UNIVERSITY OF PAVIA – IUSS SCHOOL FOR ADVANCED STUDIES PAVIA

Department of Brain and Behavioral Sciences (DBBS)
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INFLUENCE OF AN INTEROCEPTIVE TRAINING ON DELAY DISCOUNTING OF HYPOTHETICAL MONEY AND FOOD

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Abstract

This study investigated the impact of an interoceptive training on delay discounting of hypothetical monetary and food rewards. Delay discounting refers to the tendency to prefer immediate, smaller rewards over larger, delayed ones. Previous literature suggests that interoception, i.e. the conscious perception of internal bodily signals, could influence decision-making processes. Thus, this research proposed that an interoceptive training, consisting of a prolonged version of the heartbeat counting task, could influence delay discounting. Specifically, the interoceptive training was hypothesised to enhance awareness of internal physiological signals, thus reducing delay discount rates. To test this hypothesis, N = 51 participants were divided into two groups: an experimental group that performed the interoceptive training and a control group that performed a control task (i.e. focusing on external cues) before completing two delay discounting tasks. One task involved monetary rewards and one task involved food rewards, administered in a counterbalanced order within participants. Results of a repeated-measure analysis of variance indicated a significant interaction between reward type and group. Unlike the control group, which had the typical higher discount rates for food compared to money, the experimental group had discount rates more similar between reward types. Specifically, the experimental group showed reduced discount rates for food. Independent samples t-tests confirmed that there were no significant differences between groups on several relevant measures, including interoceptive accuracy and sensibility, hunger level at the time of testing, and trait impulsivity, ensuring that these variables did not influence the observed differences in delay discounting. These results suggest that an interoceptive training can potentially moderate the usual high propensity to devalue future edible rewards. These findings underscore the potential of interoception-focused interventions to influence food-related decisions, suggesting that heightened attention to internal states may help mitigate impulsive behaviour.

Keywords*: Delay discounting, Food reward, Heartbeat counting task, Impulsivity, Interoception, Interoceptive training, Intertemporal choice, Monetary reward*

1. Introduction

Choosing between something we want right now and sacrificing it for our long-term goals is a challenge that we face daily. The outcomes of those decisions can significantly impact our lives, health, success, and even the environment. Despite our aspirations to achieve these long-term objectives, it can often be difficult to forego immediate and accessible gratification.

This is why understanding what can aid us in these decisions is crucial. A growing number of neuroscientific research suggests that interoception, the awareness of internal physiological states, namely how we perceive and integrate them with other information, can influence our ability to make decisions and behaviours as diverse as eating, exercising, spending, and beyond.

This thesis explores the impact of an interoceptive training, specifically through a prolonged heartbeat counting task, on intertemporal choices, i.e. choices between options available at different times. By investigating this relationship, this study aims to contribute to understanding interoceptive processes and their implications for improving decision-making strategies in everyday life.

1.1 Delay Discounting

Often, people prefer getting smaller rewards now over waiting for bigger ones later (i.e. intertemporal choice) because a person's appeal towards a future reward tends to decrease the longer they have to wait for it. This tendency is called *delay discounting* (DD) and can impact a wide range of behaviours, such as health related choices, financial planning, time management etc. This makes it an important area of study both in clinical and healthy populations. Individuals can vary widely in their propensity to discount future rewards. The rate at which people devalue future rewards affects their behaviour and this has been linked to several pathologies such as addiction, substance abuse, obesity, risky behaviours (Rung & Madden, 2018), compulsive gambling, and also ADHD, involving difficulty with self-control and forward planning (Wang et al., 2021).

In 1975, George Ainslie's study laid the groundwork for understanding impulsiveness in decision-making, describing how immediate rewards can overshadow bigger future ones due to hyperbolic discounting of future values.

DD is a complex phenomenon, and different rewards have been shown to be discounted differently. For example, Odum et al. (2020) revealed that monetary rewards are generally discounted less steeply compared to non-monetary rewards such as food or addictive substances, which individuals tend to value more in the present than in the future. This differential discounting is significant because it suggests that the urgency of certain needs or desires can override longer-term gains, indicating that not just addictive substances but also everyday items like food are subject to rapid devaluation, highlighting the pervasive nature of impulsive decision-making across different life aspects.

Moreover, DD can have both state-like qualities, influenced by immediate situational factors, and trait-like properties, demonstrating consistency over time and situations. For example, pathological gamblers have shown high discount rates in gambling context but not in non-gambling context (Dixon et al., 2006). This means that the subjective value of rewards can change based on the relevance of context and environment. This also underscores the importance of considering contextual factors when researching or addressing impulsive behaviours and designing interventions. There is also evidence that genetic factors can contribute to variations in DD among adolescents (Anokhin et al. 2011) suggesting a genetic basis for some individuals' inclination to choose immediate gratification over long-term rewards.

1.1.1 Measurement of Delay Discounting and Methodological Approaches

When studying how people evaluate immediate and future rewards, researchers utilise the hyperbolic discounting model, which represents well in humans the decline in perceived value of rewards as the wait for them lengthens. This model can be useful across various contexts from financial choices to leisure planning and helps in predicting decisions in different economic and consumer scenarios (Green & Myerson, 2004).

To measure DD, intertemporal choice tasks or questionnaires where individuals choose between smaller immediate rewards and larger delayed ones are employed (Amlung et al., 2017). For instance, one may choose between $40 today or $100 in a month. In one of the most typical procedures, these tasks systematically vary the size of the immediate reward and the length of the delay, calculating a point where the participant values immediate and delayed rewards equally (so-called indifference points). These choices help plot a curve that quantifies how steeply a person discounts delayed rewards, using a formula that accounts for the size of the reward and the length of the delay (Sellitto et al., 2010). Higher values indicate stronger preferences for immediate gratification.

It has been shown that not all rewards are discounted at the same rate, for example smaller delayed rewards are discounted more steeply than larger ones. However, when the rewards are probabilistic, larger rewards are discounted more heavily, revealing that both the size and certainty of rewards significantly influence their perceived value (Estle et al., 2007; Myerson et al., 2003). Alternatives to this model include quantifying the area under the curve based on the indifference points, or calculating the relative proportion of choices for immediate rewards, known as the impulsive choice ratio.

1.1.2 Addiction and Obesity

Research into DD has consistently demonstrated its relevance to understanding impulsivity in addiction. Individuals with addiction discount delayed rewards more steeply compared to healthy controls (MacKillop et al., 2011). This tendency correlates not only with the development of addictive habits but also with challenges in overcoming these behaviours. This tendency has been observed across various addictive substances, including alcohol and tobacco, as well as in gambling, where immediate rewards are valued more highly than future benefits (Amlung et al., 2017; Odum et al., 2020). Moreover, the meta-analysis by Amlung et al. (2017) highlighted the link between severity of addiction and the propensity to discount delayed rewards. This variability suggests a need for detailed studies to clarify the role of DD across different types of addictions of variable severities (Amlung et al., 2017). Additionally, steep DD was found to be a predictive factor of the initiation of cigarette smoking in adolescents (Audrain-McGovern et al., 2009), as well as relapse after quitting in adults (Yoon et al., 2007, Rung & Madden, 2018).

The tendency to discount delayed rewards steeply also appears to be a significant factor influencing eating behaviours that contribute to obesity. DD has indeed been found to be particularly high in obese individuals (Amlung et al., 2016). Moreover, high DD enhances the consumption of tasty foods in people who are highly responsive to food rewards, especially if they have low inhibitory control (Appelhans et al., 2011).

Obesity and drug addiction share similar traits, for example as excessive consumption and difficulty in regulating impulses. The desire for food rewards is primarily controlled by the mesolimbic dopamine system, the brain’s reward circuit, which also drives the urge to participate in activities like sex, gambling, and substance use (Appelhans et al., 2011).

1.2 Interoception

Interoception is the sensing of internal body signals and is essential for maintaining bodily homeostasis and regulating autonomic and cognitive functions. It is a complex construct that has been defined differently across studies, influencing how researchers measure and interpret its role in human cognition and behaviour (Desmedt et al., 2023, Craig, 2009). Interoception was first defined as “sensations from the interior of the body, especially the viscera” (Sherrington, 1906) and was understood as the processing of visceral signals only, typically related to the cardiovascular, respiratory, gastrointestinal, and genito-urinary systems. This early definition primarily distinguished interoception from exteroception and proprioception, which involve external and positional body signals, respectively.

However, recent accounts propose a broader and more inclusive conceptualization. For example, Craig expanded the definition as “sensory input representing the condition of the entire body” (Craig, 2009). This implies that interoception includes the sense, both conscious and not, of any change in the mechanical, thermal, or chemical conditions of the tissues (including the skin), such as cardiovascular, respiratory and gastro-intestinal activity, but also temperature changes, immune and hormonal activity, mechanical stress or damage, local metabolism, skin parasite penetration, hunger, satiety, thirst, fatigue, pain, and itching (Desmedt et al., 2023, Craig, 2002, 2009).

These differences between traditional and contemporary views highlight an evolving understanding that interoception involves not just the detection but also the interpretation and integration of internal bodily cues (Desmedt et al., 2023). Modern definitions emphasise a multisensory integration process, where interoceptive awareness results from the central nervous system's synthesis of various sensory inputs, including somatic and visceral signals. It represents a detailed, holistic mapping of the body's internal landscape that also impacts our emotional and decision-making processes (Craig, 2002), motivational drives, behavioural responses (Wang & Chang, 2024) and in shaping our self-awareness (Tsakiris & Critchley, 2016). For the above reasons, it has also been defined as the "eighth sensory system" (Schmitt & Schoen, 2022).

Consequently, interoception is linked to mental health, and has significant impact on conditions such as anxiety, depression, and other neuropsychiatric disorders (Tsakiris & Critchley, 2016). The way we react to our environment is heavily influenced by these internal cues as the brain uses these signals to adjust our emotional and cognitive responses, which is essential for making decisions. Thus, it is reasonable to hypothesise that our body's internal feedback might play an important role in our daily interactions and choices (Critchley & Garfinkel, 2015). Moreover, recent studies suggest that improved interoceptive awareness could enhance individuals' sensitivity to a range of internal states, from hunger and satiety to emotional arousal, which seems to be crucial in making decisions about immediate versus delayed rewards (Desmedt et al., 2023).

1.2.1 Different dimensions of interoception

Interoceptive differences can be measured by questionnaires and behavioural tests. The tests either use natural fluctuation of internal physiology or experimentally induced changes (Critchley & Garfinkel, 2017). A common method is the heartbeat detection task, which assesses a person's ability to sense their own heartbeat through counting, tapping, or timing it against external stimuli. Despite some limitations, these methods are broadly used and provide useful data if applied correctly.

The term "interoceptive awareness" is used to imply both the results from questionnaires and how accurately someone performed on tasks (Desmedt et al., 2023). But new approaches differentiate between objective measures like the heartbeat detection task and subjective measures, which include how confident someone feels about their ability to sense their heartbeat or their answers on questionnaires. Moreover, "metacognitive interoceptive awareness" describes how closely a person's perceived ability matches their actual accuracy (Critchley & Garfinkel, 2017). A comprehensive description of the different dimensions of interoception is presented in table 1. As noted by Desmedt et al. (2023), the field still faces challenges due to the variability in how interoception is measured and conceptualised, which can impact the replicability and interpretation of research findings.

Table 1: Dimensions of human interoception (Adapted from Critchley & Garfinkel, 2017)

Table 1

Dimensions of human interoception

Dimensional level	Nature	Index
Afferent signal	Neural	Visceral afferent nerve recording Intracranial recording Heartbeat evoked potential Respiratory evoked potential Neuroimaging
Preconscious impact on other processes	Behavioural, neural	Cardiac modulation of eyeblink startle Cardiac modulation of fear Respiratory modulation of memory
Accuracy	Objective behavioural performance score	Heartbeat detection tasks Respiratory resistance load detection Water Load task Balloon dilation of stomach/colon
Sensibility	Subjective self-report	Confidence measures on interoceptive tasks Questionnaires probing interoceptive sensitivity
Metacognitive	Correspondence between subjective self-report and objective performance accuracy	Receiver Operating Characteristic (ROC) curves between task performance and rated confidence Correlational measures of task and confidence scores Trait measures, for example correspondence between task performance and body perception questionnaire score
Executive	Behavioural	Shifting from interoceptive to exteroceptive attention, for example within dual tasks or between tasks.

1.3 Interoception and Decision-Making

In their investigation of decision-making within complex situations that involve uncertainty, rewards and penalties Bechara et al., (1997) suggest that individuals often rely on non-conscious biases before employing explicit reasoning strategies. The study found that healthy participants started to make advantageous, strategically beneficial choices in a gambling task before fully recognizing which strategy yielded the best outcome. In stark contrast, patients with prefrontal cortex damage continued to make poor choices even after identifying risky options. This study (Bechara et al., 1997) shows that the implicit emotional cues guide early decision-making processes, potentially before these cues reach conscious awareness. In healthy individuals, nonconscious emotional responses appear to direct early decision choices, hinting at a foundational role for intuitive processes in complex decision environments. Thus, interoceptive awareness might significantly shape our initial, unconscious decision-making steps.

1.3.1 Neural correlates of Delay Discounting and Interoception

Intertemporal choices are regulated by two main key processes: a valuation process that estimates the reward of different options (medial orbitofrontal cortex (mOFC) and ventral striatum) and a control process (dorsolateral prefrontal cortex) to align these valuations with long-term goals (Kable and Glimcher, 2010; Sellitto et al., 2010; Sellitto et al., 2016; Peters & Büchel, 2011).

Another important brain region involved in DD is the insula, which is located deep within the cerebral cortex and is integral to our perception and emotional responses, connecting bodily sensations to cognitive functions. As its role is to make us aware of bodily states and predict how we might physically react to situations, it can direct our decisions based on our immediate bodily needs, thus favouring immediate gratification over long term goals. In fact, individuals with damage to the insula have demonstrated a lower tendency to prefer immediate rewards as compared with control participants (Sellitto et al., 2016).

The insula acts as a central hub for processing interoceptive signals. These signals include thermal, nociceptive, metabolic, and visceromotor cues that inform the brain about the body's internal condition. The insula's ability to process and integrate these signals affects our perception, emotion, and even the sense of self (Critchley and Garfinkel, 2015). Such processing underscores the insula's role in translating bodily states into conscious feelings and decision-making criteria that guide our behaviour based on internal needs rather than external stimuli alone.

Intertemporal decision-making involves a complex network of brain regions including the thalamus, sensory, parietal, temporal, cingulate, prefrontal, motor, and insular cortices, along with the basal ganglia (Frost & McNaughton, 2017). These areas create a network that underpins DD through recurrent neural loops (Frost & McNaughton, 2017). The insular cortex, central to this network, processes sensory information from the body to impact cognitive evaluations of both immediate and future rewards. The insula is particularly active during tasks that require high interoceptive awareness like detecting one’s heartbeat (Couto et al., 2014). The insula also connects interoceptive signals to cognitive operations, influencing decisions that balance current against future rewards, especially relevant in situations involving DD where the body’s internal state can significantly sway choices (Paulus & Stewart, 2014).

fMRI studies of DD reveal that the ventral striatum and prefrontal cortex navigate the balance between immediate rewards and future benefits (Luhmann, 2009). Moreover, the anterior insular cortex, particularly its dorsal part (dAIC) integrates interoceptive signals. Increased activity in the dAIC correlates with a reduced preference for immediate rewards, this suggests that enhanced activation in this region improves the assessment of the benefits of delayed rewards (Halcomb et al., 2022). This activity is also tied to the default mode network, which facilitates introspective and self-referential thoughts and may play a significant role by linking bodily states with cognitive evaluations of time and reward outcomes (Halcomb et al., 2022). When individuals choose larger, delayed rewards over smaller, immediate ones, the anterior insula shows increased activity. This supports the role of the insula in balancing immediate and long-term benefits, suggesting that variations in its function and structure could affect decision-making behaviours and potentially explain differences in impulsivity across individuals (Churchwell & Yurgelun-Todd, 2013).

Activation in the anterior insular cortex (AIC), particularly during tasks that require focusing on internal signals like breathing, stomach, and heartbeat rhythms, highlights its role in monitoring internal states, essential for decision-making processes dependent on body awareness (Wang et al., 2019). Additionally, damage to the AIC impairs interoceptive discrimination abilities, emphasising its importance in processing internal cues that guide self-regulation and decision-making.

On the other hand, it has been shown that the insular cortex exhibits hyperactivation in response to drug-related cues in individuals with drug addiction while showing hypoactivation during cognitive control tasks (Paulus & Stewart, 2014). When there is heightened activity in the insula, it can lead to more acute bodily awareness, which might make immediate rewards (drugs or food) seem more tempting, thus counteracting impulse control.

Interoceptive awareness and emotional states influence decision-making, particularly in contexts where impulsivity and risk-taking are involved (Herman et al., 2018b). Specifically, negative emotional states tend to increase impulsivity, while enhanced interoceptive awareness could lead to more advantageous decision-making in situations that involve risk. Consequently, by improving sensitivity to internal states one could potentially improve self-regulation and decision-making. However, while risk-taking behaviours often coincide with impulsivity, this study (Herman et al., 2018a) suggests that these behaviours can manifest differently depending on one's emotional state and level of interoceptive awareness.

1.4 Rationale and Hypothesis

Given the considerable impact of delay discounting on various aspects of personal and public health, ranging from addiction to potentially harmful behaviours like seatbelt use and risky sexual activity (Rung & Madden, 2018), it is important to explore potential interventions that could modify these behaviours.

Several interventions, such as mindfulness and episodic future thinking, were successful in modifying DD behaviours by improving psychological and physiological awareness (Rung & Madden, 2018). For example, mindfulness-based interventions have shown potential in reducing impulsivity by enhancing the present moment awareness (Rung & Madden, 2018). On the other hand, episodic future thinking was shown to decrease impulsive choices by vividly imagining future consequences of actions, which leads to more consideration for delayed rewards (Lin & Epstein, 2014). As heightened sense of interoception might influence not only perceptual sensitivity but also decision-making processes (Pollatos et al., 2023), an interoceptive training might have the potential to recalibrate the valuation processes underlying steep DD.

Moreover, the neurobiological mechanisms of impulsivity suggest a significant overlap with interoceptive processes. However, despite substantial research, there remains a relatively unexplored area concerning how interoceptive attention specifically impacts DD across different rewards.

There are existing studies that explore the effects of interoceptive training on decision-making, often using biofeedback to improve accuracy and assess outcomes. For example, Sugawara et al. (2020) enhanced interoceptive accuracy through immediate feedback but noted minimal impact on decision-making. In contrast, Rae et al. (2019) focused on how cardiac cues influenced decisions, highlighting the role of heightened interoceptive awareness in driving actions. Similarly, Price and Hooven (2018) emphasised the natural enhancement of bodily awareness through mindfulness practices, aiming to improve emotional regulation and decision-making without relying on feedback mechanisms.

Our study seeks to explore this by examining how interoceptive training by focusing on heartbeat without external feedback will affect delay discounting rate in primary and secondary rewards.

We hypothesise that undergoing the training will foster more balanced decision-making, thereby reducing the inclination to prefer immediate over delayed choices across both types of rewards. The goal is to gain deeper insights into how natural bodily awareness can steer decision-making and possibly recalibrate impulsive behaviours.

2. Materials and Methods

2.1 Experimental Design

The study implemented a between-subject design (experimental group vs. control group) to investigate the effects of an interoceptive training on decision-making, specifically, DD. Participants were randomly assigned to either the experimental group or the control group. Each group underwent two versions of the DD tasks (within-subject conditions: food and money), administered in a counterbalanced order across subjects.

2.2 Participants

Assuming the use of a repeated-measure ANOVA (two conditions of the decision task and two groups) with an α error probability = 0.05 and a ß power = 0.80, the number of subjects that would have allowed us to achieve an effect size f = 0.50 is 48 subjects. We therefore recruited N = 55 participants to cope with possible drop-outs. The participants were students from the Faculty of Psychology of the University of Pavia and received University Credits for compensation.

Four participants were excluded due to methodological issues, leaving a final sample of 51 participants. Participants were awarded University credits (CFU) for graduation purposes. All participants were naïve as to the purpose of the study. The whole experiment was conducted in Italian for native Italian speakers and in English for non-Italian participants fluent in English. Each session took on average 90 minutes (ranging from 65 to 125 minutes). Table 1 shows the total number of participants included in each group, the number of participants who performed the food condition first, and the number of participants who performed the money condition first. Additionally, it displays demographic information such as the gender distribution, age, Body Mass Index (BMI), and level of education.

Table 2: Participant Distribution and Demographic Information

Group	Total Number of Participants (F/M)	DD Food First	DD Money First	Age (years)	BMI	Education (years)
Experimental	22/4	N = 13	N = 13	23.73 (2.52)	24.25 (6.05)	15.0 (1.70)
Control	19/6	N = 13	N = 12	23.76 (3.05)	21.61 (2.78)	14.88 (1.62)

Note: *For age, BMI, and education, numbers are means (Standard Deviations). DD = Delay Discounting task; F = Females; M = Males; BMI = Body Mass Index.*

2.3 Procedure

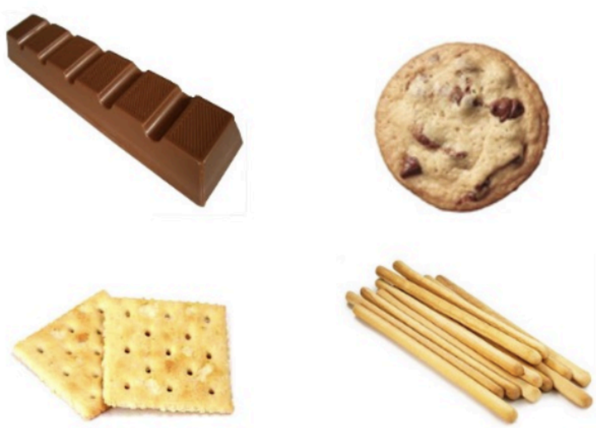
Informed Consent

Prior to the beginning of the study, the experimenter introduced herself and provided participants with a brief overview of the experiment, including its approximate duration and the use of the pulse oximeter. Participants were encouraged to ask any questions they had about the procedure before proceeding. Participants were then presented with an informed consent form outlining the study procedures and emphasising the confidentiality of their personal information. Participants indicated their voluntary agreement to participate by signing the consent form. The study was approved by the local Ethics Committee of the University of Pavia.

Initial Questionnaire

Participants completed a paper-based initial questionnaire. This questionnaire collected details, such as the time in hours since their last food intake and their preferred food choice among four options presented on paper. Food options included two sweet snacks (cookie and chocolate bar) and two salty snacks (cracker and breadstick). The selected food would later be used as stimulus in the food condition of the DD task. Participants also rated their hunger level on a Likert scale ranging from -5 (not hungry at all) to 5 (extremely hungry). The four food options presented to participants are shown in Figure 1.

Figure 1: The four food options provided to participants in the initial questionnaire: chocolate bar, cookie, cracker, and breadstick



Experiment design

The experiment included several tasks administered using OpenSesame software (Mathôt et al., 2012). All participants completed the same tasks, though the sequence varied between the experimental and control groups to control for order effects.

Experimental Group Sequence:

1. Heartbeat Counting Task (HCT)

2. DD Task (Money and Food conditions, in a counterbalanced order across participants)

3. Time Estimation Tasks (Time Task and Duration Task, in a counterbalanced order across participants)
4. Sound Task
5. Paper Questionnaires (in a counterbalanced order across participants)

Control Group Sequence:

1. Sound Task
2. DD Task (Money and Food conditions, in a counterbalanced order across participants)
3. Time Estimation Tasks (Time Task and Duration Task, in a counterbalanced order across participants)
4. Heartbeat Counting Task (HCT)
5. Paper Questionnaires (in a counterbalanced order across participants).

2.4 Task Descriptions

2.4.1 Interoceptive Training

The primary objective of the interoceptive training was to investigate whether engaging in a prolonged HeartBeat Counting Task (HCT) developed by Schandry (1981) prior to decision-making tasks would influence participants' DD behaviour. Specifically, the study aimed to determine if participants who performed the HCT task immediately before the DD tasks would exhibit less DD compared to those who performed a control task (Sound Task) first, focusing on exteroceptive perception.

Additionally, before beginning the HCT and Sound task, participants completed pre-task questionnaires to assess their current states of boredom and relaxation on a Likert scale from -5 (Not at all) to 5 (Extremely). Immediately following these tasks, post-task questionnaires were administered to assess their emotional responses, including boredom, relaxation, excitement, and pleasantness, using the same Likert scale.

HeartBeat Counting Task: The HCT Task was designed to engage participants in interoceptive training by having them count their heartbeats. The task aimed to heighten their awareness of internal bodily signals. Participants wore a pulse oximeter on their left index finger to measure the actual heartbeat count. The experimenter took note of the actual number. Participants could not look at the instrument. They were instructed to count the heartbeats they felt in their chest over several sessions. They were also explained that zero would be a plausible answer. The task lasted approximately 9 minutes and consisted of 15 trials with randomised durations ranging from 25 to 55 seconds, the first session serving as a practice trial. Participants had their eyes closed during the task. A beep from the computer signalled the beginning of each trial. At the end of each trial, another beep from the computer signalled them to stop counting and record their counted heartbeats and rate their confidence on a scale from 0 to 10 by typing numbers on the computer keyboard.

This task was also used as a measure of interoceptive accuracy for both groups. The HCT accuracy was calculated by comparing, for each interval, the number of heartbeats reported by the participant with the number of actual heartbeats and then averaging the score of the six intervals obtained using the formula in (Schandry, 1981). The HCT score can, thus, vary between 0 and 1: the closer to 1, the better the interoceptive accuracy.

Sound Task: The Sound Task served as a control training, focusing on exteroceptive rather than interoceptive perception. Participants listened to auditory beeps from the computer, with trial durations matched to those in the HCT task. They recorded the number of sounds they heard per trial and rated their confidence in their count on a scale from 0 to 10 by typing numbers on the computer keyboard. This task allowed us to distinguish the effects of interoceptive training on DD from those of a neutral, non-interoceptive task, by maintaining the experimental session duration equal between groups. The accuracy of this task was determined by the difference between the actual number of sounds and the number reported by the participants

2.4.2 Delay Discounting Tasks

Participants completed two separate DD tasks to evaluate their preference for immediate versus delayed rewards: one involving a food reward and one involving a monetary reward. All rewards used were hypothetical, but participants were encouraged to make their choices as if they were real.

In both tasks, participants chose between a smaller immediate reward and a larger delayed reward. The delays varied and included periods such as 2 days, 2 weeks, 1 month, 3 months, 6 months, and 1 year. At each delay, participants made 5 choices, for a total number of trials = 30. The immediate reward amount was always 20 on the first trial, and then it was adjusted via a staircase procedure based on participants' previous choices to equate the subjective values of immediate and delayed rewards. For example, on the first trial, participants might choose between €20 now versus €40 in 3 months, or between 20 cookies now versus 40 cookies in 3 months. In the second trial, participants might choose between 30 units of reward now versus 40 units of reward in 3 months, if they had chosen the delayed reward in the previous trial. Otherwise, in the second trial, participants might choose between 10 units of reward now versus 40 units of reward in 3 months, if they had chosen the immediate reward in the previous trial. The exact procedure is explained in Sellitto et al. 2010. The picture below depicts a choice trial in the money DD task (Sellitto et al., 2010).

Participants made their selections by pressing on the keyboard "A" for the left option and "L" for the right option. The preferred option remained highlighted for 1 second, followed by an inter-trial interval of 1 second. Figure 2 shows the setup for the DD task.

Figure 2: The experimental setup for the delay discounting task

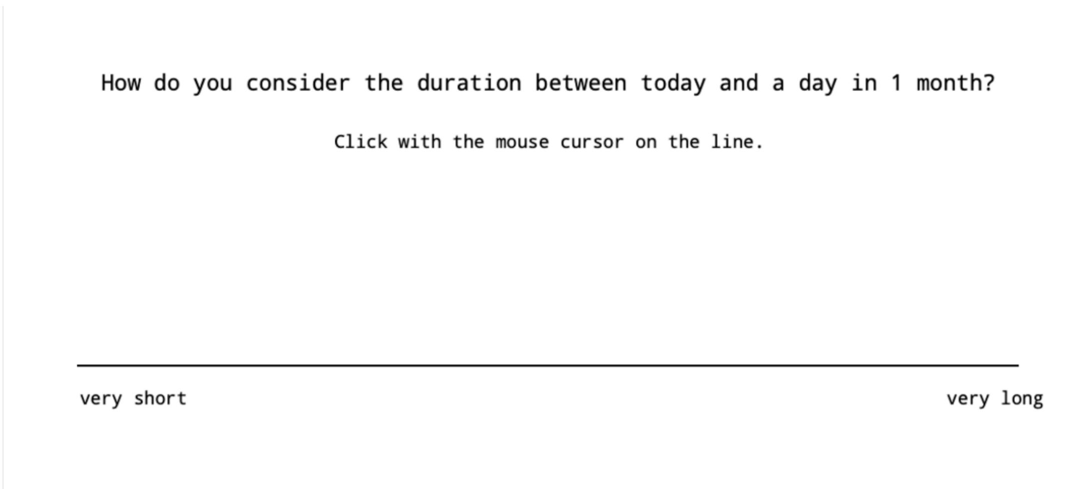
Participants were presented with a choice between a smaller immediate reward and a larger delayed reward. The selection remained visible for one second, illustrating the decision-making process. The depicted trial shows a monetary reward; for the food condition, the rewards were the food items selected in the initial questionnaire (see Figure 1). This picture has been adapted from Sellitto et al. 2010.

2.4.3 Time Estimation tasks

The time estimation tasks assessed participants' perception of various temporal intervals, encompassing duration and time tasks.

Duration Task: Participants estimated the duration between the current day and various future time periods, specifically 2 days, 14 days, 30 days, 90 days, 180 days, and 365 days, which are the same time periods used in the DD tasks. They indicated their subjective feeling of duration on a visual analogue scale from "very short" to "very long" by clicking on the scale with the mouse cursor. Participants were instructed to carefully read the questions and imagine the time period indicated before marking their response via the mouse cursor. This task provides additional information on how participants perceive the time lengths included in the DD tasks (see Figure 3).

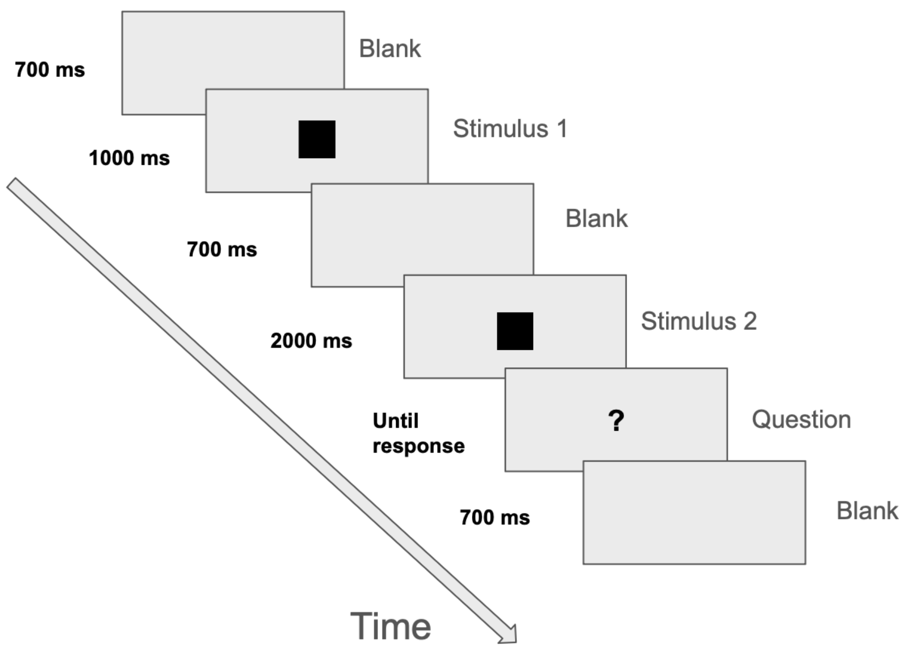
Figure 3: Duration Task interface



Participants used a visual analogue scale to indicate their perception of the duration between the current day and various future time periods (1 month in the current example). The scale ranged from "very short" to "very long".

Time Task: Participants viewed two visual stimuli sequentially and determined which stimulus seemed to last longer. After the two stimuli appeared, participants were asked to indicate their choice by pressing a key corresponding to the longer-lasting stimulus (either “A” for the first option or “L” for the second option). This task, consisting of 34 trials, provided insights into participants' perception of short and long time intervals based on visual stimuli (see Figure 4).

Figure 4: Time Task interface



Participants viewed two visual stimuli sequentially and determined which stimulus appeared to last longer. The task involved 34 trials.

2.4.4 Questionnaires

After completing all computer-based tasks, participants filled out several questionnaires on paper, each designed to measure different aspects of their global cognitive and emotional functioning. The order of the questionnaires was counterbalanced across participants to control for order effects. Overall, these questionnaires provided a comprehensive profile of each participant's cognitive abilities, body image perceptions, anxiety levels, interoceptive awareness, impulsiveness, and basic demographic information, contributing valuable data for the study's analyses.

Montreal Cognitive Assessment (MoCA): The questionnaire consists of various tasks that evaluate different cognitive domains, including attention, language, abstraction, memory, and orientation to time and place (Santangelo et al., 2015). For example, participants may be asked to recall a list of words or draw a clock showing a specific time. MoCa was administered with pre-recorded voice instructions to ensure standardisation.

Body Dissatisfaction Scale (BDS): This scale is used to measure body dissatisfaction. Participants (i) circled the picture of a body shape that they felt resembled their own body shape and (ii) then they circled the picture of the body shape they desired to have. These pictures are related to specific BMI categories. This method allows participants to express their body image perception visually and is effective in measuring body dissatisfaction (BMI related to the body they think they have minus BMI related to the body they would like to have), providing valuable insights into body image concerns (Mutale et al., 2016).

Body Shape Questionnaire (BSQ): The BSQ is a self-report questionnaire used to assess concerns about body shape. It includes 34 items rated on a Likert scale from 1 (never) to 6 (always) (Cooper et al., 1987). Example items include, “Have you been so worried about your shape that you have been feeling you ought to diet?”.

State-Trait Anxiety Inventory (STAI-X): The STAI-X, developed by Spielberger et al. (1983), measures both state and trait anxiety through two separate scales, each containing 20 items. State anxiety (STAI-XS) reflects a temporary condition, while trait anxiety (STAI-XT) measures a general tendency to experience anxiety. Items are rated on a 4-point scale. Example items include, “I feel calm” (reverse scored) or “I am tense” for state anxiety, and “I feel secure” (reverse scored) or “I worry too much over something that really doesn’t matter” for trait anxiety.

Multidimensional Assessment of Interoceptive Awareness (MAIA): This questionnaire evaluates different dimensions of interoceptive sensibility, such as noticing, emotional awareness, self-regulation, and body listening (Mehling et al., 2012). Participants rate their agreement with statements on a 6-point Likert scale. Example items include, “I notice how my body changes when I am angry” and “I can return to a state of calm after feeling anxious.” The MAIA measures eight dimensions: Noticing, Not Distracting, Not Worrying, Attention Regulation, Emotional Awareness, Self-Regulation, Body Listening, and Trusting.

Eysenck Impulsiveness Scale (EIS): The EIS measures impulsiveness, venturesomeness, and empathy in adults. Participants responded to yes/no questions that gauge their tendency to act on impulse, take risks, and empathise with others (Eysenck et al., 1985).

Demographics Survey: This survey collected basic information about the participants, including age, gender, weight, height, handedness, education level, diet status, and regular sport activity. Specifically, participants were asked to indicate their gender (F/M/O), age, education level, dominant hand (right/left/ambidextrous), height, weight, whether they were currently on a diet (yes/no), and whether they regularly engaged in sports activities (yes/no).

3.Results

The primary focus of this study was to investigate the impact of interoceptive training on delay discounting (DD) behaviour in money and food. Prior to addressing the main research questions, baseline analyses were conducted to ensure the data met the necessary assumptions. All data analyses were performed using JASP version 0.18.3.

Descriptive statistics were calculated for all relevant variables (see Table 1).

Outlier analyses were conducted to identify and exclude any data points (± 2SD) that might skew the results. Based on this analysis, participants with extreme BMI values, extreme DD values (Log-*k* scores), and age outliers were excluded from all further analysis whereby these variables were relevant. Specifically, two participants with extreme BMI values, two participants with extreme DD values in the food task, and one participant with an extreme age value were removed.

DD scores were calculated using the *k* parameter. To estimate *k*, we used a non-linear regression and applied to the data the formula SV = A/(1 + kD), where SV is the subjective value, A is the amount of the fix larger reward, and D is the delay in days. The linear regression (via the least-square method, implemented in the Statistica Statsoft software) estimated the *k* parameter that best described participant's choices as a function of time (delay). A higher *k* value means people prefer small immediate rewards over larger delayed ones (Sellitto et al., 2010). The estimated *k* values were log-transformed before being entered in the analyses as they were positively skewed.

3.1 Baseline Analysis

Before examining the main effects of the interoceptive training on decision-making, it was important to ensure that no pre-existing differences between the groups could confound the results. To address this, a series of independent-sample t-tests were conducted to assess whether participants differed on any key variables.

Analyses showed no significant differences between the experimental and control groups across any relevant variables. Specifically, the tests revealed that HCT accuracy ($t(44) = -0.40$, $p = 0.689$), Sound accuracy ($t(44) = -1.37$, $p = 0.178$), Time accuracy ($t(44) = 0.50$, $p = 0.618$), age ($t(44) = 0.17$, $p = 0.865$), education ($t(44) = 0.42$, $p = 0.674$), and BMI ($t(44) = 1.07$, $p = 0.290$) were comparable between groups. Notably, the Levene's test was significant for sound accuracy, suggesting a violation of the equal variance assumption; therefore, Welch's t-test was employed, which also indicated no significant difference ($t(23.698) = -1.32$, $p = 0.200$).

Similarly, no significant differences were observed across various psychological and cognitive assessments, including MAIA, EIS, STAI-X, BSQ, and MOCA (all ps > 0.290).

3.2 Main Analysis

Repeated-measure analysis of variance (ANOVA) was conducted to assess the effect of the experimental intervention (HCT) on DD behaviour. Group (experimental or control) was taken as a between-subject factor, while Log-*k* values of the reward type (money and food) as within-subject factor. The task order (whether participants performed DD money or DD food first) included as a covariate.

This aimed to explore whether the interoception training (HCT task) would influence participants' DD differently than the control task (expected to have a null effect on DD).

A repeated-measure ANOVA with reward type (money, food) and group (experimental, control) as factors revealed a significant interaction between reward type and group ($F(1, 42) = 4.29$, $p = 0.045$, $\eta^2_p = 0.10$), indicating that the effect of reward type on DD differed significantly between the groups. No significant main effects of reward type ($F(1, 42) = 1.50$, $p = 0.228$) or task order ($F(1, 42) = 1.09$, $p = 0.303$) were observed. The between-subjects effects analysis showed no significant effects for the group ($F(1, 42) = 1.41$, $p = 0.241$, $\eta^2_p = 0.03$), task order, or their interaction (all ps > 0.05).

Post Hoc Tests

Further analyses with Bonferroni corrected post hoc tests revealed:

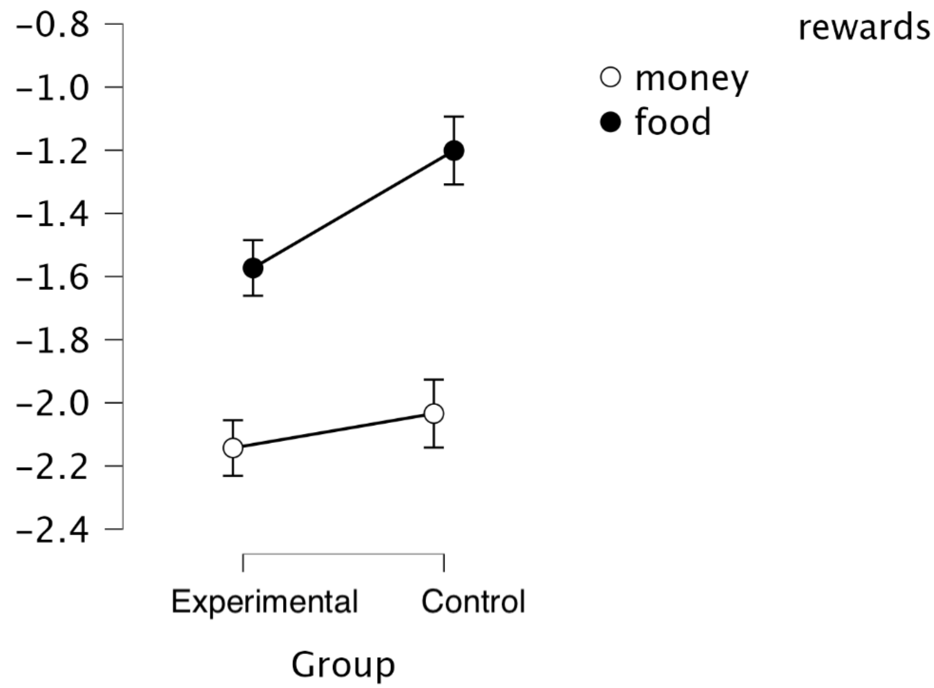
- Between the control group's discounting of money vs. food, there was a significant difference with food being discounted more steeply than money (mean difference = 0.85, SE = 0.19, t = -4.44, p < .001).

- For the experimental group, no significant difference was observed between the discounting of money and food (mean difference = -0.52, SE = 0.20, t = -2.54, p = 0.090), suggesting a more similar DD behaviour across reward types.

No other significant differences were observed in relation to task order or between other group comparisons (all ps > 0.33). These results suggest that interoceptive training in the experimental group may have moderated the typical pattern of steeper discounting for food compared to money, potentially indicating a more balanced evaluation of immediate versus delayed rewards across different types.

The plot below (Figure 5) shows the mean Log-*k* values for money and food rewards in the two groups. The experimental group shows much closer delay discount rates for both reward types (no significant difference) than those in the control group, with food being discounted here more than money. This means that the interoceptive intervention lowered delay discount rates for food in the experimental group.

Figure 5: The effect of interoception on delay discounting



*Note: This figure illustrates the logarithm of the discount parameter (*Log-*k) for monetary (open circles) and food (filled circles) rewards in experimental and control groups. Higher values (less negative) on the y-axis indicate more impulsive behaviour in decision-making, with the experimental group showing less impulsivity across both types of rewards compared to the control group.*

3.3 Secondary Analysis

3.3.1 Delay Discounting Across Different Participant Groups

The independent samples t-test revealed no significant differences between participants on a diet and those not on a diet for Log-k values of food ($t(44) = -1.34$, $p = 0.187$) and money ($t(44) = -0.76$, $p = 0.453$). Similarly, no significant differences were found between participants who regularly engage in sports and those who do not, with Log-k values for food ($t(44) = -0.42$, $p = 0.680$) and money ($t(44) = 0.63$, $p = 0.534$). Additionally, the time of day the experiment was conducted (morning vs. afternoon) did not significantly affect the outcomes, as indicated by Log-k values for food ($t(44) = -0.87$, $p = 0.390$) and money ($t(44) = -0.49$, $p = 0.624$). Lastly, the preference for sweet versus savoury food showed no significant differences in DD for food ($t(44) = 0.15$, $p = 0.886$) and money ($t(44) = -0.73$, $p = 0.472$).

3.3.2 HCT accuracy

We additionally looked at the interoceptive accuracy more in detail. The accuracy scores of 14 HCT task sessions were divided into three parts (with part I being the average of first four session accuracy scores, part II - next 6 sessions and finally, part III - the last four sessions) to see if there was a change in accuracy over the sessions. The repeated-measure ANOVA revealed no significant differences in the HCT task accuracy across three parts: $F(2, 90) = 0.02$, $p = 0.978$, indicating consistent accuracy throughout the task. The mean accuracy was 0.54 (SD = 0.23) for part I, 0.53 (SD = 0.24) for part II, and 0.54 (SD = 0.26) for part III.

However, there were significant differences in HCT confidence ratings (how accurate participants thought they were in each session): $F(2, 90) = 3.95$, $p = 0.023$. Confidence significantly increased from the first part (M = 4.63, SD = 2.12) to the second part (M = 5.12, SD = 2.31), then insignificantly decreased in HCT-III (M = 4.93, SD = 2.49).

3.3.3 Delay discounting and interoceptive sensibility

We checked whether there was any correlation between DD and the MAIA subscales. Participants with higher DD for money (Log-*k* money) also showed lower scores in the "trust" subscale ($r = -0.31$, $p = 0.039$), which refers to experience of one's body as safe and trustworthy. However we had no a priori hypothesis on this.

3.3.4 HCT and Sound tasks

We further looked into the two tasks, the experimental training and the control training. HCT. People who found the HCT task exciting also showed to be more relaxed after the task compared to their relaxation levels before the task ($r = 0.40$, $p = 0.031$).

Heartbeat counting accuracy positively correlated with confidence in the heartbeat task ($r = 0.44$, $p = 0.003$), but also with emotional awareness ($r = 0.35$, $p = 0.016$) and body listening ($r = 0.328$, $p = 0.026$).

Confidence in heartbeat counting positively correlated with MAIA scores: noticing ($r = 0.34$, $p = 0.020$), and body listening ($r = 0.31$, $p = 0.039$).

Control task. Concerning the Sound task, participants who reported to be more relaxed after the sound task compared to before had lower sound task accuracy ($r = -0.42$, $p = 0.022$).

3.3.5 BMI, body shape concerns and body dissatisfaction

Participants' BMI was significantly related to various relevant factors. It positively correlated with perceived BMI ($r = 0.78$, $p < .001$) meaning that participants tended to line up on the BDS scale. Additionally, BMI was correlated with body shape concerns (BSQ, $r = 0.37$, $p = 0.012$).

Higher ideal BMI scores (the BMI corresponding to selected body shape they wanted to have from BDS scale) was connected with self-regulation ($r = 0.35$, $p = 0.017$), trusting scores in MAIA questionnaire ($r = 0.37$, $p = 0.012$), and negatively correlated with body shape concerns (BSQ, $r = -0.40$, $p = 0.007$) and trait anxiety ($r = -0.45$, $p = 0.002$), meaning that participants whose had higher ideal BMI had less concerns on their body shape and less anxiety in general.

Similarly, participants with higher scores in BDS scale (whose ideal BMI was higher than their perceived BMI) had lower scores on body shape concerns questionnaire ($r = -0.62$, $p < .001$) and higher scores in not distracting (MAIA, $r = 0.38$, $p = 0.008$).

Negative correlations were found with BSQ scores and parts of the interoception questionnaire: not distracting ($r = -0.40$, $p = 0.006$) and trust ($r = -0.49$, $p < .001$).

4. Discussion

4.1 Overview of Study Findings

Choosing between immediate gratification and future benefits is a daily challenge, requiring a nuanced balance between short-term appeal and long-term advantages. Our study explored the impact of interoceptive attention, specifically through focusing on heartbeat, on decision-making processes concerning intertemporal choices involving hypothetical monetary and food rewards.

To test this, participants were divided into two groups. One group engaged in interoceptive training by concentrating on their internal bodily sensations, specifically their heartbeat while the other group participated in exteroceptive training by attending to external auditory stimuli, specifically computer-generated tones, before making decisions. The experimental and the control groups did not differ on key variables such as interoceptive accuracy and sensitivity, exteroception accuracy, hunger levels, time perception, and impulsivity. This parity in baseline measures ensured that any observed differences in delay discounting (DD) behaviour could be directly attributable to the intervention. Indeed, unlike the control group, which displayed typically higher discount rates for food compared to money, the experimental group showed more uniform discount rates between the two reward types, particularly evidencing a reduced discount rate for food. This adjustment could be interpreted that attention to internal states may effectively moderate the usually high propensity to discount future edible rewards.

4.2 Impact of Interoceptive Training on Decision-Making

Interoceptive training typically enhances sensitivity to internal states like heart rate and stomach sensations, fostering more reflective decision-making across different contexts. In our study, we observed that participants who focused on their heartbeat before decision-making demonstrated more consistent decision-making across different types of rewards. Unlike the control group, which showed a higher tendency to discount food rewards quickly, those trained showed even consideration for both types of rewards. This suggests that interoceptive training could potentially recalibrate how people value immediate and delayed rewards, possibly by enhancing bodily awareness (Dunn et al., 2010; Garfinkel et al., 2015; Werner et al., 2009).

Research indicates that non-monetary outcomes like food are typically devalued more steeply than monetary rewards, highlighting the strong influence of physiological states on reward valuation (Odum et al., 2020). By aligning the discount rates for immediate, consumable rewards more closely with those for secondary rewards, interoceptive training could help manage impulsive behaviours, particularly those related to food consumption (Odum & Rainaud, 2003) as primary rewards like food are directly impacted by physiological states. There is a distinction between how the brain processes different rewards, while immediate rewards trigger fast, emotion-driven responses, delayed rewards require more thoughtful, strategic thinking (McClure et al., 2007).

Engaging in the Heartbeat Counting Task likely enhances participants' internal state awareness, leading to better-informed decision-making, particularly in managing impulsive urges and in making healthier choices that extend beyond immediate taste pleasures (Sugawara et al., 2020; Craig, 2002).

By focusing on internal states, interventions like HCT can reduce the usual preference for immediate rewards, which is a common challenge in various clinical and behavioural settings (Herman and Stanton, 2022).

4.3 Theoretical Foundations of Interoceptive Awareness

The outcomes of our study align with key theories that explore how bodily awareness shapes emotional and motivational states. For instance, Damasio's somatic marker hypothesis proposes that emotional processes guide (or bias) behaviour, particularly decision-making, in response to certain stimuli (Damasio, 1994). Similarly, Thayer and Lane's neurovisceral integration model suggests that a well-regulated autonomic nervous system contributes to optimal social and adaptive behaviours by affecting decision-making (Thayer & Lane, 2000). Furthermore, research by Craig on the neurobiological foundations of interoceptive awareness highlights how awareness of physical states may influence cognitive processing and decision-making (Craig, 2002), while Critchley's work extends this by examining how heart-based viscerosensory signalling can affect the perception and decision-making process (Critchley, 2004). Collectively, these theories suggest a profound integration of sensory and emotional information, which supports the potential of interoceptive training to recalibrate how individuals assess and respond to rewards.

4.4 Methodological Approaches in Interoceptive Training

In contrast to other interoceptive training studies that often employ biofeedback to enhance participants' accuracy, our study employs a distinctive approach by not providing direct feedback. For example, the study by Sugawara et al. (2020) used biofeedback to provide participants with immediate feedback on their performance, Although this significantly improved interoceptive accuracy, it did not yield notable changes in decision-making.

Another study (Rae et al., 2019) investigated the impact of cardiac cues on decision-making using a modified Go/NoGo task. While they did not use biofeedback, the emphasis was on how specific cardiac phases influenced decisions. They found that higher interoceptive awareness led participants to withhold actions. This aligns with our methodological emphasis on intrinsic awareness rather than induced responses through explicit feedback.

Additionally, Price and Hooven (2018) introduced Mindful Awareness in Body-oriented Therapy, which like our study, does not rely on feedback mechanisms but instead fosters a deepened bodily awareness through mindfulness practices to enhance decision-making and emotional regulation. These methodological distinctions highlight the possible diverse approaches within interoceptive training research.

4.5 Implications

The interaction of various brain regions in responding to immediate versus delayed rewards is complex. Research shows that limbic areas involved in emotional processing exhibit increased activity in response to immediate rewards, whether primary (like food) or secondary (like money), while areas associated with deliberative thinking, such as the lateral prefrontal and parietal cortex, show a more consistent response across different decision types, indicating a reduced sensitivity to reward immediacy (McClure et al.,2007). Furthermore, studies suggest that the ability to delay gratification might not correlate with lower impulsivity in other decision-making areas such as risk tolerance, indicating that impulsivity in DD might not universally apply across different decision-making scenarios (Holt et al., 2003). Integrating insights from the Competing Neurobehavioral Decision Systems theory offers further understanding of how the brain manages these decisions. It describes two neural systems: one that pursues immediate rewards and another that considers longer-term benefits and controls impulsive actions (McClure et al., 2007). This framework helps explain the neural foundations of decision-making and the valuation of immediate versus delayed rewards.

Additional insights from research into metabolic functions reveal how immediate physiological needs significantly influence the steep discounting of primary rewards that satisfy metabolic demands, in contrast to secondary rewards that lack immediate physiological benefits (Charlton & Fantino, 2008).

These insights into the neural dynamics and metabolic influences on decision-making can explain why interventions like interoceptive training have an impact on our choices. By enhancing awareness of internal states, these trainings may recalibrate the neural pathways that weigh immediate against delayed gratifications. This shift could be particularly influential in decisions where physiological cues are direct factors, such as hunger influencing food choices.

In practical terms, participants in our study who were more attuned to their inner states due to interoceptive training could bypass immediate gratifications in favour of long-term health benefits. For example, individuals attuned to their inner states might bypass unhealthy snacks not just as a healthier choice but as a strategic decision aimed at achieving more substantial, long-term rewards like improved health. This suggests that enhancing bodily awareness can lead to more considered decisions, aligning with findings from Barrett and Bar (2009) who discussed the role of emotional salience in decision-making connected with sensory perception. This awareness potentially shifts how delayed rewards are valued.

These insights collectively advocate for the potential of interoceptive training to influence decision-making processes, specifically in contexts where immediate gratifications are prevalent.

4.6 Limitations

One notable limitation in our study stems from the use of hypothetical instead of real rewards to explore DD processes. Although this is a practical method for studying decision-making, it introduces potential biases that could affect the results as hypothetical rewards may be discounted at lower rates compared to actual rewards (Bickel et al., 1999). This suggests a possible underestimation of true discounting behaviour and raises concerns similar to those associated with self-report measures, where responses might not fully capture behaviours in real-life situations.

Additionally, the sample size and diversity may limit the generalizability of our findings. As the participants were university students, the results might not accurately represent broader population dynamics, including variations in socioeconomic status. This could influence the applicability of the findings to other groups, necessitating further research with a more varied demographic.

5. Conclusion

Given the broad impact of delay discounting on various aspects of personal and public health, it is important to investigate possible interventions to lower discount rate in intertemporal choices. This study examined whether an interoceptive training, consisting of focusing on the heartbeat, could have an effect on delay discounting on hypothetical monetary and edible rewards.

Our results indicate the possibility that interoceptive attention may enhance sensitivity to internal cues, potentially leading to more consistent decision-making across different reward types, as participants trained to focus on their internal states appeared to have a more balanced valuation in contrast to the control group's rapid discounting of food rewards. This suggests that by improving bodily awareness, an interoceptive training might help recalibrate how individuals value both immediate and future benefits, possibly leading to healthier decision-making patterns, particularly concerning food.

By enhancing awareness of internal states, we speculate that this training may adjust the neural pathways that balance immediate and future gratifications. Such adjustments might be particularly noticeable in decisions directly influenced by physiological cues, such as hunger impacting food choices. However, these suggestions must be taken cautiously, as we did not investigate this issue from the neuroimaging point of view.

It is interesting to consider whether the benefits of interoceptive training might persist in the long-term, offering a sustainable approach to prioritising future rewards over immediate temptations. These findings suggest directions for further research and practical applications aimed at refining decision-making behaviours, especially given the complexities of impulsivity and its varied manifestations across different decision-making scenarios.

Furthermore, although there were no improvements in accuracy over the 14-session Heartbeat Counting Task it would be interesting to explore whether longer or more frequent training sessions without feedback might improve accuracy.

In conclusion these findings show a potential of interoception-focused interventions for improving delay discounting patterns.

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