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Using cognitive modelling to investigate the psychological processes of the Go/NoGo discrimination task in male abstinent heroin misusers

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ABSTRACT

Aims To use cognitive modelling to investigate psychological processes underlying decision-making in male abstinent heroin misusers (AHMs). **Design** A case–control study design. **Setting** A drug misuse treatment centre in Taiwan. **Participants** Eighty-eight male AHMs and 48 male controls. **Measurements** Four parameters representing the attention to wins, learning rate, response sensitivity and incentive of heroin-related stimuli from the modified Go/NoGo discrimination task. **Findings** A modified cue-dependent learning (CD) model with four parameters representing attention to wins, learning rate, response sensitivity and incentive of heroin-related stimuli had a lower value of the sum of Bayesian information criterion (showing a better fit) than the original CD model (9555.50 versus 11 192.22, $P < 0.001$). The AHM group had a higher value of the heroin-incentive parameter than the control group (0.26 versus −1.66, $P < 0.05$). The attention to wins and heroin-incentive parameters were associated positively with total commission rate and negatively with total omission rate in the AHM group ($P < 0.001$). **Conclusions** Male abstinent heroin misusers appear to be more influenced by heroin-related stimuli during decision-making than males with no history of heroin misuse.

Keywords Cognitive modelling, cue-dependent learning model, decision-making, heroin misuse, substance misuse, the Go/NoGo discrimination task.

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INTRODUCTION

Chronic drug misuse is associated with decision-making deficits linked to brain regions such as the anterior cingulate cortex (ACC), orbitofrontal cortex (OFC), dorsolateral prefrontal cortex (DLPFC) and basal ganglia [1–6]. Recently, computational and cognitive models have been applied to investigate the underlying psychological and biological mechanisms of human learning and decision-making [3,7,8]. For example, a temporal difference reinforcement learning (TDRL) model, which emphasized the expected rewards of action-situation associations, was applied to explain the mechanism of conditioning learning [7].

Choice tasks such as the Iowa Gambling Task (IGT) [9] and the Go/NoGo discrimination task [10,11] are used frequently to simulate decision-making behaviours. The expectancy-valence (EV) model [12], which captures subjective motivational and cognitive processes involved in decision-making, was used to analyse drug misusers' performance on the IGT [12–15]. A variant of the EV model, called the cue-dependent learning (CD) model [11], was developed to analyse the data of the Go/NoGo discrimination task, which measures participants' ability to learn to respond to 'good' cues (numbers presented on the screen) that produce gains and refrain from responding to 'bad' cues that produce losses. Both the EV and CD models identified three parameters to describe impacts of

motivational, learning and response processes on participants' decision-making in these tasks. Cognitive modelling has helped to differentiate various psychological processes underlying decision-making on the IGT in cannabis and cocaine misusers [16,17].

Heroin is one of the most commonly misused opiates. Few studies have applied cognitive modelling to investigate decision-making in heroin misusers. Moreover, previous studies on drug misusers' decision-making using cognitive models for the IGT [16,17] did not examine the effects of drug-related stimuli. The incentive–sensitization theory suggests that drug-related cues acquire incentive salience and seize drug misusers' attention powerfully [18–21]. Attentional bias towards substance-related cues may temporarily cause impulsive decision-making [22] and decrease inhibitory control in substance misusers [23]. To investigate the influences of heroin-related stimuli on decision-making in heroin misusers, we modified the Go/NoGo discrimination task [10,11] by replacing the number stimuli with picture stimuli comprising heroin-related and neutral pictures.

Yechiam *et al*. [11] developed the CD model, a variant of the EV model, for analysing the Go/NoGo discrimination task. Their work revealed that the CD model was more accurate than the EV model in fitting the data of the Go/NoGo discrimination task [11]. The CD model has three model parameters. The first parameter, the attention to wins parameter, represents the strength of motivation for rewards. The CD model, as well as the EV model, assumes that decision-makers form an expectancy valence for a given trial based on wins and losses of all previous trials and the expectancy valence will then influence their choice on the next trial [12,16,24,25]. The decision-maker's valuation of the valence of payoffs depends on the amount of attention he pays to rewards. The second parameter, the learning rate parameter, represents one's ability to learn contingencies between actions and outcomes. The CD model proposes that participants learn by associating a specific positive or negative outcome with each cue in the task [11]. In the CD model, a faster (larger) learning rate led to better performance. The third parameter, the response sensitivity parameter, describes the decision-maker's response style. In the CD model, higher response sensitivity indicates that decision-makers' choices become more influenced by their expectancies over time, whereas lower response sensitivity indicates that decision-makers' choices are random and independent of their expectancies. The present study added an additional parameter, the heroin-incentive parameter, which represents the incentive of heroin-related stimuli into the CD model to form a modified CD model. The higher value of this parameter indicates that decision-makers are more attracted and influenced by heroin-related stimuli during decision-making.

Heroin and psychostimulants (e.g. cocaine) have different pharmacodynamic profiles [26,27] and influence decision-making in diverse ways [28]. For example, cocaine largely increases dopamine levels in the dorsolateral striatum which underlie the formation of a habit-like response [29]. Cocaine misusers may overestimate the expected rewards of drugs and exhibit habitual drug-use behaviours [28]. Heroin also increases dopamine levels in the nucleus accumbens, which causes euphoria [26]. However, heroin misusers experience intense physical and emotional pain, which become the forces driving drug use [29]. Heroin misusers may overvalue the expected drug effects (i.e. reducing pain) and ignore other alternative actions to achieve this goal. Thus, heroin-seeking is goal-directed rather than habitual [8]. Moreover, according to the incentive–sensitization theory [18], heroin misusers may be oversensitive to heroin-related cues. Exposure to heroin-related cues may elicit strong cravings in heroin misusers and increase their tendency to act impulsively on such cues regardless of payoff.

We used the original and modified CD models to analyse the modified Go/NoGo discrimination task performance in abstinent heroin misusers (AHMs) and controls. As mentioned above, heroin-seeking is driven by the motivation to eliminate pain rather than pursue rewards. Heroin misusers demonstrate hypersensitivity to heroin-related cues and heightened consideration of drug-related choices during decision-making [28]. We hypothesized that the modified CD model that included a parameter capturing the impact of heroin-related stimuli would fit the data more accurately than the original CD model. The AHMs would be more influenced by heroin-related cues during decision-making and exhibit more approach behaviours in response to those cues than the controls. Moreover, we hypothesized that the AHMs would not show the lower response sensitivity that was observed in psychostimulant misusers [16]. Lower response sensitivity reflects an impulsive response style associated with trait impulsivity [17]. Previous studies have indicated that increased trait impulsivity is not necessarily associated with heroin addiction [30–34].

METHOD

Participants

Eighty-eight male AHMs were recruited from the inmate population at the Sindian Drug Abuser Treatment Centre, Taiwan. The inmates at this treatment centre are isolated from the outside community to prevent them from accessing drugs, and random urine screenings are performed to ensure drug abstinence. One hundred and two inmates completed a screening questionnaire to

provide demographic and substance use history. Inmates were included as AHMs if they (i) had a history of heroin use, (ii) reported heroin as their main drug of choice and (iii) were not taking any opioid substitution treatment. Fourteen inmates were excluded because heroin was not their main drug of choice. The majority of the AHMs reported a history of heavy heroin use (83% daily) and most injected the heroin (71.6%). The mean age at first heroin use was 25.1 years [standard deviation (SD) = 7.63]. Approximately half (46.59%) of the AHMs reported a history of other drug use. The mean duration of abstinence was 9.1 months (SD = 4.7).

Forty-eight male controls without a history of illegal drug use, alcohol misuse or alcohol dependence were recruited from the local community. The exclusion criteria for AHMs and controls included (i) reported current or past psychiatric disease (excluding substance-related disorders for AHMs) or (ii) an inability to comply with study instructions.

Measures

Raven's Standard Progressive Matrices (RSPM) [35]

We used the RSPM to estimate participants' non-verbal IQ scores. The Chinese version of the RSPM revealed good concurrent validity and reliability [36].

The modified Go/NoGo discrimination task

Participants were instructed to decide whether or not to respond (by pressing a button) to the stimulus presented on the screen. Stimuli consisted of four 'good' pictures (two heroin-related and two neutral) and four 'bad' pictures (two heroin-related and two neutral). Each picture was repeated 10 times in random order for 80 experimental trials. In each trial, a picture was displayed for 2.5 sec or until participants responded. Responding to a 'good' cue generated the message 'You win NT$5 dollars!' (i.e. US$ 0.17) and a high-pitched tone (400 Hz); responding to a 'bad' cue generated the message 'You lose NT$5 dollars!' and a low-pitched tone (100 Hz). Visual and auditory feedbacks for participants' responses remained for 2 sec. The intertrial interval was 1 sec. When a participant did not respond, neither wins nor losses were produced. Each participant was allotted NT$100 dollars at the beginning of the task. Prior to the experimental trials, participants completed 12 practice trials involving eight presentations of 'good' pictures (each of the 'good' pictures was presented twice) and four presentations of 'bad' pictures to learn the contingencies between cues and outcomes. The ratio of 'good' to 'bad' stimuli presented in the practice trials was identical to that used by Helmers *et al*. [10].

Materials

The neutral pictures were selected from the international affective picture system (IAPS: 5890, 6150, 7130, 7700) [37]. The heroin-related pictures were chosen from a set of images of heroin and heroin paraphernalia used in an earlier study on heroin addiction [38]. The pictures subtended a visual angle of $13.8° \times 10.4°$.

Procedure

This study was approved by the Taipei City Hospital Institutional Review Board. All participants provided written informed consent. After completing the RSPM test, participants were seated 50 cm in front of a computer to complete the computerized task.

Cognitive modelling of the task

Two cognitive models were compared. Model 1 is the CD model [11] and model 2 is the modified CD model. The parameters of the models are described below.

The attention to wins parameter

$$v(t) = W * R(t) + (1 - W) * P(t) \qquad \text{(eqn 1)}$$

Equation 1 is identical to the formula representing the valence in the EV model [12]. The term $v(t)$ denotes the valence experienced on trial t, and W represents attention to wins relative to losses. Rewards and punishments received on trial t are denoted by $R(t)$ and $P(t)$, respectively.

The learning rate parameter

The decision-maker forms separate expectancies for responding and not responding to each cue (11). Only when participants respond to a cue, the expectancy of that cue is updated:

$$E_j(t) = E_j(t-1) + \Phi * \delta_j(t) * [v(t) - E_j(t-1)] \qquad \text{(eqn 2)}$$

where $E_i(t)$ denotes the expectancy of cue j on trial t. The new expectancy equals the sum of previous expectancies and an adjustment resulting from the prediction error $v(t) - E_i(t-1)$ [11]. The learning rate, Φ, controls the amount of adjustment. When cue j appears on trial t, a dummy variable $\delta_i(t)$ equals 1, and the expectancy of cue j is updated; when cue j is absent on trial t, $\delta_i(t)$ equals 0, and the expectancy of cue j does not change.

The response sensitivity parameter: choice consistency

The probability of responding or not responding to cue j that appeared on trial $t + 1$ is calculated as follows:

Table 1 Demographic and substance use characteristics.

	AHM group (n = 88)	*Control group (n = 48)*	*Comparison*	*P-value*
Age (years)	40.81 (8.36)	39.04 (9.76)	$t_{(134)} = 1.11$	0.270
Age range	21–62	22–57		
Educational level				
Elementary school or lower	5.7%	0%	$\chi^2_{(3)} = 49.24$	<0.001
Middle school	48.9%	8.3%		
High school	43.2%	47.9%		
College school or higher	2.2%	43.8%		
RSPM	42.78 (7.50)	48.20 (11.22)	$t_{(134)} = -3.37$	0.001

AHM = abstinent heroin misuse; RSPM = Raven's Standard Progressive Matrices.

$$\Pr = \frac{exp(\theta * E_{j,go})}{\exp(\theta * E_{j,go}) + exp(\theta * E_{j,nogo})} E_{(NOGO)} = 0$$

$$\theta(t) = \left(t/10\right)^c \quad \text{(eqn 3)}$$

where $E_{j,k}(t)$ represents the expectancy of either responding or not responding to cue j on trial t, and the expectancy of not responding equals 0. The consistency between choices and expectancies is denoted by θ. The choice consistency changes with experience, and $\theta(t) = \left(t/10\right)^c$ describes this change. The response sensitivity parameter, c reflects the extent to which the decision maker's choices converge toward his expectancies.

The heroin-incentive parameter

We included an additional parameter to represent the incentive value of heroin-related stimuli in equation 3. The new formula, equation 4, is presented as follows:

$$\Pr = \frac{\exp(\theta * E_{j,go} + \delta_{Heroin}(t) * \mathrm{U})}{\exp(\theta * E_{j,go} + \delta_{Heroin}(t) * \mathrm{U}) + \exp(\theta * E_{j,nogo})} E_{(NOGO)} = 0$$

$$\theta(t) = \left(t/10\right)^c \quad \text{(eqn 4)}$$

where U is the heroin-incentive parameter, which directly influences the probabilities of responding and not responding in each trial. The incentive of heroin-related stimuli is assumed to be a fixed value that is not influenced by the learning process.

In sum, model 1 (i.e. the CD model) consists of W, Φ and c parameters specified by equations 1, 2 and 3; model 2 consists of W, Φ, c and U parameters specified by equations 1, 2 and 4.

Statistical analysis

Group differences on demographic variables were examined using t-tests and χ^2 tests. Group differences on the task performance (error rates) were investigated using t-tests or a univariate analysis of covariance (ANCOVA). ANCOVAs were used when the demographic variables were significantly different between the two groups. A commission error is defined as failure to inhibit to respond to a 'bad' cue, and an omission error is defined as failure to respond to a 'good' cue. The average rates of errors were calculated as the number of errors of a certain type (e.g. commissions or omissions) divided by the number of relevant cues (e.g. good or bad cues).

Model-fitting and parameter estimation were implemented with the PROC NLIN procedure of SAS software. The original and modified CD models and a random guessing (baseline) model were fitted to the data. Parameters of each model were estimated for each participant separately using a maximum likelihood method. The model parameters from the most accurate model were then used for subsequent analyses. We conducted t-tests or ANCOVAs to examine group differences for model parameters. Pearson's correlations were calculated to evaluate the associations of model parameters with task performance. The calculations for correlations, t-tests, χ^2 tests and ANCOVAs were performed using SPSS software. To ensure that this study has adequate statistical power, a power analysis was performed using G power software.

RESULTS

Group characteristics

Demographic variables of participants are summarized in Table 1. There was no significant age difference between groups. The two groups differed significantly on educational level and estimated non-verbal IQ.

Performance on the modified Go/NoGo discrimination task

Univariate ANCOVAs with educational level and estimated non-verbal IQ as covariates were conducted for the

Table 2 Means and standard deviations of error rates on the modified Go/NoGo discrimination task.

Error rate	*AHM group (n = 88)*	*Control group (n = 48)*	$F_{(1, 132)}$	*P-value*
Omission				
Heroin	0.16 (0.23)	0.25 (0.33)	8.28	0.005
Neutral	0.09 (0.22)	0.07 (0.18)	0.96	0.329
Commission				
Heroin	0.31 (0.23)	0.22 (0.20)	1.95	0.165
Neutral	0.18 (0.19)	0.16 (0.18)	0.39	0.533
Total omission	0.13 (0.15)	0.16 (0.21)	2.99	0.086
Total commission	0.24 (0.18)	0.19 (0.17)	0.28	0.599
Total error	0.18 (0.12)	0.17 (0.12)	0.91	0.341

AHM = abstinent heroin misuse.

Table 3 Parameter values for model 2.

	AHM group (n = 88)	*Control group (n = 48)*	$F_{(1, 132)}$	*P-value*
Attention to wins (*W*)	0.60 (0.31)	0.66 (0.26)	2.66	0.105
Learning rate (Φ)	0.63 (0.40)	0.70 (0.36)	<0.01	0.949
Response sensitivity (*c*)	2.95 (0.62)	2.83 (0.57)	0.74	0.392
Heroin-incentive (*U*)	0.26 (4.08)	−1.66 (9.68)	4.91	0.028

AHM = abstinent heroin misuse; *W* = attention to wins parameter; Φ = learning rate parameter; *c* = response sensitivity parameter; *U* = heroin-incentive parameter.

error rates (Table 2). The results indicated that the AHMs exhibited lower omission rates than the controls for heroin-related pictures but not for neutral pictures. No other significant group differences were found.

Model comparison

A Bayesian information criterion (BIC) was used as a model evaluation index. The model with a lower value of BIC is the model that performed better than the others [39,40]. The sum of BIC across all participants (BIC-sum) for each model was calculated. Both model 1 (BIC-sum = 11 192.22) and model 2 (BIC-sum = 9555.50) performed better than the baseline model (BIC-sum = 14 682.90). Because models 1 and 2 are nested, we computed a χ^2 test of the difference between models 1 and 2 in the −2*log-likelihood. If model 2 improves the accuracy of fitting, the −2*log-likelihood of model 2 will be significantly lower than that of model 1. The result of the χ^2 test revealed a significantly improved fit of model 2 over model 1 ($\chi^2 = 1636.72$, d.f. = 136, $P < 0.001$).

Group comparisons on model parameters

ANCOVAs indicated that the AHM group had a larger heroin-incentive parameter than the control group (Table 3). There were no significant differences between the groups in the other model parameters.

Associations of model parameters with task performance

Correlations between model parameters and error rates are summarized in Table 4. In the AHM group, attention to wins and heroin-incentive parameters were associated positively with total commission rate but negatively with total omission rate. Specifically, lower omission and higher commission rates for neutral pictures were associated with higher attention to wins, and lower omission and higher commission rates for heroin-related pictures were associated with higher value of the heroin-incentive parameter in the AHM group. The attention to wins was not correlated significantly with error rates of the controls. Higher values of the heroin-incentive parameter were associated with lower omission and higher commission rates for heroin-related pictures in the control group. Higher learning rates were associated with lower total omission and lower total commission rates in both groups. The response sensitivity was not correlated significantly with participants' error rates.

Power analysis

The power analysis demonstrated that the sample sizes ($n1 = 88$, $n2 = 48$) would be needed to detect a medium effect size with power of 0.80 and alpha at 0.05.

Table 4 Correlations between the parameters and error rates.

	AHM group (n = 88)				*Control group (n = 48)*			
	Parameters				*Parameters*			
Error type	*W*	*Φ*	*c*	*U*	*W*	*Φ*	*c*	*U*
Omission								
Heroin	−0.04	−0.25*	−0.18	−0.68***	0.18	−0.25	−0.08	−0.51***
Neutral	−0.33**	−0.25*	0.16	0.17	−0.15	−0.27*	−0.23	0.04
Commission								
Heroin	0.15	−0.27*	−0.11	0.48***	0.12	−0.24	−0.16	0.29*
Neutral	0.28**	−0.44***	0.05	0.04	0.09	−0.35*	0.08	−0.06
Total omission	−0.30**	−0.38***	−0.01	−0.43***	0.05	−0.34*	−0.16	−0.41**
Total commission	0.24*	−0.43***	−0.04	0.31**	0.11	−0.32*	−0.06	0.17
Total error	−0.01	−0.57***	−0.05	−0.01	0.13	−0.50***	−0.16	−0.24

AHM = abstinent heroin misuse; *W* = attention to wins parameter; Φ = learning rate parameter; *c* = response sensitivity parameter; *U* = heroin-incentive parameter. *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

DISCUSSION

This study used cognitive modelling to investigate psychological processes underlying the performance of AHMs and controls on the modified Go/NoGo discrimination task. To our knowledge, this study is the first to use cognitive modeling to investigate decision-making in heroin misusers. We found that the modified CD model that included an additional parameter to capture the influence of heroin-related stimuli on decision-making fitted the data more accurately than the original CD model.

The AHM group had a higher value on the heroin-incentive parameter than the control group. The two groups did not differ in the attention to wins, learning rate or response sensitivity parameters. This study suggests that the AHMs pay more attention to heroin-related cues and their decisions are more influenced by those cues than the controls. This finding is consistent with the incentive–sensitization theory, which suggests that drug misusers are highly attracted to drug-related cues [18–21]. Several studies have reported attentional biases towards substance-related cues in substance misusers [41–43].

The AHMs did not differ from the controls in their attention to rewards. Previous studies using other tasks have demonstrated that cannabis and cocaine misusers exhibited hypersensitivity to rewards [16,17,44]. This study suggests that not all drug misusers exhibit a greater preference for rewards than controls. Because the task we used is different from the previous studies, future studies should apply this task to examine decision-making in users of other drugs.

According to Yechiam *et al.* [11], increased attention to rewards was associated with more commission and fewer omission errors, because individuals paying more attention to rewards tended to take risks to obtain uncertain rewards (i.e. responding to a cue under uncertainty). Our results indicated that only the AHMs' decision-making errors are associated with attention to rewards. Moreover, for the AHMs, increased attention to rewards was associated with more commission and fewer omission errors for neutral cues but not for heroin-related pictures. More commission and fewer omission errors for heroin-related cues were correlated with higher attention to heroin-related stimuli. These findings imply that when the AHMs are exposed to heroin-related cues their heightened attention to heroin-related stimuli may decrease the influence of other motivational processes (e.g. pursuing rewards) on their decisions.

Although the AHMs were more attracted by heroin-related cues, they did not make more commission errors to heroin-related cues than the controls. This result does not support the argument that attentional bias towards heroin-related cues results in impulsive decision-making and decreased inhibitory control [22]. According to Redish *et al.* [28], heroin-seeking is goal-directed rather than habitual. Exposure to heroin-related cues does not automatically induce approach behaviours to those cues in the AHMs. When the AHMs are exposed to heroin-related cues, increased attention to those cues may elicit craving and thus increase the probability of approach behaviours to those cues [45]. However, whether or not drug-related cues elicit craving is modulated by perceived drug availability [22]. When drug availability is perceived as low, subjective cravings will not occur [46,47]. All the AHMs in this study were inmates living in the treatment centre and were isolated from the outside community to prevent drug access. Low perceived heroin availability may result in a decreased likelihood of craving and approach behaviours in the AHMs.

Interestingly, the AHMs made fewer omission errors to heroin-related cues. One explanation is that heightened attention to heroin-related cues increases the likelihood of approaching those cues in the AHMs. However, this explanation does not account for the absence of group difference in the commission errors to heroin-related cues. Another possible explanation is due to a conflict between the controls' beliefs about heroin-related stimuli and the identity of these stimuli in the task. The controls may possess negative beliefs about heroin-related stimuli (e.g. heroin causes harmful consequences). When heroin-related cues are designated as 'good', the controls are more likely to experience such conflict and make fewer correct responses to those cues. Future studies should include measures of attitudes and emotional reactions to drug-related stimuli to clarify their potential effects on decision-making performance.

In conclusion, this study indicates that the AHMs pay more attention to heroin-related stimuli and their decisions are more influenced by heroin-related stimuli than the controls. This study also suggests that the incentive value of heroin-related cues strongly influences the AHMs' decision-making, even though they may exhibit intact decision-making performance. The incentive value of heroin-related cues has been reported to be sustained in heroin misusers even after prolonged abstinence [48]. The results of our study have practical implications; they point to the importance of including cognitive strategy training to reduce the impact of heroin-related cues as part of relapse prevention programmes [48,49]. Assisting heroin misusers in identifying the negative consequences of drugs may help to devalue the expected drug effects. Cognitive emotion-regulation strategies may provide alternative actions to drug use for reducing emotional pain.

This study has limitations. First, all the AHMs were male inmates who lived in the drug treatment centre. Further studies should include various subgroups of heroin misusers who receive maintenance treatment or live in different environments. The results should also be replicated with female heroin misusers. Secondly, the results from the present study should be interpreted with caution, because approximately half the AHMs reported a history of other drug use. Thirdly, the amount of money won and lost following the participants' responses may have been too small to induce participants' motivation to pursue rewards. This factor should be taken into account in future research.

Declaration of interests

None.

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