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Research report

Prefrontal activity during IOWA Gambling Task in young adult women

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A R T I C L E I N F O

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A B S T R A C T

This study aims to investigate the relationships between personality traits of impulsivity, using the UPPS-P Impulsive Behaviour Scales shortened version, and prefrontal cortex (PFC) activity during the IOWA Gambling Task (IGT) in young adult women. The study included a sample of 83 young, healthy females (19.8 ± 1.4 years), who voluntarily took part in the study. Repeated measures analysis during the IGT revealed a significant increase in HbO (all p <.001; η_p^2 >.31) and a decrease in Hbr (all p <.003; η_p^2 >.08) in all prefrontal quadrants. This increase in oxygenation occurs primarily during the choice period under ambiguity (r =.23; p =.039). Additionally, there was a significant linear decrease in selecting the decks associated with a high frequency of losses (p <.001), while the favorable deck with low losses showed a linear increase (F = 12.96; p <.001). Notably, discrepancies were found between UPPS-P and IGT impulsivity ratings. The Lack of Perseverance and Lack of Premeditation scales from the UPPS-P were identified as significant predictors of HbO levels, mainly in the two quadrants of the left hemisphere's, lateral (adjusted R^2 =.23; p <.001; f^2 =.34) and rostral (adjusted R^2 =.13; p <.002; f^2 =.17). These findings suggest that young adult women predominantly adopt a punishment-avoidance strategy during IGT, exhibiting increased activation in the left hemisphere, especially during the task's initial phase characterized by ambiguity.

1. Introduction

Impulsivity is a behavioral pattern characterized by the imperative need of acting without voluntary control. Impulsivity traits include unplanned acts, without prior reflection, in response to internal or external stimuli, and without considering the possible consequences to oneself or to others [56]. Impulsivity traits are present in many theories of personality. Thus, Eysenck and Eysenck [36] included a subscale of Impulsivity in the dimension of Extraversion, although they later reformulated it by differentiating Venturesomeness [37]. For Gray [44], impulsivity is related to Susceptibility to Reward. Cloninger et al. [20] included impulsivity in the Novelty Seeking temperament trait. Impulsive Sensation Seeking was considered a human basic personality trait in Zuckerman's alternative five-factor personality model [1,87]. Barrat [7] proposed a three-factor impulsivity model, and Dickman [32] suggested differentiating between functional and dysfunctional impulsivity.

Impulsivity is a multidimensional construct [6,72]. Dalley et al. [26] identified various impulsive behaviors, including impulsive choice, characterized by preferring small rewards over delayed larger ones. This behavior often leads to poor decision-making by preferring more seductive options over more conservative options [82] and is linked to addictive behaviors [55]. Impulsive behaviors are prevalent among young adults [3,74,86], predicting future addiction tendencies in adulthood [70].

Different strategies have been proposed for the study of impulsivity, including self-report questionnaires and cognitive tasks. The UPPS-P questionnaire derived from the NEO-PI-R [22] is commonly employed. It comprises four facets: Urgency, Lack of Premeditation, Lack of Perseverance and Sensation Seeking [85]. Steward et al. [75] described the existence of positive correlations between measures of impulsive choice and scores on the Urgency and Lack of Premeditation scales in young, but not older, patients with gambling addiction. Verdejo-García et al. [82] have suggested that impulsive choice would be related to facets such as unplanned impulsivity or Lack of Premeditation.

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The Iowa Gambling Task (IGT) is a cognitive task related to impulsive choice [26,82]. While some studies report a negative relationship between impulsivity and IGT performance [43,83], others find no such association [8,62,66]. In a recent meta-analysis, Elliott et al. [34] have shown a modest effect size between performance on this test and Positive and Negative Urgency. However, some authors have highlighted the divergences in the assessment of impulsivity using self-questionnaires and neurocognitive tasks [23,72,81]. Moreover, most of the studies have been conducted with neurological and psychopathological samples of different ages and with a higher presence of male participants.

Neurobiological correlates, particularly those involving lateral prefrontal cortex, are associated with impulsive choice [26,27,41]. Studies on patients with prefrontal lesions [79] and by non-invasive brain stimulation [15] have shown the importance of the prefrontal cortex, and especially the dorsolateral area, in aspects such as attention, working memory, learning rules or planning. These studies have also highlighted the existence of hemispheric differences with a predominance of the right hemisphere, the stimulation of which would decrease impulsivity [15].

The dorsolateral prefrontal cortex is also involved in IGT performance [2], with increased activity in women, but not in men, during tasks related to gains and losses [19]. Increased left hemisphere activity has been associated with less favorable choices [40,71]. While previous studies utilized neuroimaging techniques involving uncomfortable situations, recent interest has shifted towards near-infrared spectroscopy (fNIRs), offering more comfortable experimental situations. fNIRs studies indicate increased activation [47], especially in the left hemisphere [46], although the interhemispheric difference was smaller in those participants with lower IGT scores [76]. This activation would occur primarily during the first phases of the task [11,49,58]. These studies have used samples of patients [58] or mixed samples of men and women [11,46,47,49,58,76]. Several studies have shown differences not only in strategy choice but also in cortical functioning during IGT between men and women [13]. Also, age acts as a modulating factor in the relationship between brain activity and impulsivity [61]. Adolescence and young adulthood are a period during which the development and maturation of the prefrontal cortex takes place [45]. During childhood and adolescence, the predominance of subcortical structures favours the emergence of risk-taking behaviour, while the maturation of the prefrontal cortex, which occurs in young adults, facilitates executive control [18,68]. The analysis of the role of the prefrontal cortex in young adults can be of significant help in the development of endophenotypes related to psychopathology since cortical activity in young adults can predict their impulsivity, as well as their future impulsivity [77].

On the other hand, as shown above, most of the studies that have analyzed IGT performance, both with psychometric measures of impulsivity and prefrontal cortex activity, have used clinical samples or samples of both sexes of different ages. Gender differences in impulsivity [25] and decision-making [31,80] are well established. Women tend to exhibit higher impulsive choice tendencies [84]. There are gender differences in addictive behaviours, with women being more prone to addictions to prescribed drugs, food or exercise, and also showing a faster progression to the disorder [39], known as telescoping phenomenon [54]. Additionally, sex differences in prefrontal cortex development and connectivity have been described [33]. Analysis of changes in brain activity in situations involving impulsive choice in women entering adulthood may improve understanding of the mechanisms that favor increased vulnerability to rapid progression to some disorders.

Our study aims to explore the relationship between UPPS-P scores and IGT performance in young adult women, alongside prefrontal lobe response during the IGT. Considering impulsivity's multidimensionality, we will examine its association with different UPPS-P subscales. Based on existing literature, we hypothesize that: a) There will be an inverse relationship between impulsivity scales scores and IGT performance, particularly associated with Urgency and Lack of Premeditation, given its relationship with impulsive choice. It predicts a greater effect in lateral prefrontal areas and the involvement of those variables more related to impulsive choice, these being the IGT score and the urgency and lack of premeditation facets of the UPPS. b) This effect will be pronounced during the ambiguity phase of the IGT, and c) Due to the involvement of the left lateral prefrontal cortex in less favorable decision making, we expect to find a negative relationship between IGT scores and left lateral prefrontal cortex oxygenation.

2. Method

2.1. Participants and procedure

The participants were 83 healthy undergraduates right-handed women (19.8 ± 1.4 years). All participants reported no history of neurological or psychopathological disorders or substance abuse after clinical evaluation by a professional. Menstrual cycle phase and oral contraceptives intake were controlled. None of the participants was taking psychotropic medication. Another condition for taking part in this experiment was no consumption of stimulants or tobacco in the earlier 12 hours. Subsequently, participants answered the UPPS questionnaire. Detailed verbal and written information about the procedure was given to all participants, who signed an informed consent. The University Ethics Committee approved the study.

The experimental recording sessions were carried out in an acoustically and electromagnetically isolated Faraday cage illuminated with dim light, with a compartment for the experimental subject and another for the researcher. Each subject was tested after sitting on a comfortable chair with the head 100 cm from a regular 32-inch TV screen. Prior to the stimuli presentation, the frontal headpiece sensor was attached, placed on the forehead, and the 16 channels were checked and calibrated.

2.2. Material

2.2.1. Impulsive Behaviour Scale (UPPS-P)

The UPPS-P Impulsive Behavior Scale shortened version was developed by Whiteside and Lynam [85]. This version has 20 items and five scales: Negative Urgency, Lack of Premeditation, Lack of Perseverance, Sensation Seeking and Positive Urgency. The Spanish version of the short UPPS-P [17] was used. Confirmatory factor analyses supported the five-factor model of the original scale. The Spanish validation obtained a good internal reliability (see [17] for details).

2.2.2. IOWA Gambling Task

Bechara et al. [9] introduced the IGT to capture the uncertainty of real-life decision-making. Participants must make 100 selections from four decks of cards displayed on a monitor screen. Participants were informed that some of these decks provided a net loss, while others provided a net gain. After each choice, the computer displayed an associated virtual monetary reward or punishment. Two of the decks were disadvantageous decks with an outcome involving losses. The other two decks were advantageous decks, but in this case, the result was a net gain. In addition, two of these decks had frequent penalties (50%), while the other two had only one penalty for every ten choices (10%). Table 1 shows the design characteristics. A 'net score' was calculated for each IGT block for each participant based on advantageous decks minus disadvantageous decks selections. In addition, an IGT punishment was calculated according to deck selections related to the frequency of losses. In addition, IGT_learning has been calculated using the difference between performance on late trials, related to decision-making under risk, and performance on early trials, related to decision-making under ambiguity [14].

2.2.3. fNIRs recording

Prefrontal activity was monitored using a 16-channel fNIR 1100 system (fNIR devices LLC, Biopac System Inc.), which detects changes in

Table 1
Characteristics of the Iowa Gambling Task (IGT) and descriptive of each deck.

	Good-Deck, High Loss-Frequency	Good Deck, Low Loss-Frequency	Bad Deck, High Loss-Frequency	Bad Deck, Low Loss-Frequency.
Gain	10–15	10–15	25	25
Loss	5–15	80	30–35	250
% Losses	50	10	50	10
Expectancy (10 cards)	25	25	-25	-25
Mean responses	17.89	30.76	15.95	35.40
Standard Deviation	7.45	12.55	6.52	12.72

oxygenated (HbO) and deoxygenated (Hbr) haemoglobin levels at of 730 and 850 nm wavelengths based on the modified Beer-Lambert law. The fNIR head probe for signal acquisition has 4 led light sources and 10 photodetectors. It was positioned at supraorbital prefrontal regions F7, Fp1, Fpz, Fp2 and F8 of the International System 10–20 EEG as a reference, corresponding to Brodmann areas 10, 11, 45, 46, and 47 [67]. The system's sampled at two measurements per second.

COBI software [4], controlled light intensity and signal amplification, synchronizing with E-Prime signals marking IGT blocks. The mean for HbO and Hbr was obtained for each of these blocks, as well as the overall mean of these values during IGT. To attenuate the effects of breathing and respiratory rate, as well as high frequency noise, a low-pass filter with a finite impulse response (FIR) with a cutoff frequency of.1 Hz and an order of 20 was applied to the raw data. Subsequently, the Sliding-window Motion Artifact Rejection (SMAR) algorithm removed motion artefacts and saturated channels. Additionally, channels displaying signal saturation or those not capturing impulses at the correct intensity (between 400 and 4000 mV) were excluded from the analysis.

From these filtered data, HbO2 and Hbr were calculated using the modified Beer-Lambert law, referencing a four-minute baseline. This baseline allowed us to calculate relative changes in HbO and Hbr in μmol/l and establish meaningful comparisons during the task performance. Finally, linear trend reduction constrained signal deviations. Hemodynamic measures were grouped into lateral left (channels 1, 2, 3, and 4), rostral left (channels 5, 6, 7 and 8), rostral right

(channels 9, 10, 11 and 12) and lateral right (channels 13, 14, 15 and 16) quadrants based on led light source channels.

2.3. Data analysis

Sample size calculation using G-PowerWin 3.9.1.7 software [38] for a medium effect size (α=.05; β=.20) indicated 67 subjects were needed for one-tailed tests, while fewer subjects were required for regression analysis with seven predictors.

We employed repeated measures analysis for IGT performance, treating blocks of 25 trials as within-subject variables. Hemodynamic changes across quadrants were analysed similarly, with block means as within-subject variables. Greenhouse-Geiser correction was applied where Mauchly's test violated sphericity. Effect sizes were reported using partial eta squared (η_p^2) categorized as small (<.06), medium (.06–.14), or large (>.14) effects according to Cohen [21].

Correlational analyses explored associations between hemodynamic variables, IGT performance, and UPPS-P scales. Multiple linear regression, utilizing stepwise method, investigation relationships between UPPS-P scales, IGT total and IGT punishment indices, as independent variables, and the hemodynamic responses in each quadrant, as dependent variables. Prior to regression, multicollinearity and autocorrelation were checked, with all values within acceptable ranges. All variance inflation factors (VIF) were less than 2.0 and Durbin-Watson test, obtaining values between 1.7 and 2.2. Cohen's f^2 were calculated to determine small (≥.02), medium (≥.15), and large (≥.35) effect sizes [21].

3. Results

3.1. IOWA gambling test performance

Table 1 displays IGT descriptive analysis. This task was divided into four blocks of 25 trials each one. Fig. 1 illustrates deck choice evolution compared to the first block. The average IGT score (2.7 ± 24.4) indicates slight preference for advantageous decks, yet 55.4% scored below zero. No differences exist between the first 40 and last 60 trials (*t*-test =.42; *p* =.68). However,

there was a significant increase in decks with lower negative choice frequencies (*t*-test = −8.11; $p <.001$), regardless of advantage. Only 8.4% favored decks with higher negative stimuli over those with lower frequencies.

The repeated measures ANOVA analysis with the four blocks as within subject factor for each deck shows a significant effect for the Disadvantageous-High Loss Frequency (D_HL) (F = 8.75; $p <.001$; η_p^2 =.10), Advantageous-High Loss Frequency (A_HL) (F = 7.25; $p <.001$; η_p^2 =.08) and Advantageous-Low Loss Frequency (A_LL) (F = 7.84; $p <.001$; η_p^2 =.08) decks, but not in the case of Disadvantageous-Low Loss Frequency (D_LL) (F =.43; $p <.73$). In the two decks with high frequency of losses, we can observe a decreasing linear fit [D_HL (F = 17.96; $p <.001$; η_p^2 =.18), A_HL (F = 11.59; $p <.001$; η_p^2 =.12)], while in the A_LL deck, the fit is linearly increasing (F = 12.96; $p <.001$; η_p^2 =.09). Significant differences were observed between decks with different percentages of losses (all $p <.002$), but no significant differences were observed between blocks characterized by the same percentage of choices with losses, except in the first block where the choices of the D_LL deck (8.6 ± 3.2) were higher than those of the A_LL deck (6.4 ± 2.5) (t = 3.96; $p <.001$). In fact, in the first block, the number of choices of the D_LL deck was higher than the others. Pearson correlation analysis between IGT measures and the UPPS-P scales did not show significant relationships.

3.2. HbO and Hbr levels during IGT

Fig. 2 shows the changes in HbO and Hbr levels during the performance of the IGT. The repeated measures ANOVA (analysis of variance) of HbO levels during the IGT shows a significant increase in all prefrontal quadrants (all $p <.001$; $\eta_p^2 >.31$), although the left hemisphere presented a linear adjustment, while the right hemisphere was

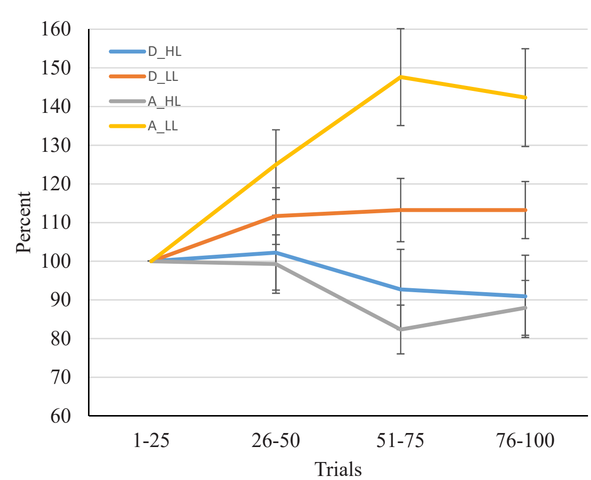

Fig. 1. Percentage of variation from the first block for each deck in blocks of 25 cards during IGT performance (sem indicated by bars) (D_HL: Disadvantageous deck High Losses; D_LL: Disadvantageous deck Low Losses; A_HL: Advantageous deck High Losses; A_LL: Advantageous deck Low Losses).

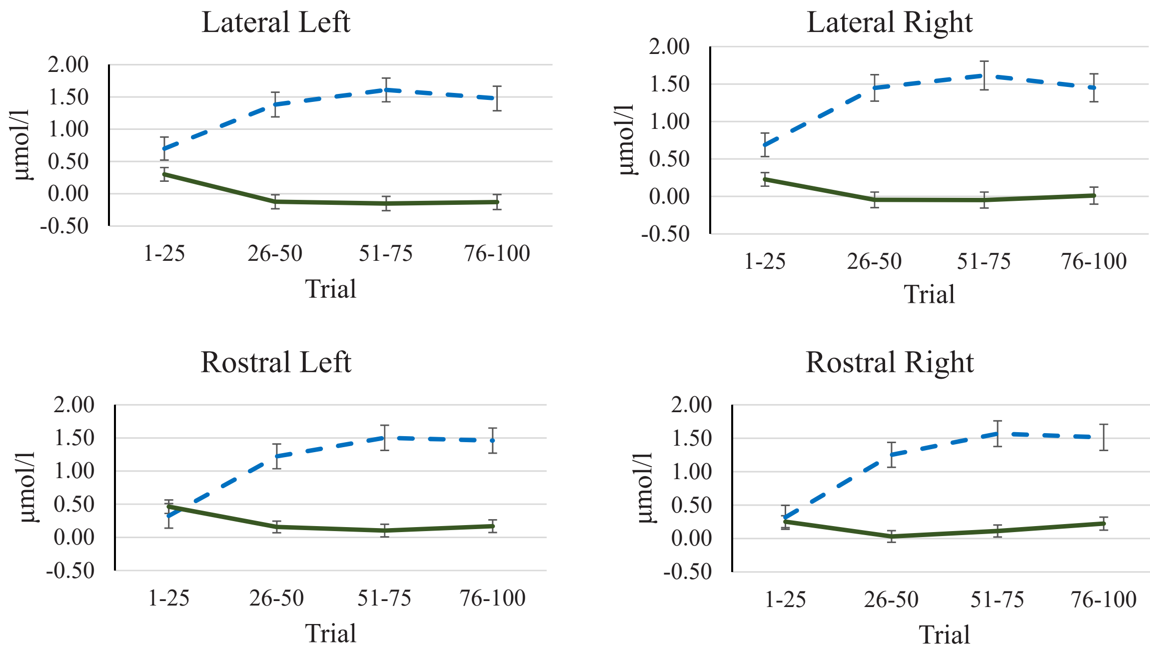

Fig. 2. HbO (dashed line) and Hbr (continuous line) levels during IGT performance for each prefrontal area (sem indicated by bars).

quadratic. On the other hand, in the repeated measures ANOVA of Hbr levels, we can see a significant decrease in Hbr levels in all quadrants (all $p < .003$; $\eta_p^2 > .08$). For this variable, all quadrants showed a quadratic fit.

The comparison of haemoglobin levels, both oxygenated and reduced, between the first two blocks, which correspond to the ambiguity decision-making phase, shows significant differences for both HbO (all $p < .001$; Cohen's $d > .75$) and Hbr (all $p < .001$; Cohen's $d > .44$) in all quadrants. In contrast, this comparison between the last two blocks, which correspond to the risk decision-making phase, only shows a significant difference in the levels of Hbr in the right rostral area ($p = .004$; Cohen's $d > .33$) and in the levels of HbO in the right lateral prefrontal cortex ($p = .013$; Cohen's $d > .58$).

Correlational analysis conducted on the lateral right prefrontal cortex revealed a positive correlation between IGT score and HbO levels during the ambiguity phase ($r = .23$; $p = .039$). However, this relationship was not significant during the risk phase ($r = -.01$; $p = .96$). No other significant correlations were observed in the other analysed quadrants.

3.3. *UPPS-P scales and IGT performance as a prefrontal oxygenation prediction power*

The internal consistency of the UPPS-P scales (Cronbach's α) ranged from.41 to.75. Lack of Perseverance (.75) and Positive Urgency (.72) exceeded the threshold of.7. A positive correlation was found between the two Urgencies ($r = .58$; $p < .001$) and between Lack of Premeditation and Lack of Perseverance ($r = .33$; $p < .003$). However, no significant relationship merged between UPPS-P scales and IGT variables, except for a near-significant trend between negative urgency and IGT-Learning score ($r = -.19$; $p < .08$).

Table 2 shows a multiple linear regression analysis performed using UPPS-P scales and IGT strategies as independent variables and HbO as dependent variable using the stepwise method. We can observe a significant fit in the two quadrants of the left hemisphere, lateral (adjusted $R^2 = .23$; $p < .001$; $f^2 = .34$) and rostral (adjusted $R^2 = .13$; $p < .002$; $f^2 = .17$), while in the right hemisphere, fits for rostral (adjusted $R^2 = .09$; $p < .008$; $f^2 = .13$) and lateral (adjusted $R^2 = .04$; $p < .048$; $f^2 = .05$) were comparatively lower. Lack of Perseverance appeared as a significant predictor in all quadrants, while Lack of Premeditation also showed significance in the left

Table 2
Results of the multiple regression analysis using UPPS-P scales and IGT strategies as predictors of HbO for each PFC quarter.

Prefrontal Quadrant		Standardized B	Adjusted R^2	*F*	*t*	*p*
Lateral Left	Overall Model		.23	8.95		<.001
	Constant				-.81	.42
	Lack of Perseverance	.53			4.92	<.001
	Lack of Premeditation	-.29			-2.80	.006
	Negative Urgency	.24			2.37	.021
Rostral Left	Overall Model		.13	6.76		.002
	Constant				1.40	.17
	Lack of Perseverance	.38			3.40	.001
	Lack of Premeditation	-.27			-2.48	.015
Rostral Right	Overall Model		.09	5.18		.008
	Constant				1.61	.11
	Lack of Perseverance	.32			2.88	.005
	Lack of Premeditation	-.26			-2.33	.022
Lateral Right	Overall Model		.04	4.05		.048
	Constant				.46	.65
	Lack of Perseverance	.22			2.01	.048

hemisphere and in the middle quadrant of the right hemisphere. Negative Urgency scores also predicted mean HbO levels in the left lateral prefrontal quadrant. Participants were categorized based on Lack of Perseverance scores into high (>10; 12.00 ± 1.17), medium (7–10; 8.94 ±.93) and low (<7; 5.53 ± 1.22) groups. Analysis of variance showed significant differences on the lack of premeditation ($F = 4.76$; p =.011; η^2 =.10) and left lateral HbO ($F = 4.12$; p =.02; η^2 =.11). Post-hoc analysis revealed higher lack of premeditation scores and HbO in the highest perseveration group than the lowest perseveration group.

Post-hoc repeated measures analysis showed no interaction between perseverance and HbO (all p >.05), but significant effects of HbO changed across all quadrants during the ambiguity period (all p <.001; η_p^2 >.46). Significant differences between Lack of Perseverance groups were observed in the left lateral ($F = 5.48$; p =.006; η_p^2 =.12) and rostral prefrontal cortex ($F = 3.54$; p =.034; η_p^2 =.08). Post-hoc pairwise comparisons showed that the high Lack of Perseverance group had higher HbO levels than the low Lack of Perseverance group in the left lateral prefrontal cortex (p =.004). In the left rostral prefrontal cortex, higher HbO levels were seen in the group with high scores on lack of perseverance than in the groups with medium and low scores, although the differences did not reach statistical significance with the latter set.

During the IGT risk period, a slight significant effect for HbO evolution was observed in the right lateral prefrontal cortex ($F = 5.58$; p =.02; η_p^2 =.07). Between-group comparisons showed a trend towards significance in the left lateral prefrontal cortex (p =.075). Fig. 3 shows the mean HbO concentration for lowest, middle, and highest scorers in Lack of Perseverance.

4. Discussion

In this study, we analysed the relationship between impulsivity, performance on the IGT and prefrontal activity among a cohort of young women. Our results focused in three key facets. First, the strategic approaches adopted by participants during the IGT. Secondly, the increase in

prefrontal oxygenation throughout the task, especially during its initial phases and, finally, the correlation between prefrontal oxygenation, particularly in the left hemisphere, with the UPPS-P scales, with particular emphasis on Lack of Perseverance.

We expected that most participants would opt for the most advantageous decks, however only 37.35% of subjects achieved net scores above zero. Interestingly, the only deck with an increase in choices was the advantageous deck with low losses, while decks with higher loss percentages experienced progressive declines in selections. Conversely, the disadvantageous deck with few losses exhibited no noticeable on its evolution. Notably, during the first block, the number of selections for the disadvantageous deck with fewer losses was higher that of others. Several factors may account for the preference for decks with lower loss ratio. Lin et al. [50] described a preference for disadvantageous decks characterised by low percentage of loss choices. Moreover, existing literature suggest that a substantial number of subjects fails to identify the most advantageous decks [78]. Studies focusing on women indicate a propensity for selecting options with minimal loss frequency [35,80]. One explanation for these results could be that women may be more sensitive to losses than wins [42,60], although additional factors such as heightened anxiety [30] or emotional states [73] may also contribute to poor IGT performance.

Furthermore, age-related differences have been documented, with young people tending to avoid decks with higher penalty percentages, and advantageous choices becoming more prevalent in middle-aged adults [10]. Crone and Van der Molen [24] found in adolescents anticipatory electrodermal responses to high frequency punished choices in an adapted task for children and adolescents. Prefrontal cortex is necessary for the correct performance of the IGT and is one of the most late-developing parts of the central nervous system [45]. However, our study focused on young adult women, an age at which we can consider that the prefrontal cortex can already exert a relevant top-down control over subcortical structures, which are more facilitators of risky behaviours. Other aspects, such as the task instructions [5] or IGT design [16,59], may also influence outcomes. Additionally, the absence of rewards for participants in our study might have impacted motivation to achieve optimal results.

Despite hypothesizing a negative association between IGT performance and impulsivity, as measured by the UPPS-P, no such relationship was observed. The prevalence of a loss-avoidance strategy among participants may have contributed to this finding. Notably, several studies have reported weak or non-existent correlations between impulsivity, as assessed through questionnaires, and laboratory-based cognitive measures [23,72,81]. Dang et al. [28] proposed two potential explanations: the limited reliability of behavioral measures or disparities in processes assessed of behavioral tasks and self-administered questionnaires. The latter aspect aligns with the multidimensional nature of impulsivity. Several authors classify impulsivity in three domains: choice impulsivity, action impulsivity and personality trait impulsivity [53]. While the former two domains pertain to laboratory tasks, the latter corresponds to facets evaluated through self-administered questionnaires. Notably, our study reported low reliability on various UPPS-P scales, which is not uncommon for scales comprising few items. However, the Lack of Perseverance scale, yielding the most remarkable results, showed satisfactory internal consistency.

Another noteworthy finding from our results is the increase in oxygenation levels throughout the IGT. Prior research has delineated two distinct phases within the task [14,49]. The initial phase is characterized by ambiguity in deck selection, while in the latter phase,

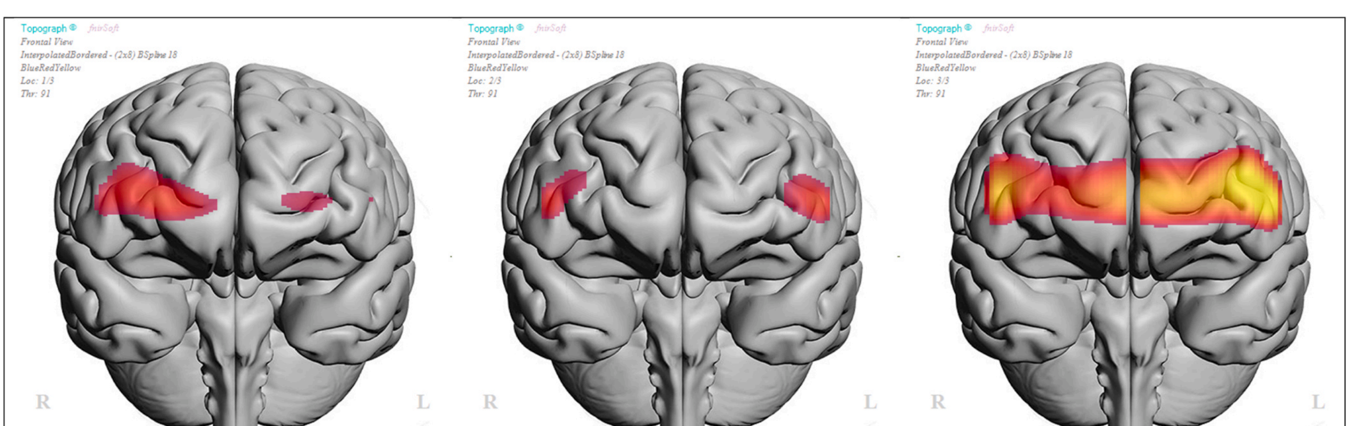

Fig. 3. Mean HbO concentration for lower, middle, and higher Lack of Perseverance scorers during IGT performance.

marked by a better understanding of decks characteristics, emphasizes risk-taking [14]. Our data indicated a primary surge in oxygenation during the task's initial phase, consistent with earlier studies [2,11,46,49,58]. This heightened cortical activation during task's outset may be attributed to attentional mechanisms or response inhibition [11]. Additionally, lateral prefrontal areas implicated in working memory [52] may contribute to this surge. In contrast, the last phase would involve the activation of the ventromedial prefrontal cortex, and the suppression or habituation of lateral areas involved in reinforcement-related learning [48]. Studies using brain stimulation [15], lesions [79], or neuroimaging [46,49,57,76] have highlighted the existence of interhemispheric differences in paradigms such as delay discounting or the IGT. The studies cited above may indicate that the right hemisphere would have a facilitating effect on delaying rewards, while the left hemisphere would favor obtaining immediate rewards. In fact, the right hemisphere has been associated with the avoidance system and processing of negative emotions, while the left hemisphere would be related to the approach system and processing of positive emotions [29,64]. Our study observed similar increases in HbO levels across all quadrants.

Moreover, Lack of Perseverance emerged as the best predictor of prefrontal oxygenation, particularly in the left lateral prefrontal area, with an inverse correlation observed with Lack of Premeditation. These scales exhibited similar correlations with behavioural tasks and psychopathological aspects [12]. Lack of perseverance in young people has been linked to addictive behaviours, such as alcohol and substance abuse, as well as problematic behaviours, like pornography consumption [69]. Furthermore, Lack of Perseverance has been associated with errors caused by interference from non-task related aspects and thus impairing executive attention, while Lack of Premeditation correlates with fewer intrusions [63]. Thus, elevated Lack of Perseverance and reduced Lack of Premeditation may foster intrusive thoughts in the left hemisphere, necessitating higher HbO levels, as suggested by regression analyses. Electrical stimulation of the left prefrontal cortex has been shown to induce intrusive conceptual thoughts via activation of executive function networks [51,65]. Neal & Gable [57] in a mixed, but mostly female, sample found higher left frontal activation related to Lack of Perseverance, Lack of Premeditation, and Negative and Positive Urgency. Notably, previous research has linked increased left frontal activation to less advantageous choices [71]. Suhr & Hammers [76], in a sample of young men and women, found that subjects with low IGT scores had lower activation in both hemispheres, although the differences were significant only in the right hemisphere. Similarly, in a sample of men and women of different ages, Kora Venu et al. [46] found greater left activity during IGT performance, while Bembich et al. [11] found a slight right lateralisation during IGT performance in a group of men and women with a higher mean age than in earlier studies. On the other hand, Bolla et al. [13] saw a greater right dorsolateral activation in men during IGT performance, while in women left activation predominated during IGT performance. Collectively, studies indicate greater left hemisphere activation during IGT performance in samples comprising predominantly young adult women. Our results would be in the same direction. Studies involving mixed or exclusively male samples, however, show a slight right hemisphere predominance.

This study presents some strengths and limitations. The homogeneous sample comprising women with similar educational backgrounds and narrow age ranges, characterized by the moment when adolescence ends and adulthood begins, enhances internal validity. However, future studies should include male participants and individuals from diverse age and educational backgrounds to discern sex and demographic-related disparities. Additionally, while fNIRS offers a less invasive means to assess cerebral oxygenation, it is limited to superficial areas and offers modest spatial resolution. Notably, movement-induced artifacts may affect recording, although filtering techniques mitigate this issue. Also, future research should explore alternative tasks and analyze elements that may influence the brain response. The same brain structures are not activated when a decision must be made as when a gain or loss feedback is obtained. Finally, individual characteristics, such as mood and hormonal variations, would also be important in future studies.

In conclusion, our findings suggest that young adult women predominantly adopt a punishment-avoidance strategy during IGT, with heightened left hemisphere activation, particularly during the task's initial phase characterized by ambiguity. These results would imply that young adult women may employ different cognitive strategies and activate different brain structures compared to men or older women. Furthermore, the predictive value of Lack of Perseverance, alongside Lack of Premeditation, suggests that factors such as intrusive thoughts in ambiguous scenarios may facilitate erroneous decision-making, heightening vulnerability to disorders like addiction.

Ethical approval

All procedures performed were following the ethical standards of the institutional research ethical committee (CEIC) of the University and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all individual participants included in the study.

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CRediT authorship contribution statement

Ferran Balada: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Anton Aluja:** Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Writing – review & editing. **Neus Aymamí:** Conceptualization, Investigation, Writing – review & editing. **Oscar García:** Conceptualization, Writing – review & editing. **Luis F. Garcia:** Conceptualization, Investigation, Methodology, Writing – review & editing.

Declaration of Competing Interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the article.

Data availability

Data will be made available on request.

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