differences in vulnerability. In addition, the absence of qualitative or contextual information on students' lived experiences restricted the ability to fully capture the subjective meaning of the behaviors assessed, potentially narrowing the interpretive depth. It is also important to acknowledge that the low variability observed in certain behaviors—such as substance

STUDY 3

use and gambling—may have reduced statistical power and hindered the detection of meaningful associations with psychological dimensions. Future research would benefit from samples with a more balanced distribution of addictive behaviors, allowing for more precise and nuanced reflections on addiction-related phenomena in university populations and a clearer delineation of differential risk profiles. Finally, because the present study was conducted in a non-clinical sample, the results should be viewed cautiously, as they may not fully reflect the complexity or severity typically observed in clinical contexts.

General Discussion

Every decision requires an evaluation of temporal horizons, subjective value, and anticipated consequences. Choosing between what is available now and what may come later requires individuals to project themselves into the future, tolerate uncertainty, and regulate the pull of immediate gratification. This fundamental tension between immediate and delayed outcomes is captured by the construct of *temporal discounting*, which describes the systematic tendency to devalue rewards as the delay to their receipt increases.

In this dissertation, temporal discounting has served as a conceptual lens for examining how individuals navigate intertemporal trade-offs and how these processes relate to broader patterns of vulnerability. By examining how delayed outcomes are evaluated, the present work examines temporal discounting from complementary theoretical, neural, and psychopathological perspectives, with the aim of clarifying its role in intertemporal decision-making and its relevance for understanding vulnerability to maladaptive behaviors. As reviewed above, temporal discounting can be also considered as a transdiagnostic marker of maladaptive decision-making, given its consistent associations with addictive behaviors, impulsivity, and a broad range of psychiatric conditions (Amlung et al., 2019). Individuals with steeper discount rates tend to favor immediate rewards, a pattern observed across substance use disorders, behavioral addictions, and impulse-control problems.

Rather than treating discounting as a unitary phenomenon, the three studies were designed to examine its dual nature, such as a trait shaped by stable neurodevelopmental features (Study 1) and a state sensitive to psychological vulnerability and contextual modulation (Study 2 and Study 3). This perspective evidenced how intertemporal decision-making intertwines with the formation of vulnerability and the capacity for regulation in young individuals. However, delay discounting is not limited to clinical populations; it also plays a meaningful role in nonclinical contexts. In university students, for example, steeper discounting has been linked to psychological profiles characterized by emotional dysregulation, intrusive thinking, and greater vulnerability to potentially addictive behaviors. Indeed, this developmental period represents a particularly informative context for studying intertemporal decision-making, as emerging adults face increasing autonomy, heightened emotional demands, and frequent exposure to

potentially risky behaviors, making them a population in which early vulnerability markers can be detected with clarity.

In the first study presented in Chapter 2, we examined whether stable neurodevelopmental features of the anterior cingulate cortex relate to intertemporal choice. The ACC constitutes a central hub for cognitive control, conflict monitoring, and effort-based decision-making, and is consistently recruited when individuals must suppress impulsive responses in favor of delayed outcomes. Its role becomes particularly salient in situations where the trade-off between immediate and future rewards is ambiguous, requiring the integration of valuation processes with regulatory mechanisms. Structural studies have shown that asymmetries in ACC sulcal morphology are associated with more efficient cognitive control, likely reflecting intra-hemispheric specialization and enhanced neural efficiency. In a large sample of young adults, individuals with asymmetric ACC sulcal patterns showed lower discount rates than those with symmetric patterns, an effect specific to this region and not observed for control sulci or other cognitive measures. This suggests that the structural hemispheric asymmetry within the ACC may shape the development of cognitive control mechanisms, supporting the ability to prioritize long-term benefits over immediate gratification. In this sense, temporal discounting emerges as a partially trait-like construct grounded in stable neurodevelopmental predispositions.

Although temporal discounting shows trait-like stability, a substantial body of research indicates that it is also sensitive to contextual and psychological influences. In line with this, Chapter 3 presented a study conducted within the Pr.I.M.E. project, a large-scale preventive program aimed at detecting early signs of vulnerability and occasional substance use among university students and at promoting healthier decision-making trajectories during emerging adulthood. Within this framework, we examined whether targeted preventive efforts may influence intertemporal choice and whether temporal discounting aligns with addiction-related risk traits in emerging adults. The results revealed that temporal discounting is associated with several risk-related traits, suggesting that reward-based decision-making contributes to individual differences in susceptibility to addiction within non-clinical populations. However, these findings raise an important question about whether the mechanisms linking temporal discounting to psychological vulnerability, while also remaining sensitive to contextual and regulatory influences, may represent viable targets for preventive intervention.

To examine the extent to which the Pr.I.M.E framework can effectively capture early indicators of addiction risk within a university population, a third study aimed at testing

whether different dimensions (personality traits, emotional regulation, psychological distress, impulsivity) can be identified as meaningful intervention targets. As part of the intervention component, the research protocol included a series of experiential workshops designed to strengthen core regulatory capacities through evidence-based mindfulness practices, body-awareness exercises, and respiratory and emotional-regulation techniques. This intervention study showed that the Pr.I.M.E. experiential laboratories produced meaningful improvements in several psychological mechanisms linked to addiction risk, including reductions in emotional dysregulation, psychological distress, and supradiaphragmatic reactivity, along with a modest shift in temporal discounting. Although the experimental group started with higher vulnerability levels, the observed changes indicate that core regulatory processes in emerging adults are malleable and can be strengthened through brief experiential practices. Overall, the findings support mechanism-focused prevention approaches that target emotion regulation, interoception, and impulse control in university settings.

To sum up, by integrating theoretical models, neural evidence, and intervention-based findings, this dissertation demonstrates that temporal discounting is shaped by both stable neurodevelopmental features and dynamic regulatory processes, and that these mechanisms jointly inform vulnerability and resilience in emerging adulthood. This multi-level perspective advances current models of intertemporal choice and offers valuable insights for future research and preventive interventions, highlighting that temporal discounting, even if viewed as a trait-like tendency, can also be modulated as a state, particularly when regulatory capacities are strengthened through targeted experiential practices.

References

- Addis, D. R., Pan, L., Vu, M. A., Laiser, N., & Schacter, D. L. (2009). Constructive episodic simulation of the future and the past: distinct subsystems of a core brain network mediate imagining and remembering. *Neuropsychologia*, 47(11), 2222–2238. <https://doi.org/10.1016/j.neuropsychologia.2008.10.026>
- Ahn, W.-Y., Rass, O., Fridberg, D. J., Bishara, A. J., Forsyth, J. K., Breier, A., Busemeyer, J. R., Hetrick, W. P., Bolbecker, A. R., & O'Donnell, B. F. (2011). Temporal discounting of rewards in patients with bipolar disorder and schizophrenia. *Journal of Abnormal Psychology*, 120(4), 911–921. <https://doi.org/10.1037/a0023333>
- Ainslie, G. (1975). Specious reward: A behavioral theory of impulsiveness and impulse control. *Psychological Bulletin*, 82(4), 463–496. <https://doi.org/10.1037/h0076860>
- Ainslie, G. (1992). *Picoeconomics: The strategic interaction of successive motivational states within the person*. Cambridge University Press.
- Allen, M., Dietz, M., Blair, K. S., van Beek, M., Rees, G., Vestergaard-Poulsen, P., Lutz, A., & Roepstorff, A. (2012). Cognitive-affective neural plasticity following active-controlled mindfulness intervention. *The Journal of neuroscience : the official journal of the Society for Neuroscience*, 32(44), 15601–15610. <https://doi.org/10.1523/JNEUROSCI.2957-12.2012>
- Alvarez, J. A., & Emory, E. (2006). Executive function and the frontal lobes: A meta-analytic review. *Neuropsychology Review*, 16(1), 17–42. <https://doi.org/10.1007/s11065-006-9002-x>
- American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Arlington, VA: American Psychiatric Publishing, 2013.
- Amlung, M. T., Sweet, L. H., Acker, J., Brown, C. L., & MacKillop, J. (2011). Dissociable brain signatures of choice conflict and immediate reward preferences in alcohol use disorders. *Addiction Biology*, 19(4), 743–753. <https://doi.org/10.1111/j.1369-1600.2011.00352.x>
- Amlung, M., Marsden, E., Holshausen, K., Morris, V., Patel, H., Vedelago, L., Naish, K. R., Reed, D. D., & McCabe, R. E. (2019). Delay Discounting as a Transdiagnostic

Process in Psychiatric Disorders: A Meta-analysis. *JAMA psychiatry*, 76(11), 1176–1186. <https://doi.org/10.1001/jamapsychiatry.2019.2102>

Amlung, M., Vedelago, L., Acker, J., Balodis, I., & MacKillop, J. (2017). Steep delay discounting and addictive behavior: a meta-analysis of continuous associations. *Addiction* (Abingdon, England), 112(1), 51–62. <https://doi.org/10.1111/add.13535>

Andreassen, C. S., Griffiths, M. D., Gjertsen, S. R., Krossbakken, E., Kvam, S., & Pallesen, S. (2013). The relationships between behavioral addictions and the five-factor model of personality. *Journal of behavioral addictions*, 2(2), 90–99. <https://doi.org/10.1556/JBA.2.2013.003>

Angeletos, G.M.; Laibson, D.; Repetto, A.; Tobacman, J.; Weinberg, S. The hyperbolic consumption model: Calibration, simulation, and empirical evaluation. In *Time and Decision: Economic and Psychological Perspectives on Intertemporal Choice*; Russell Sage Foundation: New York, NY, USA, 2003; ISBN 9781610443661

Aranovich, G. J., Cavagnaro, D. R., Pitt, M. A., Myung, J. I., & Yechiam, E. (2016). On the cognitive mechanisms underlying probability matching. *Journal of Behavioral Decision Making*, 29(5), 451–467. <https://doi.org/10.1002/bdm.1888>

Armstrong, E., Schleicher, A., Omran, H., Curtis, M., & Zilles, K. (1995). The ontogeny of human gyrification. *Cerebral Cortex*, 5(1), 56–63. <https://doi.org/10.1093/cercor/5.1.56>

Arnsten, A. Stress signalling pathways that impair prefrontal cortex structure and function. *Nat Rev Neurosci* **10**, 410–422 (2009). <https://doi.org/10.1038/nrn2648>

Arnett, J. J. (2000). Emerging adulthood: A theory of development from the late teens through the twenties. *American Psychologist*, 55(5), 469–48. <https://doi.org/10.1037/0003-066X.55.5.469>

Attali, D. et al. Deep transcranial ultrasound stimulation using personalized acoustic metamaterials improves treatment-resistant depression in humans. *Brain Stimulation* 18, 1004–1014 (2025).

Auerbach, R. P., et al., (2016). Mental disorders among college students in the World Health Organization World Mental Health Surveys. *Psychological medicine*, 46(14), 2955–297. <https://doi.org/10.1017/S0033291716001665>

Baker, F., Johnson, M. W., & Bickel, W. K. (2003). Delay discounting in current and never-before cigarette smokers: Similarities and differences across commodity, sign, and magnitude. *Journal of Abnormal Psychology*, 112(3), 382–392. <https://doi.org/10.1037/0021-843X.112.3.382>

Bar M. (2010). Wait for the second marshmallow? Future-oriented thinking and delayed reward discounting in the brain. *Neuron*, 66(1), 4–5. <https://doi.org/10.1016/j.neuron.2010.04.001>

Barnett P, Saunders R, Buckman JEJ, Cardoso A, Cirkovic M, Leibowitz J, Main N, Naqvi SA, Singh S, Stott J, Varsani L, Wheatly J, Pilling S. Are students less likely to respond to routinely delivered psychological treatment? A retrospective cohort analysis. *Compr Psychiatry*. 2022 Nov;119:152348. doi: 10.1016/j.comppsy.2022.152348.

Barnett P., Arundell L.-L., Matthews H., Saunders R., Pilling S. 'Five hours to sort out your life': qualitative study of the experiences of university students who access mental health support. *BJPsych Open*. 2021;7(4) doi: 1.1192/bjo.2021.947.

Bartels, D. M., & Urminsky, O. (2015). To know and to care: How awareness and valuation of the future jointly shape consumer spending. *Journal of Consumer Research*, 41(6), 1469–1485. <https://doi.org/10.1086/680670>

Bartra, O., McGuire, J. T., & Kable, J. W. (2013). The valuation system: A coordinate-based meta-analysis of BOLD fMRI experiments examining neural correlates of subjective value. *NeuroImage*, 76, 412–427. <https://doi.org/10.1016/j.neuroimage.2013.02.063>

Bechara, A. (2005). Decision making, impulse control and loss of willpower to resist drugs: A neurocognitive perspective. *Nature Neuroscience*, 8(11), 1458–1463. <https://doi.org/10.1038/nn1584>

Beck, R. C., & Triplett, M. F. (2009). Test–retest reliability of a group-administered paper–pencil measure of delay discounting. *Experimental and Clinical Psychopharmacology*, 17(5), 345–355. <https://doi.org/10.1037/a0017078>

Bedewy, D., & Gabriel, A. (2015). Examining perceptions of academic stress and its sources among university students: The perception of Academic Stress Scale. *Health Psychology, Open*, 1-9. <https://doi.org/10.1177/2055102915596714>

Behrens, T. E. J., Hunt, L. T. & Rushworth, M. F. S. The Computation of Social Behavior. *Science* 324, 1160–1164 (2009).

Bennett, T. H., & Holloway, K. R. (2014). Drug misuse among university students in the UK: implications for prevention. *Substance use & misuse*, 49(4), 448–455. <https://doi.org/10.3109/10826084.2013.846378>

Benoit, R. G., Gilbert, S. J., & Burgess, P. W. (2011). A neural mechanism mediating the impact of episodic prospection on farsighted decisions. *Journal of Neuroscience*, 31(18), 6771–6779. <https://doi.org/10.1523/JNEUROSCI.6559-10.2011>

Benson, H. (1996). *Timeless healing: The power and biology of belief*. Scribner.

Berenson, K. R., Gregory, W. E., Glaser, E., Romirowsky, A., Rafaeli, E., Yang, X., & Downey, G. (2016). Impulsivity, rejection sensitivity, and reactions to stressors in borderline personality disorder. *Cognitive Therapy and Research*, 40(4), 510–521. <https://doi.org/10.1007/s10608-016-9762-9>

Berridge, K. C., & Robinson, T. E. (1998). What is the role of dopamine in reward: Hedonic impact, reward learning, or incentive salience? *Brain Research Reviews*, 28(3), 309–369. [https://doi.org/10.1016/S0165-0173\(98\)00019-8](https://doi.org/10.1016/S0165-0173(98)00019-8)

Bickel, W. K. & Mueller, E. T. Toward the Study of Trans-Disease Processes: A Novel Approach With Special Reference to the Study of Co-morbidity. *Journal of Dual Diagnosis* 5, 131–138 (2009).

Bickel, W. K., Jarmolowicz, D. P., Mueller, E. T., Koffarnus, M. N., & Gatchalian, K. M. (2012). Excessive discounting of delayed reinforcers as a trans-disease process contributing to addiction and other disease-related vulnerabilities: emerging evidence. *Pharmacology & therapeutics*, 134(3), 287–297. <https://doi.org/10.1016/j.pharmthera.2012.02.004>

Bickel, W. K., Marsch, L. A., Buchhalter, A. R., & Badger, G. J. (2008). Computerized behavior therapy for opioid-dependent outpatients: a randomized controlled trial. *Experimental and clinical psychopharmacology*, 16(2), 132–143. <https://doi.org/10.1037/1064-1297.16.2.132>

Bjork, J. M., Momenan, R., & Hommer, D. W. (2009). Delay discounting correlates with proportional lateral frontal cortex volumes. *Biological Psychiatry*, 65(8), 710–713. <https://doi.org/10.1016/j.biopsych.2008.11.023>

Black, A. C., & Rosen, M. I. (2011). A money management-based substance use treatment increases valuation of future rewards. *Addiction*, 106(3), 623–633. <https://doi.org/10.1111/j.1360-0443.2010.03100.x>

Blackburn, A. N., Schirda, B., & Carlson, J. M. (2021). Mindfulness-based emotion regulation reduces delay discounting in individuals with addictive behaviors. *Addictive Behaviors*, 114, 106741. <https://doi.org/10.1016/j.addbeh.2020.106741>

Bobova, L., Finn, P. R., Rickert, M. E., & Lucas, J. (2009). Disinhibitory psychopathology and delay discounting in alcohol dependence: personality and cognitive correlates. *Experimental and clinical psychopharmacology*, 17(1), 51.

Borst, G. et al. Folding of the anterior cingulate cortex partially explains inhibitory control during childhood: A longitudinal study. *Developmental Cognitive Neuroscience* 9, 126–135 (2014).

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: An update. *Trends in Cognitive Sciences*, 8(12), 539–546. <https://doi.org/10.1016/j.tics.2004.10.003>

Boyer, P. (2008). Evolutionary economics of mental time travel? *Trends in Cognitive Sciences*, 12(6), 219–224. <https://doi.org/10.1016/j.tics.2008.03.003>

Bressi, C., et al. (1996). Cross validation of the factor structure of the 20-item Toronto Alexithymia Scale: an Italian multicenter study. *Journal of psychosomatic research*, 41(6), 551–559. [https://doi.org/10.1016/s0022-3999\(96\)00228-0](https://doi.org/10.1016/s0022-3999(96)00228-0)

Brown, S. M., Manuck, S. B., Flory, J. D., & Hariri, A. R. (2018). Neural correlates of impulsive choice in bipolar disorder. *Psychiatry Research: Neuroimaging*, 275, 1–8. <https://doi.org/10.1016/j.psychresns.2018.03.005>

Bulley, A., Henry, J. D., & Suddendorf, T. (2016). Prospection and the present moment: The role of episodic foresight in intertemporal choices between immediate and delayed rewards. *Review of General Psychology*, 20(1), 29–47. <https://doi.org/10.1037/gpr0000061>

Cachia, A. et al. Longitudinal stability of the folding pattern of the anterior cingulate cortex during development. *Developmental Cognitive Neuroscience* 19, 122–127 (2016).

Cachia, A. et al. The Shape of the ACC Contributes to Cognitive Control Efficiency in Preschoolers. *Journal of Cognitive Neuroscience* 26, 96–106 (2014).

Cachia, A. et al. Towards Deciphering the Fetal Foundation of Normal Cognition and Cognitive Symptoms From Sulcation of the Cortex. *Front. Neuroanat.* 15, 712862 (2021).

Calluso, C., Devetag, M. G., & Donato, C. (2021). "I Feel Therefore I Decide": Effect of Negative Emotions on Temporal Discounting and Probability Discounting. *Brain sciences*, 11(11), 1407. <https://doi.org/10.3390/brainsci11111407>

Calluso, C., Tosoni, A., Cannito, L., & Committeri, G. (2019). Concreteness and emotional valence of episodic future thinking (EFT) independently affect the dynamics of intertemporal decisions. *PloS one*, 14(5), <https://doi.org/10.1371/journal.pone.0217224>

Calluso, C., Tosoni, A., Pezzulo, G., Spadone, S., Committeri, G. (2015). Intertemporal choices in the brain: A process tracing study using mouse tracking. *Frontiers in Psychology*, 6, 709. <https://doi.org/10.3389/fpsyg.2015.00709>

Calluso, C., Tosoni, A., Pezzulo, G., Spadone, S., Committeri, G. (2017). Choosing for the future: The role of cognitive control in intertemporal decision making. *Journal of Neuroscience*, 37(13), 3490–3501. <https://doi.org/10.1523/JNEUROSCI.2340-16.2017>

Calluso, C., Tosoni, A., Pezzulo, G., Spadone, S., Committeri, G. (2019). Neural dynamics of intertemporal choice: Evidence from fMRI and mouse-tracking. *NeuroImage*, 185, 347–359. <https://doi.org/10.1016/j.neuroimage.2018.10.041>

Calluso, C., Tosoni, A., Pezzulo, G., Spadone, S., Committeri, G. (2020). Computational mechanisms of impulsive choice: A multimethod approach. *Cortex*, 125, 83–95. <https://doi.org/10.1016/j.cortex.2019.12.003>

Canali, S. (2021). *Regolare le emozioni: Teorie e metodi per lo sviluppo e il potenziamento dell'autocontrollo*. Roma: Carocci.

Capone, V., Caso, D., Donizzetti, A. R., & Procentese, F. (2020). University Student Mental Well-Being during COVID-19 Outbreak: What Are the Relationships between Information Seeking, Perceived Risk and Personal Resources Related to the Academic Context? *Sustainability*, 12(17), 7039. <https://doi.org/10.3390/su12177039>

Caprara, G. V., Barbaranelli, C., Borgogni, L., & Vecchione, M. (2008). BFQ-2. Big five questionnaire, 2.

Caretti, V., Craparo, G., Giannini, M., Gori, A., Iraci, G., Lucchini, A., ... & Schimmenti, A. (2016). Addictive Behavior Questionnaire (ABQ). Manuale e questionari.

Caretti, V., Gori, A., Craparo, G., Giannini, M., Iraci-Sareri, G., & Schimmenti, A. (2018). A New Measure for Assessing Substance-Related and Addictive Disorders: The Addictive Behavior Questionnaire (ABQ). *Journal of clinical medicine*, 7(8), 194. <https://doi.org/10.3390/jcm7080194>

Carlisi, C. O., Norman, L. J., Lukito, S. S., Radua, J., Mataix-Cols, D., Rubia, K., & others. (2017). Comparative multimodal meta-analysis of structural and functional brain abnormalities in autism spectrum disorder and obsessive-compulsive disorder. *Biological Psychiatry*, 82(2), 83–102. <https://doi.org/10.1016/j.biopsych.2016.10.006>

Carrà, G., Sciarini, P., Segagni-Lusignani, G., Clerici, M., Montomoli, C., & Kessler, R. C. (2011). Do they actually work across borders? Evaluation of two measures of psychological distress as screening instruments in a non Anglo-Saxon country. *European Psychiatry*, 26(2), 122-127.

Casey, B. J., Giedd, J. N. & Thomas, K. M. Structural and functional brain development and its relation to cognitive development. *Biological Psychology* 54, 241–257 (2000).

Chambel, M.J., & Curral, L. (2005). Stress in academic life: Work characteristics as predictors of student well-being and performance. *Applied Psychology*, 54, 135-147. <https://doi.org/10.1111/j.1464-0597.2005.00200.x>

Charlton, S. R., & Fantino, E. (2008). Commodity specific rates of temporal discounting: Does metabolic function underlie differences in rates of discounting? *Behavioural Processes*, 77(3), 334–342. <https://doi.org/10.1016/j.beproc.2007.07.014>

Cheng, Y., Jiang, H., & Lin, X. (2021). Delay discounting in behavioral addictions: A meta-analysis. *Addictive Behaviors*, 112, 106603. <https://doi.org/10.1016/j.addbeh.2020.106603>

Chesson, H. W. et al. Discount rates and risky sexual behaviors among teenagers and young adults. *J Risk Uncertainty* 32, 217–230 (2006).

Chi, J. G., Dooling, E. C. & Gilles, F. H. Gyrar development of the human brain. *Annals of Neurology* 1, 86–93 (1977).

Chib, V. S., Rangel, A., Shimojo, S., & O'Doherty, J. P. (2009). Evidence for a common representation of decision values for dissimilar goods in human ventromedial prefrontal cortex. *Journal of Neuroscience*, 29(39), 12315–12320. <https://doi.org/10.1523/JNEUROSCI.2575-09.2009>

Cho, S. S. , Pellecchia, G. , Aminian, K. , Ray, N. , Segura, B. , Obeso, I. , & Strafella, A. P. (2013). Morphometric correlation of impulsivity in medial prefrontal cortex. *Brain Topography*, 26, 479–487. 10.1007/s10548-012-0270-x

Coffey, S. F., Gudleski, G. D., Saladin, M. E., & Brady, K. T. (2003). Impulsivity and rapid discounting of delayed hypothetical rewards in cocaine-dependent individuals. *Experimental and Clinical Psychopharmacology*, 11(1), 18–25. <https://doi.org/10.1037/1064-1297.11.1.18>

Cona, G., Koçillari, L., Palombit, A., Bertoldo, A., Maritan, A., & Corbetta, M. (2019). Archetypes of human cognition defined by time preference for reward and their brain correlates: An evolutionary trade-off approach. *NeuroImage*, 185, 322–334. <https://doi.org/10.1016/j.neuroimage.2018.10.050>

Corballis, M. C. Left Brain, Right Brain: Facts and Fantasies. *PLoS Biol* 12, e1001767 (2014).

Crean, J. P., de Wit, H., & Richards, J. B. (2000). Reward discounting as a measure of impulsive behavior in a psychiatric outpatient population. *Experimental and Clinical Psychopharmacology*, 8(2), 155–162.

Crone, E. A., & Dahl, R. E. (2012). Understanding adolescence as a period of social-affective engagement and goal flexibility." *Developmental Cognitive Neuroscience*, 2(1), 1-10.

Daniel, T. O., Stanton, C. M., & Epstein, L. H. (2013). The future is now: Reducing impulsivity and energy intake using episodic future thinking. *Psychological Science*, 24(11), 2339–2342. <https://doi.org/10.1177/0956797613488780>

de Ruijter, A., van der Linden, D., & van der Heijden, B. (2023). Impatience and job satisfaction: A lifespan perspective. *Journal of Vocational Behavior*, 143, 103826. <https://doi.org/10.1016/j.jvb.2023.103826>

de Wit, H., Flory, J. D., Acheson, A., McCloskey, M., & Manuck, S. B. (2007). IQ and nonplanning impulsivity are independently associated with delay discounting in middle-aged adults. *Personality and Individual Differences*, 42(1), 111–121.

Deary, I. J., Penke, L. & Johnson, W. The neuroscience of human intelligence differences. *Nat Rev Neurosci* 11, 201–211 (2010).

Della Vigna, S., & Paserman, M. D. (2005). Job search and impatience. *Journal of Labor Economics*, 23(3), 527–588. <https://doi.org/10.1086/430286>

DeSteno, D., Li, Y., Dickens, L., & Lerner, J. S. (2014). Gratitude: a tool for reducing economic impatience. *Psychological science*, 25(6), 1262–1267. <https://doi.org/10.1177/0956797614529979>

Dixon, M. R., Marley, J., & Jacobs, E. A. (2006). Delay discounting by pathological gamblers. *Journal of Applied Behavior Analysis*, 36(4), 449–458.

Dombrovski, A. Y., Szanto, K., Siegle, G. J., Wallace, M. L., Forman, S. D., Sahakian, B., & Clark, L. (2011). Lethal forethought: Delayed reward discounting differentiates high- and low-lethality suicide attempts in old age. *Biological Psychiatry*, 70(2), 138–144. <https://doi.org/10.1016/j.biopsych.2011.01.027>

Doyle, J. R. (2013). Survey of time preference, delay discounting models. *Judgment and Decision Making*, 8(2), 116–135. <https://doi.org/10.1017/S1930297500005052>

Drobetz, R., Maercker, A., Meyer, A. H., & Forstmeier, S. (2014). Delay discounting and cognitive control: A meta-analysis. *Journal of Psychiatric Research*, 59, 56–63. <https://doi.org/10.1016/j.jpsychires.2014.08.011>

Duchesnay, E. et al. Classification Based on Cortical Folding Patterns. *IEEE Trans. Med. Imaging* 26, 553–565 (2007).

Duckworth, A. L., & Steinberg, L. (2015). Unpacking self-control. *Child Development Perspectives*, 9(1), 32–37. <https://doi.org/10.1111/cdep.12107>

Eisenberg D., Lipson S.K., Ceglarek P., Kern A., Phillips M.V. Routledge; 2018. College student mental health: The national landscape. Promoting behavioral health and reducing risk among college students; pp. 75–86.

El Ansari, W., Sebens, R., & Labeed, S. (2015). Multiple risk factors: prevalence and correlates of alcohol, tobacco and other drug (ATOD) use among university students in Egypt. *Journal of Substance Use*, 20(6), 380-388.

Esposito, C., Di Napoli, I., Di Martino, S., Prilleltensky, I., & Arcidiacono, C. (2022). The I COPPE Scale Short Form for measuring multidimensional well-being: Construct validity and reliability from US, Argentinian, and Italian large samples. *Journal of community psychology*, 50(2), 696-711

Essen, D. C. V. A tension-based theory of morphogenesis and compact wiring in the central nervous system. *Nature* 385, 313–318 (1997).

Essex, B. G., Clinton, S. A., Wonderley, L. R., & Zald, D. H. (2012). The impact of the posterior parietal cortex on intertemporal choice. *Cognitive, Affective, & Behavioral Neuroscience*, 12(4), 742–751. <https://doi.org/10.3758/s13415-012-0105-7>

Estle, S. J., Green, L., Myerson, J. & Holt, D. D. Differential effects of amount on temporal and probability discounting of gains and losses. *Memory & Cognition* 34, 914–928 (2006).

Estle, S. J., Green, L., Myerson, J., & Holt, D. D. (2007). Discounting of monetary and directly consumable rewards. *Psychological Science*, 18(1), 58–63. <https://doi.org/10.1111/j.1467-9280.2007.01849.x>

Evenden, J. L. (1999). Varieties of impulsivity. *Psychopharmacology*, 146(4), 348–361. <https://doi.org/10.1007/PL00005481>

Fang, H., & Silverman, D. (2006). Time-inconsistency and welfare program participation: Evidence from the NLSY. *International Economic Review*, 47(4), 1041–1072. <https://doi.org/10.1111/j.1468-2354.2006.00362.x>

Fassbender, C., Houde, S., Silver-Balbus, S., Ballard, K., Kim, B., Rutledge, K. J., Dixon, J. F., Iosif, A. M., Schweitzer, J. B., & McClure, S. M. (2014). The decimal effect: behavioral and neural bases for a novel influence on intertemporal choice in healthy individuals and in ADHD. *Journal of cognitive neuroscience*, 26(11), 2455–2468. https://doi.org/10.1162/jocn_a_00642

Favieri, F., French, M. N., Casagrande, M., & Chen, E. Y. (2023). Physical activity interventions have a moderate effect in increasing physical activity in university students – A meta-analysis. *Journal of American College Health*, 71(9), 2823-2834.

Favieri, F., Forte, G., Casagrande, M., & Tambelli, R. (2025). Attachment Representations, emotion regulation Difficulties and behavioral addiction Risk: Testing a mediation model in undergraduate students. *Addictive behaviors reports*, 23, 100657. <https://doi.org/10.1016/j.abrep.2025.100657>

Fedoroff, I. C., Polivy, J., & Herman, C. P. (1997). The effect of pre-exposure to food cues on the eating behavior of restrained and unrestrained eaters. *Appetite*, 28(1), 33–47. <https://doi.org/10.1006/appe.1996.0057>

Fellows, L. K., & Farah, M. J. (2005). Different underlying impairments in decision-making following ventromedial and dorsolateral frontal lobe damage in humans. *Cerebral cortex* (New York, N.Y. : 1991), 15(1), 58–63. <https://doi.org/10.1093/cercor/bhh108>

Field, M., Santarcangelo, M., Sumnall, H., Goudie, A., & Cole, J. (2006). Delay discounting and the behavioural economics of cigarette purchases in smokers: The effects of nicotine deprivation. *Psychopharmacology*, 186(2), 255–263. <https://doi.org/10.1007/s00213-006-0385-4>

Figner, B., Knoch, D., Johnson, E. J., Krosch, A. R., Lisanby, S. H., Fehr, E., & Weber, E. U. (2010). Lateral prefrontal cortex and self-control in intertemporal choice. *Nature Neuroscience*, 13(5), 538–539. <https://doi.org/10.1038/nn.2516>

Fish, A. M. et al. Influences of Brain Size, Sex, and Sex Chromosome Complement on the Architecture of Human Cortical Folding. *Cereb. Cortex* cercor;bhw323v1 (2016) doi:10.1093/cercor/bhw323.

Fornito, A., Yücel, M., Wood, S., Stuart, G. W., Buchanan, J. A., Proffitt, T., Anderson, V., Velakoulis, D., & Pantelis, C. (2004). Individual differences in anterior cingulate/paracingulate morphology are related to executive functions in healthy males. *Cerebral cortex* (New York, N.Y. : 1991), 14(4), 424–431. <https://doi.org/10.1093/cercor/bhh004>

Franco-Watkins, A. M., Pashler, H., & Rickard, T. C. (2010). Does working memory training transfer to improved delay discounting? *Psychonomic Bulletin & Review*, 17(2), 195–201. <https://doi.org/10.3758/PBR.17.2.195>

Frederick, S., Loewenstein, G., & O'donoghue, T. (2002). Time discounting and time preference: A critical review. *Journal of economic literature*, 40(2), 351-401.

Freeney, Y., & O'Connell, M. (2010). Impulsivity and academic achievement. *Learning and Individual Differences*, 20(6), 635–641. <https://doi.org/10.1016/j.lindif.2010.08.003>

Frith, C. D., & Frith, U. (2006). The neural basis of mentalizing. *Neuron*, 50(4), 531–534. <https://doi.org/10.1016/j.neuron.2006.05.001>

Frost, R., & McNaughton, N. (2017). The neural basis of delay discounting: A review and preliminary model. *Psychological Bulletin*, 143(7), 761–784. <https://doi.org/10.1037/bul0000104>

Garofalo, S., Degni, L. A. E., Sellitto, M., Braghittoni, D., Starita, F., Giovagnoli, S., di Pellegrino, G., & Benassi, M. (2022). Unifying Evidence on Delay Discounting: Open Task, Analysis Tutorial, and Normative Data from an Italian Sample. *International journal of environmental research and public health*, 19(4), 2049. <https://doi.org/10.33>

Mazur, J. E. (1987). An adjusting procedure for studying delayed reinforcement. In M. L. Commons, J. E. Mazur, J. A. Nevin, & H. Rachlin (Eds.), *The effect of delay and of intervening events on reinforcement value* (pp. 55–73). Lawrence Erlbaum Associates, Inc.

Geschwind, N. Cerebral Lateralization: Biological Mechanisms, Associations, and Pathology: III. A Hypothesis and a Program for Research. *Arch Neurol* 42, 634 (1985).

Giordano, L. A., Bickel, W. K., Loewenstein, G., Jacobs, E. A., Marsch, L., & Badger, G. J. (2002). Mild opioid deprivation increases the degree that opioid-dependent outpatients discount delayed heroin and money. *Psychopharmacology*, 163(2), 174–182. <https://doi.org/10.1007/s00213-002-1159-0>

Glasser, M. F. et al. A multi-modal parcellation of human cerebral cortex. *Nature* 536, 171–178 (2016).

Gogtay N, Giedd JN, Lusk L, Hayashi KM, Greenstein D, Vaituzis AC, Nugent TF 3rd, Herman DH, Clasen LS, Toga AW, Rapoport JL, Thompson PM. Dynamic mapping of human cortical development during childhood through early adulthood. *Proc Natl Acad Sci U S A*. 2004 May 25;101(21):8174-9. doi: 10.1073/pnas.0402680101.

Goldstein, R. Z., Tomasi, D., Rajaram, S., Cottone, L. A., Zhang, L., Maloney, T., Telang, F., Alia Klein, N., & Volkow, N. D. (2007). Role of the anterior cingulate and medial orbitofrontal cortex in processing drug cues in cocaine addiction. *Neuroscience*, 144(4), 1153–1159. <https://doi.org/10.1016/j.neuroscience.2006.11.034>

Goschke, T. (2014). Dysfunctions of decision-making and cognitive control as transdiagnostic mechanisms of mental disorders: Advances, gaps, and needs in current research. *International Journal of Methods in Psychiatric Research*, 23(S1), 41–57. <https://doi.org/10.1002/mPr.1410>

Green, L., & Myerson, J. (2004). A discounting framework for choice with delayed and probabilistic rewards. *Psychological bulletin*, 130(5), 769–792. <https://doi.org/10.1037/0033-2909.130.5.769>

Green, L., Myerson, J., & McFadden, E. (1997). Rate of temporal discounting decreases with amount of reward. *Journal of the Experimental Analysis of Behavior*, 67(3), 373–383.

Gross, J. J. (2015). Emotion regulation: Current status and future prospects. *Psychological Inquiry*, 26(1), 1–26. <https://doi.org/10.1080/1047840X.2014.940781>

Guan S, et al. Myopic decisions under negative emotions correlate with altered time perception. *Front. Psychol.* 2015;6:468. doi: 10.3389/fpsyg.2015.00468

Hamilton, K. R., Mitchell, M. R., Wing, V. C., Balodis, I. M., Bickel, W. K., Fillmore, M., et al. (2015). Choice impulsivity: definitions, measurement issues, and clinical implications. *Personal. Disord. Theory, Res. Treat.* 6, 182–198. doi: 10.1037/per0000099

Hamilton, K. R., Smith, J. F., Gonçalves, S. F., Nketia, J. A., Tasheuras, O. N., Yoon, M., ... & Shackman, A. J. (2020). Striatal bases of temporal discounting in early adolescents. *Neuropsychologia*, 144, 107492.

Han, S. D. et al. White matter correlates of temporal discounting in older adults. *Brain Struct Funct* 223, 3653–3663 (2018).

Hardisty, D. J., Appelt, K. C., & Weber, E. U. (2013). Good or bad, we want it now: Fixed-cost present bias for gains *and* losses explains magnitude asymmetries in intertemporal choice. *Journal of Behavioral Decision Making*, 26(4), 348–361. <https://doi.org/10.1002/bdm.1771>

Hare, T. A., Camerer, C. F., & Rangel, A. (2009). Self control in decision making involves modulation of the vmPFC valuation system. *Science*, 324(5927), 646–648. <https://doi.org/10.1126/science.1168450>

Hare, T. A., O'Doherty, J. P., Camerer, C. F., Schultz, W., & Rangel, A. (2008). Dissociating the role of the orbitofrontal cortex and the striatum in the computation of goal values and prediction errors. *Journal of Neuroscience*, 28(22), 5623–5630. <https://doi.org/10.1523/JNEUROSCI.1309-08.2008>

Hasin, D., & Katz, H. (2007). Somatoform and substance use disorders. *Psychosomatic medicine*, 69(9), 870–875. <https://doi.org/10.1097/PSY.0b013e31815b00d7>

Hassabis, D., & Maguire, E. A. (2007). Deconstructing episodic memory with construction. *Trends in Cognitive Sciences*, 11(7), 299–306. <https://doi.org/10.1016/j.tics.2007.05.001>

Haushofer, J., & Fehr, E. (2014). On the psychology of poverty. *Science*, 344(6186), 862–867. <https://doi.org/10.1126/science.1232491>

Heil, S. H., Johnson, M. W., Higgins, S. T., & Bickel, W. K. (2006). Delay discounting in currently using and currently abstinent cocaine-dependent outpatients and non-drug-using matched controls. *Addictive behaviors*, 31(7), 1290–1294. <https://doi.org/10.1016/j.addbeh.2005.09.005>

Hemaloka, M. (2024). Personality factors associated with drug addiction in young and adults (a review of literature). *Pravacana*, 15(1). <https://doi.org/1.4038/p.v15i1.1>

Hendrickson, K. L., & Rasmussen, E. B. (2013). Mindfulness and impulsivity: Implications for delay discounting. *Personality and Individual Differences*, 55(8), 889–894. <https://doi.org/10.1016/j.paid.2013.07.002>

Hendrickson, K. L., & Rasmussen, E. B. (2017). Mindfulness, cognitive control, and delay discounting. *Behavioural Processes*, 134, 19–26. <https://doi.org/10.1016/j.beproc.2016.06.003>

Hilgetag, C. C. & Barbas, H. Role of Mechanical Factors in the Morphology of the Primate Cerebral Cortex. *PLoS Comput Biol* 2, e22 (2006).

Hölzel, B. K., Carmody, J., Vangel, M., Congleton, C., Yerramsetti, S. M., Gard, T., & Lazar, S. W. (2011). Mindfulness practice leads to increases in regional brain gray matter density. *Psychiatry research*, 191(1), 36–43. <https://doi.org/1.1016/j.pscychresns.201.08.006>

Huang, X., Huang, Z., & Wyer, R. S. (2016). The influence of nostalgia on delay discounting. *Journal of Consumer Research*, 43(3), 372–387. <https://doi.org/10.1093/jcr/ucw034>

Huster, R. J. et al. Effects of anterior cingulate fissurization on cognitive control during stroop interference. *Human Brain Mapping* 30, 1279–1289 (2009).

Hutcherson, C. A., Seppala, E. M., & Gross, J. J. (2008). Loving-kindness meditation increases social connectedness. *Emotion*, 8(5), 720–724. <https://doi.org/10.1037/a0013237>

Imhoff, S., Harris, M., Weiser, J., & Reynolds, B. (2014). Delay discounting, impulsivity, and depression. *Psychological Reports*, 114(2), 647–657. <https://doi.org/10.2466/03.02.PR0.114k22w4>

Impulsivity: The Behavioral and Neurological Science of Discounting. (American Psychological Association, Washington, 2010). doi:10.1037/12069-000.

Insel, T. R., Cuthbert, B. N., Garvey, M., et al. (2010). Research Domain Criteria (RDoC): Toward a new classification framework for research on mental disorders. *American Journal of Psychiatry*, 167(7), 748–751. <https://doi.org/10.1176/appi.ajp.2010.09091379>

Ioannidis, K., Hook, R., Wickham, K., Grant, J. E., & Chamberlain, S. R. (2019). Impulsivity in gambling disorder: A systematic review and meta-analysis. *Neuroscience & Biobehavioral Reviews*, 106, 51–78. <https://doi.org/10.1016/j.neubiorev.2019.07.007>

Jackson, J. N., & MacKillop, J. (2016). Attention-deficit/hyperactivity disorder and monetary delay discounting: A meta-analysis. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, 1(4), 316–325. <https://doi.org/10.1016/j.bpsc.2016.01.007>

Jacobson, E. (1929). *Progressive relaxation*. University of Chicago Press.

Janis, I. B., & Nock, M. K. (2009). Are self-report measures of impulsivity reliable in predicting behavior? *Psychiatry Research*, 168(1), 70–74.

Jimura, K., Chushak, M. S., & Braver,

T. S. (2013). Impulsivity and self-control during intertemporal decision making linked to the neural dynamics of reward value representation. *The Journal of neuroscience : the*

official journal of the Society for Neuroscience, 33(1), 344–357. <https://doi.org/10.1523/JNEUROSCI.0919-12.2013>

Johnson, M. W., & Bickel, W. K. (2002). Within-subject comparison of real and hypothetical money rewards in delay discounting. *Journal of the Experimental Analysis of Behavior*, 77(2), 129–146. <https://doi.org/10.1901/jeab.2002.77-129>

Johnson, M. W., & Bickel, W. K. (2008). "An algorithm for identifying nonsystematic delay-discounting data": Correction to Johnson and Bickel (2008). *Experimental and Clinical Psychopharmacology*, 16(4), 321. <https://doi.org/10.1037/1064-1297.16.4.321>

Johnson, M. W., Bickel, W. K., & Baker, F. (2010). Moderate drug use and fatalism predict discounting of delayed rewards. *Experimental and Clinical Psychopharmacology*, 18(1), 51–61. <https://doi.org/10.1037/a0017968>

K.K. Szpunar, J.M. Watson, & K.B. McDermott, Neural substrates of envisioning the future, *Proc. Natl. Acad. Sci. U.S.A.* 104 (2) 642-647, <https://doi.org/10.1073/pnas.0610082104> (2007).

Kable, J. W., & Glimcher, P. W. (2007). The neural correlates of subjective value during intertemporal choice. *Nature neuroscience*, 10(12), 1625–1633. <https://doi.org/10.1038/nn2007>

Kable, J. W., & Glimcher, P. W. (2010). An “as soon as possible” effect in human intertemporal decision making: Behavioral evidence and neural mechanisms. *Journal of Neurophysiology*, 103(5), 2513–2531. <https://doi.org/10.1152/jn.00177.2009>

Kalenscher, T., & Pennartz, C. M. (2008). Is a bird in the hand worth two in the future? The neuroeconomics of intertemporal decision-making. *Progress in neurobiology*, 84(3), 284–315. <https://doi.org/10.1016/j.pneurobio.2007.11.004>

Kano, M., Fukudo, S. The alexithymic brain: the neural pathways linking alexithymia to physical disorders. *BioPsychoSocial Med* 7, 1 (2013). <https://doi.org/10.1186/1751-0759-7-1>

Kanske, P., Heissler, J., Schönfelder, S., Bongers, A. & Wessa, M. How to Regulate Emotion? Neural Networks for Reappraisal and Distraction. *Cerebral Cortex* 21, 1379–1388 (2011).

Kaplan, B. A., Amlung, M., Reed, D. D., Jarmolowicz, D. P., McKerchar, T. L., & Lemley, S. M. (2014). Automating scoring of delay discounting for the 21- and 27-item monetary choice questionnaires. *Behavior Analyst*, 37(2), 293–304. <https://doi.org/10.1007/s40614-014-0010-0>

Kaplan, B.A.; Reed, D.D.; McKerchar, T.L. Using a Visual Analogue Scale to Assess Delay, Social, and Probability Discounting of an Environmental Loss. *Psychol. Rec.* 2014, 64, 261–

Kekic, M., McClelland, J., Campbell, I. C., & Schmidt, U. (2016). The role of impulsivity in eating disorders: A systematic review. *Psychological Medicine*, 46(11), 2373–2393. <https://doi.org/10.1017/S0033291716000584>

Keltner, D., & Lerner, J. S. (2010). Emotion. In S. T. Fiske, D. T. Gilbert, & G. Lindzey (Eds.), *Handbook of social psychology* (5th ed., pp. 317–352). John Wiley & Sons, Inc.. <https://doi.org/10.1002/9780470561119.socpsy001009>

Kim, B. K., & Zauberman, G. (2013). Can Victoria's Secret change the future? A subjective time perception account of sexual-cue effects on impatience. *Journal of Experimental Psychology: General*, 142(1), 328–335. <https://doi.org/10.1037/a0028954>

Kirby, Kris N. & Marakovic, Nino N., 1995. "Modeling Myopic Decisions: Evidence for Hyperbolic Delay-Discounting within Subjects and Amounts," *Organizational Behavior and Human Decision Processes*, Elsevier, vol. 64(1), pages 22-30, October.

Kirby, K.N. One-year temporal stability of delay-discount rates. *Psychonomic Bulletin & Review* 16, 457–462 (2009). <https://doi.org/10.3758/PBR.16.3.457>.

Kirby, K. N., Petry, N. M., & Bickel, W. K. (1999). Heroin addicts have higher discount rates for delayed rewards than non-drug-using controls. *Journal of experimental psychology. General*, 128(1), 78–87. <https://doi.org/10.1037//0096-3445.128.1.78>

Kirby, K. N., Winston, G. C. & Santiesteban, M. Impatience and grades: Delay-discount rates correlate negatively with college GPA. *Learning and Individual Differences* 15, 213–222 (2005).

Kirmayer, L. J., & Taillefer, S. (1997). Somatoform disorders. In S. M. Turner & M. Hersen (Eds.), *Adult psychopathology and diagnosis* (3rd ed., pp. 333–383). John Wiley & Sons, Inc.

Klimecki, O. M., Leiberg, S., Lamm, C., & Singer, T. (2013). Functional neural plasticity and associated changes in positive affect after compassion training. *Cerebral cortex (New York, N.Y. : 1991)*, 23(7), 1552–1561. <https://doi.org/10.1093/cercor/bhs142>

Knutson, B., Rick, S., Wimmer, G. E., Prelec, D., & Loewenstein, G. (2007). Neural predictors of purchases. *Neuron*, 53(1), 147–156. <https://doi.org/10.1016/j.neuron.2006.11.010>

Koban, L. et al. An fMRI-Based Brain Marker of Individual Differences in Delay Discounting. *J. Neurosci.* 43, 1600–1613 (2023).

Koffarnus, M. N., Jarmolowicz, D. P., Mueller, E. T., & Bickel, W. K. (2013). Changing delay discounting in the light of the competing neurobehavioral decision systems theory: a review. *Journal of the experimental analysis of behavior*, 99(1), 32–57. <https://doi.org/10.1002/jeab.2>

Kollins, S. H. (2003). Delay discounting is associated with substance use in college students. *Addictive Behaviors*, 28(6), 1167–1173. [https://doi.org/10.1016/S0306-4603\(02\)00220-4](https://doi.org/10.1016/S0306-4603(02)00220-4)

Koob, G. F., & Volkow, N. D. (2016). Neurobiology of addiction: A neurocircuitry analysis. *The Lancet Psychiatry*, 3(8), 760–773. [https://doi.org/10.1016/S2215-0366\(16\)00104-8](https://doi.org/10.1016/S2215-0366(16)00104-8)

Kotov, R., Gamez, W., Schmidt, F., & Watson, D. (2010). Linking “big” personality traits to anxiety, depressive, and substance use disorders: A meta-analysis. *Psychological Bulletin*, 136(5), 768–821. <https://doi.org/10.1037/a0020327>

Kral, T. R. A., Schuyler, B. S., Mumford, J. A., Rosenkranz, M. A., Lutz, A., & Davidson, R. J. (2018). Impact of short- and long-term mindfulness meditation training on amygdala reactivity to emotional stimuli. *NeuroImage*, 181, 301–313. <https://doi.org/10.1016/j.neuroimage.2018.07.013>

Kühberger A. (1998). The Influence of Framing on Risky Decisions: A Meta-analysis. *Organizational behavior and human decision processes*, 75(1), 23–55. <https://doi.org/10.1006/obhd.1998.2781>

Kwan, D., Craver, C. F., Green, L., Myerson, J., Gao, F., Black, S. E., & Rosenbaum, R. S. (2013). Cueing the personal future to reduce discounting in

intertemporal choice: Is episodic prospection necessary? *Hippocampus*, 23(11), 1185–1192. <https://doi.org/10.1002/hipo.22158>

Laibson, D. (1997). Golden Eggs and Hyperbolic Discounting. *The Quarterly Journal of Economics*, 112(2), 443–477. <http://www.jstor.org/stable/2951242>

Lane, R. D., Weihs, K. L., Herring, A., Hishaw, A., & Smith, R. (2015). Affective agnosia: Expansion of the alexithymia construct and a new opportunity to integrate and extend Freud's legacy. *Neuroscience & Biobehavioral Reviews*, 55, 594–611. <https://doi.org/10.1016/j.neubiorev.2015.06.007>

Lange, F., & Eggert, F. (2015). Mapping self-reported to behavioral impulsiveness: the role of task parameters. *Scandinavian journal of psychology*, 56(2), 115–123. <https://doi.org/10.1111/sjop.12173>

Lau, B., & Glimcher, P. W. (2008). Value representations in the primate striatum during matching behavior. *Neuron*, 58(3), 451–463. <https://doi.org/10.1016/j.neuron.2008.02>.

LeBoeuf, R. A. (2006). Discount rates for time versus dates: The sensitivity of discounting to time-interval description. *Journal of Marketing Research*, 43(1), 59–72. <https://doi.org/10.1509/jmkr.43.1.59>

LeMay, M. MORPHOLOGICAL CEREBRAL ASYMMETRIES OF MODERN MAN, FOSSIL MAN, AND NONHUMAN PRIMATE. *Annals of the New York Academy of Sciences* 280, 349–366 (1976).

Lempert, K. M., & Phelps, E. A. (2016). The malleability of intertemporal choice. *Trends in Cognitive Sciences*, 20(1), 64–74. <https://doi.org/10.1016/j.tics.2015.09.005>

Lempert, K. M., Glimcher, P. W., & Phelps, E. A. (2015). Emotional arousal and discount rate in intertemporal choice are reference dependent. *Journal of experimental psychology. General*, 144(2), 366–373. <https://doi.org/10.1037/xge0000047>

Lempert, K. M., Porcelli, A. J., Delgado, M. R., & Tricomi, E. (2012). Individual differences in delay discounting under acute stress: The role of trait perceived stress. *Frontiers in Psychology*, 3, 251. <https://doi.org/10.3389/fpsyg.2012.00251>

Lempert, K. M., Speer, M. E., Delgado, M. R., & Phelps, E. A. (2024). Positive memory recall does not reliably reduce delay discounting. *Psychological Science*. <https://doi.org/10.1177/0956797623122345>

Lempert, K. M., Speer, M. E., Delgado, M. R., & Phelps, E. A. (2017). Positive autobiographical memory retrieval reduces temporal discounting. *Social cognitive and affective neuroscience*, 12(10), 1584-1593.

Lempert, K. M., Steinglass, J. E., Pinto, A., Kable, J. W., & Simpson, H. B. (2020). Reduced entorhinal cortex thickness is associated with temporal discounting in older adults and individuals with mild cognitive impairment. *Neuropsychologia*, 146, 107537. <https://doi.org/10.1016/j.neuropsychologia.2020.107537>

Lempert, K. M., Steinglass, J. E., Pinto, A., Kable, J. W., & Simpson, H. B. (2019). Can delay discounting deliver on the promise of RDoC? *Psychological Medicine*, 49(2), 190–199. <https://doi.org/10.1017/S0033291718001770>

Lerner, J. S., & Keltner, D. (2000). Beyond valence: Toward a model of emotion-specific influences on judgement and choice. *Cognition and Emotion*, 14(4), 473–493. <https://doi.org/10.1080/026999300402763>

Lerner, J. S., Li, Y., & Weber, E. U. (2013). The financial costs of sadness. *Psychological Science*, 24(1), 72–79.

Lerner, J. S., Small, D. A., & Loewenstein, G. (2004). Heart strings and purse strings: Carryover effects of emotions on economic decisions. *Psychological science*, 15(5), 337–341. <https://doi.org/10.1111/j.0956-7976.2004.00679.x>

Levin, M. E., Haeger, J., Ong, C. W. & Twohig, M. P. An Examination of the Transdiagnostic Role of Delay Discounting in Psychological Inflexibility and Mental Health Problems. *Psychol Rec* 68, 201–210 (2018).

Li, X., Hu, P., & Liu, J. (2019). The neuroanatomical correlates of individual differences in delay discounting: A voxel-based morphometry study. *Journal of Pacific Rim Psychology*, 13, Article e29. <https://doi.org/10.1017/prp.2019.22>

Li, L., Yu, H., Liu, Y., Meng, Y. J., Li, X. J., Zhang, C., ... & Li, T. (2021). Lower regional grey matter in alcohol use disorders: evidence from a voxel-based meta-analysis. *BMC psychiatry*, 21(1), 247.

Lin, H., & Epstein, L. H. (2014). Living in the moment: effects of time perspective and emotional valence of episodic thinking on delay discounting. *Behavioral neuroscience*, 128(1), 12–19. <https://doi.org/10.1037/a0035705>

Loewenstein, G. (1996). Out of control: Visceral influences on behavior. *Organizational Behavior and Human Decision Processes*, 65, 272–292. doi:10.1006/obhd.1996.0028

Loewenstein, G., & Lerner, J. S. (2003). The role of affect in decision making. In R. J. Davidson, K. R. Scherer, & H. H. Goldsmith (Eds.), *Handbook of affective sciences* (pp. 619–642). Oxford University Press.

Loewenstein, G., Rick, S., & Cohen, J. D. (2008). Neuroeconomics. *Annual review of psychology*, 59, 647–672. <https://doi.org/10.1146/annurev.psych.59.103006.093710>

Logue, A. W. (1988). Research on self-control: An integrating framework. *Behavioral and Brain Sciences*, 11(4), 665–679. <https://doi.org/10.1017/S0140525X00053978>

Luo, S., Ainslie, G., & Monterosso, J. (2014). The behavioral and neural effect of emotional primes on intertemporal decisions. *Social cognitive and affective neuroscience*, 9(3), 283–291. <https://doi.org/10.1093/scan/nss132>

Ma, X., Yue, Z. Q., Gong, Z. Q., Zhang, H., Duan, N. Y., Shi, Y. T., Wei, G. X., & Li, Y. F. (2017). The effect of diaphragmatic breathing on attention, negative affect and stress in healthy adults. *Frontiers in Psychology*, 8, 874. <https://doi.org/10.3389/fpsyg.2017.00874>

Mackillop, J., Miller, J. D., Fortune, E., Maples, J., Lance, C. E., Campbell, W. K., & Goodie, A. S. (2014). Multidimensional examination of impulsivity in relation to disordered gambling. *Experimental and clinical psychopharmacology*, 22(2), 176–185. <https://doi.org/10.1037/a0035874>

Mackillop, J., Amlung, M. T., Few, L. R., Ray, L. A., Sweet, L. H., & Munafò, M. R. (2011). Delayed reward discounting and addictive behavior: A meta-analysis. *Psychopharmacology*, 216(3), 305–321. <https://doi.org/10.1007/s00213-011-2229-0>

Madden, G. J., Begotka, A. M., Raiff, B. R., & Kastern, L. L. (1997). Delay discounting of real and hypothetical rewards. *Journal of the Experimental Analysis of Behavior*, 77(3), 317–327.

Madden, G. J., & Bickel, W. K. (Eds.). (2010). *Impulsivity: The behavioral and neurological science of discounting*. American Psychological Association. <https://doi.org/10.1037/12069-000>

Mangin, J.-F., Jouvent, E. & Cachia, A. In-vivo measurement of cortical morphology: means and meanings. *Current Opinion in Neurology* 23, 359–367 (2010).

Marco-Pallarés, J., Mohammadi, B., Samii, A., & Münte, T. F. (2010). Brain activations reflect individual discount rates in intertemporal choice. *Brain Research*, 1320, 123–129. <https://doi.org/10.1016/j.brainres.2010.01.025>

Marek, S. et al. Reproducible brain-wide association studies require thousands of individuals. *Nature* 603, 654–660 (2022).

Marlatt, G. A., & Donovan, D. M. (Eds.). (2005). *Relapse prevention: Maintenance strategies in the treatment of addictive behaviors* (2nd ed.). Guilford Press.

Marx, I., Hacker, T., Yu, X., Cortese, S., & Sonuga-Barke, E. (2021). Delay discounting in ADHD: A meta-analytic review. *Psychological Medicine*, 51(2), 195–206. <https://doi.org/10.1017/S003329171900302X>

Mathan, J. et al. Effects of parental socioeconomic status on offspring's fetal neurodevelopment. *Cerebral Cortex* 34, (2024).

Mazur J (1987) An adjusting procedure for studying delayed reinforcement. In Commons ML, Mazur JE and Nevin JA (eds), *Quantitative Analyses of Behavior: Vol. 5: The Effect of Delay and of Intervention*

McClelland, J. et al. A systematic review of temporal discounting in eating disorders and obesity: Behavioural and neuroimaging findings. *Neuroscience & Biobehavioral Reviews* 71, 506–528 (2016).

McClure, S. M., Ericson, K. M., Laibson, D., Loewenstein, G., & Cohen, J. D. (2007). Time discounting for primary rewards. *Journal of Neuroscience*, 27(21), 5796–5804. <https://doi.org/10.1523/JNEUROSCI.4246-06.2007>

McClure, S. M., Laibson, D., Loewenstein, G., & Cohen, J. D. (2004). Separate neural systems value immediate and delayed monetary rewards. *Science*, 306(5695), 503–507. <https://doi.org/10.1126/science.1100907>

McClure, S. M., York, M. K. & Montague, P. R. The neural substrates of reward processing in humans: the modern role of FMRI. *Neuroscientist* 10, 260–268 (2004).

McIntyre-Wood, C., Madan, C., Owens, M., Amlung, M., Sweet, L. H., & MacKillop, J. (2022). Neuroanatomical foundations of delayed reward discounting decision making II: Evaluation of sulcal morphology and fractal dimensionality. *NeuroImage*, 257, 119309. <https://doi.org/10.1016/j.neuroimage.2022.119309>

McIntyre-Wood, N., Stokes, M. G., & Hampshire, A. (2022). Sulcal depth in the right inferior frontal cortex predicts individual differences in impulsivity. *Cortex*, 148, 160–173. <https://doi.org/10.1016/j.cortex.2021.12.010>

McKerchar, T. L., & Renda, C. R. (2012). Delay and probability discounting in humans: An overview. *The Psychological Record*, 62(4), 817–834.

Meier, S., & Sprenger, C. (2010). Present-biased preferences and credit card borrowing. *American Economic Journal: Applied Economics*, 2(1), 193–210. <https://doi.org/10.1257/app.2.1.193>

Meier, S., & Sprenger, C. (2012). Time discounting predicts creditworthiness. *Psychological Science*, 23(1), 56–58. <https://doi.org/10.1177/0956797611425931>

Michie, S., Abraham, C., Whittington, C., McAteer, J., & Gupta, S. (2009). Effective techniques in healthy eating and physical activity interventions: A meta-regression. *Health Psychology*, 28(6), 690–701. <https://doi.org/1.1037/a0016136>

Miller, B. P., Reed, D. D., & Amlung, M. (2023). Reliability and validity of behavioral-economic measures: A review and synthesis of discounting and demand. *Journal of the experimental analysis of behavior*, 120(2), 263–280. <https://doi.org/10.1002/jeab.860>

Miller, E. K. & Cohen, J. D. An Integrative Theory of Prefrontal Cortex Function. *Annu. Rev. Neurosci.* 24, 167–202 (2001).

Miller, J. D., Zeichner, A., & Wilson, L. F. (2008). Personality correlates of delay discounting. *Personality and Individual Differences*, 44(1), 140–150.

Mitchell, S. H. (2004). Measuring impulsivity and modeling its association with cigarette smoking. *Behavioral and Cognitive Neuroscience Reviews*, 3(4), 261–275. <https://doi.org/10.1177/1534582305276838>

Monterosso, J. R., Ainslie, G., Xu, J., Cordova, X., Domier, C. P., & London, E. D. (2007). Frontoparietal cortical activity of methamphetamine-dependent and comparison subjects performing a delay discounting task. *Human brain mapping*, 28(5), 383–393. <https://doi.org/10.1002/hbm.20281>

Morawetz, C., Bode, S., Baudewig, J., & Heekeren, H. R. (2017). Effective amygdala-prefrontal connectivity predicts individual differences in successful emotion regulation. *Social cognitive and affective neuroscience*, 12(4), 569–585. <https://doi.org/10.1093/scan/nsw169>

Moriguchi, Y., & Komaki, G. (2013). Neuroimaging studies of alexithymia: physical, affective, and social perspectives. *BioPsychoSocial medicine*, 7(1), 8. <https://doi.org/10.1186/1751-0759-7-8>

Mostert, J. C., Onnink, A. M. H., Klein, M., Dammers, J., Harneit, A., Schulten, T., ... Franke, B. (2015). Cognitive heterogeneity in adult ADHD: A systematic review. *Neuroscience & Biobehavioral Reviews*, 57, 278–292. <https://doi.org/10.1016/j.neubiorev.2015.09.019>

Munasinghe, L., & Sicherman, N. (2005). Why do dancers smoke? Time preference, occupational choice, and wage growth. *Journal of Economic Behavior & Organization*, 57(3), 369–391. <https://doi.org/10.1016/j.jebo.2003.11.004> (

Myerson, J., Green, L., & Warusawitharana, M. (2001). Area under the curve as a measure of discounting. *Journal of the experimental analysis of behavior*, 76(2), 235–243. <https://doi.org/10.1901/jeab.2001.76-235>

Nakao, M., Barsky, A. J., Kumano, H., & Kuboki, T. (2002). Relationship between somatosensory amplification and alexithymia in a Japanese psychosomatic clinic. *Psychosomatics*, 43(1), 55-60.

Neff, K. D., & Germer, C. K. (2013). A pilot study and randomized controlled trial of the mindful self-compassion program. *Journal of clinical psychology*, 69(1), 28–44. <https://doi.org/10.1002/jclp.21923>

Nevin JA, Rachlin H, editors. Quantitative analysis of behavior: the effects of delay and of intervening events on reinforcement value. Hillsdale, NJ: Ballinger Publishing Company; 1986

Noonan, M. P., Walton, M. E., Behrens, T. E. J., Sallet, J., Buckley, M. J., & Rushworth, M. F. S. (2010). Separate value comparison and learning mechanisms in macaque medial and lateral orbitofrontal cortex. *Proceedings of the National Academy of Sciences*, 107(47), 20547–20552. <https://doi.org/10.1073/pnas.1012246107>

Nyklicek, I., & Vingerhoets, A. J. J. M. (1996). Alexithymia is associated with low tolerance to experimental painful stimulation. *Psychosomatic Medicine*, (58), 66.

Odum, A. L. (2011a). Delay discounting: I'm a k, you're a k. *Journal of the Experimental Analysis of Behavior*, 96(3), 427–439. <https://doi.org/10.1901/jeab.2011.96-423>

Odum, A. L. (2011b). Delay discounting: Trait variable? *Behavioural Processes*, 87(1), 1–9. <https://doi.org/10.1016/j.beproc.2011.02.007>

Odum, A. L., & Baumann, A. A. (2010). Delay discounting: State and trait variable. In G. J. Madden & W. K. Bickel (Eds.), *Impulsivity: The behavioral and neurological science of discounting* (pp. 39–65). APA. <https://doi.org/10.1037/12069-002>

Odum, A. L., Baumann, A. A., & Rimington, D. D. (2006). Discounting of delayed hypothetical money and food: effects of amount. *Behavioural processes*, 73(3), 278–284. <https://doi.org/10.1016/j.beproc.2006.06.008>

Odum, A. L., & Rainaud, C. P. (2003). Discounting of delayed hypothetical money, alcohol, and food. *Behavioural Processes*, 64(3), 305–313. [https://doi.org/10.1016/S0376-6357\(03\)00145-1](https://doi.org/10.1016/S0376-6357(03)00145-1)

Odum, A. L., Becker, R. J., Haynes, J. M., Galizio, A., Frye, C. C. J., Downey, H., Friedel, J. E., & Perez, D. M. (2020). Delay discounting of different outcomes: Review and theory. *Journal of the experimental analysis of behavior*, 113(3), 657–679. <https://doi.org/10.1002/jeab.589>

Ohmura, Y., amlungi, T., Kitamura, N., & Wehr, P. (2006). Three-month stability of delay and probability discounting measures. *Behavioural Processes*, 73(1), 107–110. <https://doi.org/10.1016/j.beproc.2006.03.001>

Olmstead, M. C. (2006). Animal models of drug addiction: Where do we go from here?. *Quarterly Journal of Experimental Psychology*, 59(4), 625-653.

Olson, E. A. et al. White Matter Integrity Predicts Delay Discounting Behavior in 9- to 23-Year-Olds: A Diffusion Tensor Imaging Study. *Journal of Cognitive Neuroscience* 21, 1406–1421 (2009).

Olson, E. A., Collins, P. F., Hooper, C. J., Muetzel, R., Lim, K. O., & Luciana, M. (2009). White matter integrity predicts delay discounting behavior in adolescents. *Brain and Cognition*, 69(1), 8–14. <https://doi.org/10.1016/j.bandc.2008.05.007>

Ono, M., Kubik, S., Abernathy, C. D., Yaşargil, M. G. & Abernathy, C. D. *Atlas of the Cerebral Sulci*. (Georg Thieme Verlag, Stuttgart New York, 1990).

Owens, M. M., Gray, J. C., Amlung, M. T., Oshri, A., Sweet, L. H., & MacKillop, J. (2017). Neuroanatomical foundations of delayed reward discounting decision making. *NeuroImage*, 161, 261–270. <https://doi.org/10.1016/j.neuroimage.2017.08.045>

Palombo, D. J., Keane, M. M., & Verfaellie, M. (2015). The medial temporal lobes are critical for reward-based decision making under conditions that promote episodic future thinking. *Hippocampus*, 25(3), 345–353. <https://doi.org/10.1002/hipo.22376>

Paret, C., Jennen-Steinmetz, C., Schmahl, C., & Ende, G. (2017). Impulsivity in borderline personality disorder: A systematic review. *Neuroscience & Biobehavioral Reviews*, 75, 1–13. <https://doi.org/10.1016/j.neubiorev.2017.01.022>

Paus, T. et al. Human Cingulate and Paracingulate Sulci: Pattern, Variability, Asymmetry, and Probabilistic Map. *Cereb Cortex* 6, 207–214 (1996).

Perales, J. C., Verdejo-García, A., Moya, M., Lozano, O., & Pérez-García, M. (2009). Bright and dark sides of impulsivity: Performance of women with high and low trait impulsivity on neuropsychological tasks. *Journal of Clinical and Experimental Neuropsychology*, 31(8), 927–944.

Peters, J., & Büchel, C. (2009). Overlapping and distinct neural systems code for subjective value during intertemporal and risky decision making. *Journal of Neuroscience*, 29(50), 15727–15734. <https://doi.org/10.1523/JNEUROSCI.3489-09.2009>

Peters, J., & Büchel, C. (2010). Episodic future thinking reduces reward delay discounting through enhancement of prefrontal–mediotemporal interactions. *Neuron*, 66(1), 138–148.

Peters, J., & Büchel, C. (2011). The neural mechanisms of intertemporal decision making: Understanding variability. *Trends in Cognitive Sciences*, 15(5), 227–239. <https://doi.org/10.1016/j.tics.2011.03.002>

Petersen, S. E. & Posner, M. I. The Attention System of the Human Brain: 20 Years After. *Annu. Rev. Neurosci.* 35, 73–89 (2012).

Petry, N. M. (2001). Delay discounting of money and alcohol in actively using alcoholics, currently abstinent alcoholics, and controls. *Psychopharmacology*, 154(3), 243–250. <https://doi.org/10.1007/s002130000638>

Petry, N. M., & Madden, G. J. (2010). Discounting and pathological gambling. In G. J. Madden & W. K. Bickel (Eds.), *Impulsivity: The behavioral and neurological science of discounting* (pp. 273–294). American Psychological Association. <https://doi.org/10.1037/12069-010>

Petry, N. M. (2002). Discounting of delayed rewards in substance abusers: Relationship to antisocial personality disorder. *Psychopharmacology*, 162(4), 425–432.

Pettruso, M. et al. Non-invasive brain stimulation targets and approaches to modulate gambling-related decisions: A systematic review. *Addictive Behaviors* 112, 106657 (2021).

Pfeiffer, D. (2001). Academic and environmental stress among undergraduate and graduate college students: A literature review (Master's thesis, University of Wisconsin-Stout). Minds@UW. Retrieved from <https://minds.wisconsin.edu/handle/1793/40121>

Pine, A., Seymour, B., Roiser, J. P., Bossaerts, P., Friston, K. J., Curran, H. V., & Dolan, R. J. (2009). Encoding of marginal utility across time in the human brain. *The Journal of neuroscience : the official journal of the Society for Neuroscience*, 29(30), 9575–9581. <https://doi.org/10.1523/JNEUROSCI.1126-09.2009>

Pinto, A., Steinglass, J. E., Greene, A. L., Weber, E. U., & Simpson, H. B. (2014). Capacity to delay reward differentiates obsessive–compulsive disorder and obsessive–compulsive personality disorder. *Biological Psychiatry*, 75(8), 653–659. <https://doi.org/10.1016/j.biopsych.2013.09.007>

Prilleltensky, I., Dietz, S., Prilleltensky, O., Myers, N. D., Rubenstein, C. L., Jin, Y., & McMahon, A. (2015). Assessing multidimensional well-being: Development and validation of the I COPPE scale. *Journal of community psychology*, 43(2), 199–226.

Poli, A., Maremmani, A. G. I., Chiorri, C., Mazzoni, G.-P., Orrù, G., Kolacz, J., Porges, S. W., Conversano, C., Gemignani, A., & Miccoli, M. (2021). Item Reduction, Psychometric and Biometric Properties of the Italian Version of the Body Perception Questionnaire—Short Form (BPQ-SF): The BPQ-22. *International Journal of Environmental Research and Public Health*, 18(7), 3835. <https://doi.org/10.3390/ijerph18073835>

Porges, S. W. (2007). The polyvagal perspective. *Biological Psychology*, 74(2), 116–143.

Porges, S. W. (2009). The polyvagal theory: New insights into adaptive reactions of the autonomic nervous system. *Cleveland Clinic Journal of Medicine*, 76(Suppl 2), S86–S90.

Priestley M., Broglia E., Hughes G., Spanner L. Student perspectives on improving mental health support services at university. *Counselling and Psychotherapy Research*. 2021;22(1):197–206.

Priestley, M., McPherson, K. E., & McAloney-Kocaman, K. (2021). Mental health and help-seeking among university students. *Journal of Mental Health*, 30(2), 188–196. <https://doi.org/10.1080/09638237.2020.1714008><https://doi.org/10.1080/09638237.2020.1714008>

Prilleltensky, I., Dietz, S., Prilleltensky, O., Myers, N. D., Rubenstein, C. L., Jin, Y., & McMahon, A. (2015). Assessing multidimensional well-being: Development and validation of the I COPPE scale. *Journal of community psychology*, 43(2), 199-226.

Pulcu, E., Trotter, P. D., Thomas, E. J., McFarquhar, M., Juhasz, G., Sahakian, B. J., Deakin, J. F. W., & Zahn, R. (2014). Temporal discounting in major depressive disorder. *Psychological Medicine*, 44(9), 1829–1839. <https://doi.org/10.1017/S0033291713002584>

Rachlin, H., & Green, L. (1972). Commitment, choice and self-control. *Journal of the Experimental Analysis of Behavior*, 17(1), 15–22. <https://doi.org/10.1901/jeab.1972.17-15>

Rachlin, H., Raineri, A., & Cross, D. (1991). Subjective probability and delay. *Journal of the Experimental Analysis of Behavior*, 55(2), 233–244. <https://doi.org/10.1901/jeab.1991.55-233>

Radu, P. T., Yi, R., Bickel, W. K., Gross, J. J., & McClure, S. M. (2011). A mechanism for reducing delay discounting by altering temporal attention. *Journal of the Experimental Analysis of Behavior*, 96(3), 363–385. <https://doi.org/10.1901/jeab.2011.96-363>

Rahl, H. A., Lindsay, E. K., Pacilio, L. E., Brown, K. W., & Creswell, J. D. (2017). Brief mindfulness meditation training reduces mind wandering: The critical role of acceptance. *Emotion*, 17(2), 224–230. <https://doi.org/10.1037/emo0000250>

Read, D., & Read, N. L. (2004). Time discounting over the lifespan. *Organizational Behavior and Human Decision Processes*, 94(1), 22–32. <https://doi.org/10.1016/j.obhdp.2004.01.002>

Read, D., & P.H.M.P. Roelofsma. 2003. Subadditive versus hyperbolic discounting: A comparison of choice and matching. *Organizational Behavior and Human Decision Processes* 91(2) 140-153.

Reuter, J., Raedler, T., Rose, M., Hand, I., Gläscher, J., & Büchel, C. (2005). Pathological gambling is linked to reduced activation of the mesolimbic reward system. *Nature Neuroscience*, 8(2), 147–148. <https://doi.org/10.1038/nn1378>

Reynolds, B. (2006). A review of delay-discounting research with humans: relations to drug use and gambling. *Behavioural Pharmacology* 17(8), 651-667, <https://doi.org/10.1097/FBP.0b013e3280115f99>

Reynolds, B., & Schiffbauer, R. M. (2004). Impulsive choice and workplace safety: a new area of inquiry for research in occupational settings. *The Behavior analyst*, 27(2), 239–246. <https://doi.org/10.1007/BF03393183>

Robbins, T. W., Gillan, C. M., Smith, D. G., de Wit, S., & Ersche, K. D. (2012). Neurocognitive endophenotypes of impulsivity and compulsivity: Towards dimensional psychiatry. *Trends in Cognitive Sciences*, 16(1), 81–91. <https://doi.org/10.1016/j.tics.2011.11.009>

Roberts, B. W. (2009). Back to the future: Personality and assessment and personality development. *Journal of Research in Personality*, 43(2), 137–145. <https://doi.org/10.1016/j.jrp.2008.12.015>

Rogers, C. R. (1961). *On becoming a person: A therapist's view of psychotherapy*. Houghton Mifflin.

Rose, E. J., Ross, T. J., Salmeron, B. J., Lee, M., Shakleya, D. M., Huestis, M., & Stein, E. A. (2012). Chronic exposure to nicotine is associated with reduced reward-related activity in the striatum but not the midbrain. *Biological psychiatry*, 71(3), 206–213. <https://doi.org/10.1016/j.biopsych.2011.09.013>

Rudebeck, P. H., Walton, M. E., Smyth, A. N., Bannerman, D. M., & Rushworth, M. F. S. (2006). Separate neural pathways process different decision costs. *Nature Neuroscience*, 9(9), 1161–1168. <https://doi.org/10.1038/nn1756>

Rung, J. M., & Madden, G. J. (2018). Experimental reductions of delay discounting and impulsive choice: A systematic review and meta-analysis. *Journal of experimental psychology. General*, 147(9), 1349–1381. <https://doi.org/10.1037/xge0000462>

Rushworth, M. F., Kolling, N., Sallet, J. & Mars, R. B. Valuation and decision-making in frontal cortex: one or many serial or parallel systems? *Current Opinion in Neurobiology* 22, 946–955 (2012).

Sadeh, N., Miglin, R., Bounoua, N., Sheehan, A. & Spielberg, J. M. Development of a cortical delay discounting assay: a potential biomarker of externalizing disorders. *Psychol. Med.* 53, 1143–1150 (2023).

Samejima, K., Ueda, Y., Doya, K., & Kimura, M. (2005). Representation of action specific reward values in the striatum. *Science*, 310(5752), 1337–1340. <https://doi.org/10.1126/science.1115270>

Santacroce, F. et al. Human intraparietal sulcal morphology relates to individual differences in language and memory performance. *Commun Biol* 7, 520 (2024).

Sapolsky, R. M. (2004). *Why zebras don't get ulcers* (3rd ed.). Holt Paperbacks

Sawicki, P., & Bialek, M. (2016). Side effects in time discounting procedures: Fixed alternatives become the reference point. *PLoS ONE*, 11(10), Article e0165245. <https://doi.org/10.1371/journal.pone.0165245>

Scarpazza, C., Sellitto, M., di Pellegrino, G. (2017). Now or not-now? The influence of alexithymia on intertemporal decision-making. *Brain Cogn* 114, 20-28. <https://doi.org/10.1016/j.bandc.2017.03.001>

Scarpazza, C., Zangrossi, A., Huang, YC. et al. (2022). Disentangling interoceptive abilities in alexithymia. *Psychological Research* 86, 844–857 <https://doi.org/10.1007/s00426-021-01538-x>

Schacter, D. L., Addis, D. R., & Buckner, R. L. (2007). Remembering the past to imagine the future: the prospective brain. *Nature reviews. Neuroscience*, 8(9), 657–661. <https://doi.org/10.1038/nrn2213>

Scherer, K. R., Shuman, V., Fontaine, J. R. J., & Soriano, C. (2013). The GRID meets the Wheel: Assessing emotional feeling via self-report. In J. R. J. Fontaine, K. R. Scherer, & C. Soriano (Eds.), *Components of emotional meaning: A sourcebook*. Oxford: Oxford University Press.

Scheres, A., de Water, E., & Mies, G. W. (2013). The neural correlates of temporal reward discounting. *Wiley Interdisciplinary Reviews: Cognitive Science*, 4(5), 523–545. <https://doi.org/10.1002/wcs.1246>

Scholten, H., Scheres, A., de Water, E., Graf, U., Granic, I., & Luijten, M. (2019). Behavioral trainings and manipulations to reduce delay discounting: A systematic review. *Psychonomic bulletin & review*, 26(6), 1803–1849. <https://doi.org/10.3758/s13423-019-01629-2>

Schüller, C. B., Kuhn, J., Jessen, F. & Hu, X. Neuronal correlates of delay discounting in healthy subjects and its implication for addiction: an ALE meta-analysis study. *The American Journal of Drug and Alcohol Abuse* 45, 51–66 (2019).

Schueller, C. B., Kuhn, J., Jessen, F., & Hu, X. (2019). Neuronal correlates of delay discounting in healthy subjects and its implication for addiction: an ALE meta-analysis study. *The American Journal of Drug and Alcohol Abuse*, 45(1), 51-66.

Schultz W. (1997). Dopamine neurons and their role in reward mechanisms. *Current opinion in neurobiology*, 7(2), 191–197. [https://doi.org/10.1016/s0959-4388\(97\)80007-4](https://doi.org/10.1016/s0959-4388(97)80007-4)

Schwaller, F. (2024) The huge toll of PhDs on mental health: data reveal stark effects. *Nature*, 634(8033):277-278. doi: 10.1038/d41586-024-03136-4.

Schwizer Ashkenazi, S. et al. Are numerical abilities determined at early age? A brain morphology study in children and adolescents with and without developmental dyscalculia. *Developmental Cognitive Neuroscience* 67, 101369 (2024).

Seamans, J. K. et al. Neural basis of cognitive control signals in anterior cingulate cortex during delay discounting. Preprint at <https://doi.org/10.1101/2024.06.07.597894> (2024).

Sellitto, M., Ciaramelli, E., & di Pellegrino, G. (2010). Myopic discounting of future rewards after medial orbitofrontal damage in humans. *Journal of Neuroscience*, 30(49), 16429–16436. <https://doi.org/10.1523/JNEUROSCI.2516-10.2010>

Senecal, N., Wang, T., Thompson, E., & Kable, J. W. (2012). Normative arguments from experts and peers reduce delay discounting. *Judgment and Decision making*, 7(5), 568-589.

Sheffer, C. E., Christensen, D. R., Landes, R., Carter, L. P., Jackson, L., & Bickel, W. K. (2014). Delay discounting predicts relapse among smokers. *Psychopharmacology*, 231(23), 4517–4524. <https://doi.org/10.1007/s00213-014-3590-8>

Sheldon, E., Simmonds-Buckley, M., Bone, C., Mascarenhas, T., Chan, N., Wincott, M., ... Barkham, M. (2021). Prevalence and risk factors for mental health problems in university undergraduate students: A systematic review. *Journal of Affective Disorders*, 287, 282–292. <https://doi.org/10.1016/j.jad.2021.03.056>

Shenhav, A., Botvinick, M. M. & Cohen, J. D. The Expected Value of Control: An Integrative Theory of Anterior Cingulate Cortex Function. *Neuron* 79, 217–240 (2013).

Sighinolfi, C., Norcini Pala, A., Chiri, L. R., Marchetti, I., & Sica, C. (2010). Difficulties in emotion regulation scale (DERS): the italian translation and adaptation. *Psicoterapia Cognitiva Comportamentale*, 16(2), 141–170.

Simpson, C. A., & Vuchinich, R. E. (2000). Reliability of a measure of temporal discounting. *The Psychological Record*, 50(1), 3–16.

Sinha, R. (2008). Chronic stress, drug use, and vulnerability to addiction. *Annals of the New York Academy of Sciences*, 1141(1), 105–130. <https://doi.org/10.1196/annals.1441.030>

Smallwood, J., & Schooler, J. W. (2015). The science of mind wandering: empirically navigating the stream of consciousness. *Annual review of psychology*, 66, 487–518. <https://doi.org/10.1146/annurev-psych-010814-015331>

Smith, C. L., & Hantula, D. A. (2008). Methodological considerations in delay discounting research. *The Psychological Record*, 58(3), 435–448. <https://doi.org/10.1007/BF03395>

Somerville LH, Casey BJ. (2010) Developmental neurobiology of cognitive control and motivational systems. *Curr Opin Neurobiol.* 20(2):236-41. doi: 10.1016/j.conb.2010.01.006.

Souther, M. K., Boateng, B. & Kable, J. W. A meta-analysis of neural systems underlying delay discounting: implications for transdiagnostic research. Preprint at <https://doi.org/10.1101/2022.10.12.511959> (2022).

Sowell ER, Thompson PM, Toga AW. (2004) Mapping changes in the human cortex throughout the span of life. *Neuroscientist.* 10(4):372-92. doi: 10.1177/1073858404263960.

Spreng, R. N., Mar, R. A., & Kim, A. S. N. (2009). The common neural basis of autobiographical memory, prospection, navigation, theory of mind, and the default mode. *Journal of Cognitive Neuroscience*, 21(3), 489–510. <https://doi.org/10.1162/jocn.2008.21029>

Sripada, C. S., Gonzalez, R., Phan, K. L., & Liberzon, I. (2011). The neural correlates of intertemporal decision- making: Contributions of subjective value, stimulus type, and trait impulsivity. *Human Brain Mapping*, 32(10), 1637–1648. <https://doi.org/10.1002/hbm.21136>

Stanger, C., Ryan, S. R., Fu, H., Landes, R. D., Jones, B. A., Bickel, W. K., & Budney, A. J. (2012). Delay discounting predicts adolescent substance abuse treatment outcomes. *Experimental and Clinical Psychopharmacology*, 20(3), 205–212. <https://doi.org/10.1037/a0026543>

Stein, J. S., Sze, Y. Y., Athamneh, L. N., Koffarnus, M. N., Epstein, L. H., & Bickel, W. K. (2016). Episodic future thinking reduces delay discounting and energy intake in overweight and obese women. *Appetite*, 103, 9–20. <https://doi.org/10.1016/j.appet.2016.03.016>

Steinberg L. (2005) Cognitive and affective development in adolescence. *Trends Cogn Sci.* 9(2):69-74. doi: 10.1016/j.tics.2004.12.005.

Steinberg L. (2010). A dual systems model of adolescent risk-taking. *Developmental psychobiology*, 52(3), 216–224. <https://doi.org/1.1002/dev.20445>

Steinglass, J. E., Lempert, K. M., Choo, T. H., Kimeldorf, M. B., Wall, M., Walsh, B. T., ... & Simpson, H. B. (2017). Temporal discounting across three psychiatric disorders: Anorexia nervosa, obsessive compulsive disorder, and social anxiety disorder. *Depression and anxiety*, 34(5), 463-470.

Steinglass, J. E., Figner, B., Berkowitz, S., Simpson, H. B., Weber, E. U., & Walsh, B. T. (2012). Increased capacity to delay reward in anorexia nervosa. *Journal of the International Neuropsychological Society*, 18(4), 773–780. <https://doi.org/10.1017/S1355617712000446>

Strickland, J. C., Johnson, M. W., & Bickel, W. K. (2021). Delay discounting and substance use: A meta-analysis. *Drug and Alcohol Dependence*, 218, 108416. <https://doi.org/10.1016/j.drugalcdep.2020.108416>

Sun, T., Patoine, C., Abu-Khalil, A., Visvader, J., Sum, E., Cherry, T. J., Orkin, S. H., Geschwind, D. H., & Walsh, C. A. (2005). Early asymmetry of gene transcription in embryonic human left and right cerebral cortex. *Science (New York, N.Y.)*, 308(5729), 1794–1798. <https://doi.org/10.1126/science.1110324>

Takahashi T. (2004). Cortisol levels and time-discounting of monetary gain in humans. *Neuroreport*, 15(13), 2145–2147. <https://doi.org/10.1097/00001756-200409150-00029>

Takahashi, T. (2005) Loss of self-control in intertemporal choice may be attributable to logarithmic time-perception. *Medical Hypotheses*, 65, 691-693. doi:10.1016/j.mehy.2005.04.040

Takahashi, T. (2007). A comparison of intertemporal choices for oneself versus someone else based on Tsallis' statistics. *Physica A*, 385, 637-644. doi:10.1016/j.physa.2007.07.020

Tang, Y. Y., Hölzel, B. K., & Posner, M. I. (2015). The neuroscience of mindfulness meditation. *Nature Reviews Neuroscience*, 16(4), 213–225. <https://doi.org/1.1038/nrn3916>

Tesch, A. D., & Sanfey, A. G. (2008). Models and methods in delay discounting. *Annals of the New York Academy of Sciences*, 1128, 90–94. <https://doi.org/10.1196/annals.1399.010>

Thorberg, F. A., Young, R. M., Sullivan, K. A., & Lyvers, M. (2011). Alexithymia and alcohol use disorders: A critical review. *Addictive Behaviors*, 36(3), 277–285. <https://doi.org/10.1016/j.addbeh.2010.12.013>

Tissier, C. et al. Sulcal Polymorphisms of the IFC and ACC Contribute to Inhibitory Control Variability in Children and Adults. *eNeuro* 5, ENEURO.0197-17.2018 (2018).

Toga, A. W. & Thompson, P. M. Mapping brain asymmetry. *Nat Rev Neurosci* 4, 37–48 (2003).

Tudor, M. E., Gallen, C. L., Skinner, S. N., & Bunge, S. A. (2021). Structural brain changes across the lifespan: Implications for cognitive control. *Neurobiology of Aging*, 105, 48–60. <https://doi.org/10.1016/j.neurobiolaging.2021.04.009>

Tudor, M. E., Gallen, C. L., Skinner, S. N., & Bunge, S. A. (2022). Sulcal morphology as a stable marker of neurodevelopment and cognitive function. *Cerebral Cortex*, 32(5), 1023–1037. <https://doi.org/10.1093/cercor/bhab327>

Tulving, E. (1985). Memory and consciousness. *Canadian Psychology*, 26(1), 1–12. <https://doi.org/10.1037/h0080017>

Tversky, A., & Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science*, 211(4481), 453–458. <https://doi.org/10.1126/science.7455683>

Upton, S. R., & Renshaw, T. L. (2019). Immediate effects of the mindful body scan practice on risk-taking behavior. *Mindfulness*, 10(1), 78–88. <https://doi.org/10.1007/s12671-018-0948-6>

Vallianatos H., Friese K., Perez J.M., Slessor J., Thind R., Dunn J., et al. ACCESS open minds at the University of Alberta: transforming student mental health services in a large Canadian post-secondary educational institution. *Early Interv Psychiatry*. 2019;13:56–64. doi: 10.1111/eip.12819.

Van den Bergh, B., Dewitte, S., & Warlop, L. (2008). Bikinis instigate generalized impatience in intertemporal choice. *Journal of Consumer Research*, 35(1), 85–97. <https://doi.org/10.1086/525505>

Van Der Meer, D. & Kaufmann, T. Mapping the genetic architecture of cortical morphology through neuroimaging: progress and perspectives. *Transl Psychiatry* 12, 447 (2022).

Van Essen, D. C. A 2020 view of tension-based cortical morphogenesis. *Proc. Natl. Acad. Sci. U.S.A.* 117, 32868–32879 (2020).

Van Essen, D. C., Glasser, M. F., Dierker, D. L., Harwell, J. & Coalson, T. Parcellations and Hemispheric Asymmetries of Human Cerebral Cortex Analyzed on Surface-Based Atlases. *Cerebral Cortex* 22, 2241–2262 (2012).

van Veen, V., Krug, M. K., Schooler, J. W., & Carter, C. S. (2009). Neural activity predicts attitude change in cognitive dissonance. *Nature Neuroscience*, 12(11), 1469–1474. <https://doi.org/10.1038/nn.2413>

Vanderveldt, A., Green, L., & Myerson, J. (2016). Discounting of monetary rewards that are both delayed and probabilistic: Delay and probability combine multiplicatively, not additively. *Journal of the Experimental Analysis of Behavior*, 105(3), 339–356. <https://doi.org/10.1002/jeab.202> Alvarez, J. A. & Emory, E. Executive Function and the Frontal Lobes: A Meta-Analytic Review. *Neuropsychol Rev* 16, 17–42 (2006).

Vanderveldt, A.; Oliveira, L.; Green, L. Delay discounting: Pigeon, rat, human—Does it matter? *J. Exp. Psychol. Anim. Learn. Cogn.* 2016, 42, 141–162

Wang, S., Kong, F., Zhou, M., Chen, T., Yang, X., Chen, G., & Gong, Q. (2017). Brain Structure Linking Delay Discounting and Academic Performance. *Human brain mapping*, 38(8), 3917–3926. <https://doi.org/10.1002/hbm.23638>

Wang, X., Zheng, L., & Li, L. (2016). The neural correlates of intertemporal decision-making: A voxel-based morphometry study. *Brain and Cognition*, 108, 1–6. <https://doi.org/10.1016/j.bandc.2016.06.001>

Washio, Y., Higgins, S. T., Heil, S. H., McKerchar, T. L., Badger, G. J., Skelly, J. M., & Dantona, R. L. (2011). Delay discounting predicts postpartum smoking relapse. *Nicotine & Tobacco Research*, 13(5), 341–347. <https://doi.org/10.1093/ntr/ntr013>

Weinsztok, S., Dufour, M., & Brunelle, N. (2021). Delay discounting in behavioral addictions: A systematic review. *Journal of Behavioral Addictions*, 10(3), 1–15. <https://doi.org/10.1556/2006.2021.00033>

Weiss, N. H., Tull, M. T., Viana, A. G., Anestis, M. D., & Gratz, K. L. (2015). Impulsive behaviors as an emotion regulation strategy. *Journal of Affective Disorders*, 170, 262–269. <https://doi.org/10.1016/j.jad.2014.08.040>

Wilson, M., & Daly, M. (2004). Do pretty women inspire men to discount the future?. *Proceedings. Biological sciences*, 271 Suppl 4(Suppl 4), S177–S179. <https://doi.org/10.1098/rsbl.2003.0134>

Wise, R. Dopamine, learning and motivation. *Nat Rev Neurosci* 5, 483–494 (2004). <https://doi.org/10.1038/nrn1406>

Wise, T. N., & Mann, L. S. (1994). The relationship between somatosensory amplification, alexithymia, and neuroticism. *Journal of psychosomatic research*, 38(6), 515–521.

Wittmann, M., Leland, D. S., Churan, J., & Paulus, M. P. (2007). Impaired time perception and motor timing in stimulant-dependent subjects. *Drug and Alcohol Dependence*, 90(2–3), 183–192. <https://doi.org/10.1016/j.drugalcdep.2007.03.005>

Ye, H., & Wang, J. (2023). Neural correlates of intertemporal choice: A meta-analytic review. *Human Brain Mapping*, 44(2), 699–718. <https://doi.org/10.1002/hbm.26134>

Yoon, J. H., Higgins, S. T., Heil, S. H., Sugarbaker, R. J., Thomas, C. S., & Badger, G. J. (2007). Delay discounting predicts postpartum relapse to cigarette smoking. *Journal of Consulting and Clinical Psychology*, 75(3), 365–371 <https://doi.org/10.1037/0022-006X.75.3.365>

Yu, R. (2012). Regional white matter volumes correlate with delay discounting. *PLoS ONE*, 7(2), e32595. <https://doi.org/10.1371/journal.pone.0032595>

Yucel, M. et al. Hemispheric and Gender-related Differences in the Gross Morphology of the Anterior Cingulate/Paracingulate Cortex in Normal Volunteers: An MRI Morphometric Study. *Cerebral Cortex* 11, 17–25 (2001).

Zack, M. et al. Effects of High Frequency Repeated Transcranial Magnetic Stimulation and Continuous Theta Burst Stimulation on Gambling Reinforcement, Delay Discounting, and Stroop Interference in Men with Pathological Gambling. *Brain Stimulation* 9, 867–875

Zeidan, F., Johnson, S. K., Diamond, B. J., David, Z., & Goolkasian, P. (2010). Mindfulness meditation improves cognition: evidence of brief mental training. *Consciousness and cognition*, 19(2), 597–605. <https://doi.org/10.1016/j.concog.2010.03.014>

Zilles, K., Palomero-Gallagher, N. & Amunts, K. Development of cortical folding during evolution and ontogeny. *Trends in Neurosciences* 36, 275–284 (2013).

Supplementary Analyses

Characterization of the CS sulcal pattern and relation with DD

For each hemisphere, the CS was classified as continuous when it formed a single uninterrupted sulcus and as interrupted when it was split into two or more segments. The CS interruption was classified as symmetric when both hemispheres showed the same

pattern (both continuous or both interrupted) and as asymmetric when the pattern differed between hemispheres (continuous in one hemisphere and interrupted in the other).

To investigate whether a distinct morphological feature of the Cingulate Cortex (i.e., the interruption of CS) was associated with DD rate, we performed a Generalized Linear Model (GLM) including the CS pattern (continuous/interrupted) and sex as categorical factors and the third factor of the PCA (delay discounting) as the dependent variable. The analysis revealed no significant association in either the right ($\beta = -0.0043$, $SE = 0.052$, $z = -0.082$, $p = 0.934$) or left ($\beta = -0.0550$, $SE = 0.057$, $z = -0.962$, $p = 0.336$) hemisphere.

In addition, we classified the symmetry/asymmetry pattern of the cingulate sulcus based on interruption and included symmetry/asymmetry CS pattern and sex as categorical factors, and the DD factor as the dependent variable. No significant result was found ($\beta = 0.0874$, $SE = 0.102$, $z = 0.860$, $p = 0.390$), supporting the specificity of the association between ACC sulcal patterns and DD.

Supplementary Table 1. Post hoc chi-square analysis of frequency distribution.

In this table, Study 1 corresponds to Yucel et al. (2001), Study 2 to Cachia et al. (2014), Study 3 to Borst et al. (2014), Study 4 to Tissier et al. (2018), and Study 5 represents the Present study.

Contrast	p-value	corrected p-value
LEFT		
Study 1 vs 2	0,0213	0,2128
Study 1 vs 3	0,9479	1
Study 1 vs 4	<0,001	<0,001
Study 1 vs 5	0,7881	1
Study 2 vs 3	0,0122	0,1219
Study 2 vs 4	<0,001	<0,001
Study 2 vs 5	0,0578	0,5781
Study 3 vs 4	<0,001	0,0001
Study 3 vs 5	0,6344	1
Study 4 vs 5	<0,001	<0,001
RIGHT		
Study 1 vs 2	0,6982	1
Study 1 vs 3	0,0237	0,2374
Study 1 vs 4	0,0534	0,5344
Study 1 vs 5	0,1921	1
Study 2 vs 3	0,0839	0,8391
Study 2 vs 4	0,1626	1
Study 2 vs 5	0,0653	0,6528

Study 3 vs 4	0,8484	1
Study 3 vs 5	0,0002	0,0024
Study 4 vs 5	0,0008	0,008
SYMMETRY/ASYMMETRY		
Study 1 vs 2	0,9142	1
Study 1 vs 3	0,5686	1
Study 1 vs 4	<0,001	0,0001
Study 1 vs 5	0,0268	0,2683
Study 2 vs 3	0,7495	1
Study 2 vs 4	<0,001	<0,001
Study 2 vs 5	0,0144	0,1443
Study 3 vs 4	<0,001	<0,001
Study 3 vs 5	0,004	0,0404
Study 4 vs 5	0,0491	0,4912

Supplementary Table 2. Association between ACC morphology and single PCA's tasks/metrics. The table reports the β values, SE, z points, and uncorrected p values of ACC symmetry/asymmetry pattern and all tasks entered into the PCA.

Measure	β_ACC	SE	z	p
MemEpNonV	0.9706	1.351	0.719	0.472
MemEpVerbAcc	0.3751	0.296	1.268	0.205
MemEpVerbRT	32.3665	29.456	1.099	0.272
WM	-2.0820	1.097	-1.898	0.058
EXE_Cog	0.5275	1.049	0.503	0.615
EXE_Inib	0.2046	1.017	0.201	0.841
FluInt_Acc	-0.0579	0.473	-0.122	0.903
FluInt_RT	1156.4718	918.156	1.260	0.208
LanP	-0.8747	1.085	-0.806	0.420
LanC	0.6330	0.984	0.643	0.520
SpeedProc	-4.7809	1.517	-3.153	0.002
Imp_200	0.0479	0.021	2.279	0.023
Imp_40	0.0423	0.028	1.508	0.132
OrientSp_Acc	0.6747	0.452	1.492	0.136
OrientSp_RT	13.0433	37.764	0.345	0.730
ATT_RT	6.8788	4.128	1.666	0.096
ATT_d	-0.0007	0.005	-0.142	0.887
ATT_spec	0.0019	0.004	0.523	0.601

