Executive functioning in addicts following health mobile cognitive stimulation

Evidence from alcohol and heroin patients

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***Abstract*—The consequences of alcohol and opioid dependence are severe and may range from physical diseases to neuropsychological deficits in several cognitive domains. Alcohol and opioid abuse has also been related to brain dysfunction specifically in the prefrontal cortex. In order to assess these deficits and the application of a novel approach of cognitive stimulation to alcohol and heroin addicts, we have carried out a neuropsychological intervention program with mobile technology. Sixty-six alcohol and heroin addicts in rehabilitation were submitted to cognitive stimulation during four weeks in a three-day/week basis. The results of the neuropsychological assessments showed an overall increase of general cognitive abilities and executive functioning following cognitive stimulation, being more pronounced in alcoholics who were assigned to treatment group with mobile technologies in comparison to paper-and-pencil group and controls. These results support the usefulness of mobile serious games for neuropsychological stimulation to overcome executive dysfunction in patients with alcohol and heroin dependence.**

Keywords-alcohol; heroin; addiction; cognitive stimulation; executive function; mobile health

I. INTRODUCTION

Alcohol and heroin abuse are a global health problem and their consequences in terms of excessive mortality and morbidity are currently a burden to society. The negative effects of these substances on brain functioning are severe and range from decreased neural connectivity [1] to cell death due to apoptotic gene expression [2]. These effects are particularly evident in the prefrontal structures of heroin addicts [3], being therefore associated with deficits in executive function [4] yielding both functional and behavioural consequences.

Heroin is an opiate that has analgesic and sedative properties; however it is the strong feeling of euphoria induced by this substance that leads to addiction [5]. This narcotic acts in the reward neural system by increasing dopamine release in the corticostriatal circuit, particularly in the nucleus accumbens [6]. The repeated exposure to the heroin molecule prompts the hyperactivation of dopaminergic and glutamatergic neurotransmitter systems [5], requiring increased drug intake in order to maintain pleasure. In light of this, some studies [e.g., 7] consider drug addiction as a chronic relapsing disorder whereby addicted individuals act impulsively, automatically and compulsorily to drug related cues, leading to a vicious cycle of abuse, addiction, dependence and relapse.

Alcohol dependence syndrome has also been related to brain dysfunction specifically in the prefrontal cortex [8]. There is evidence through neuroimaging and neuropsychological studies that suggests a decrease in specific cognitive abilities [for a review, see 8], particularly those associated to the frontal lobes (i.e., executive control, impulsivity and attention).

Executive functioning comprises several cognitive domains, such as working memory, attention, planning, decision-making and inhibitory control [9]. There is evidence indicating that heroin addicts act impulsively, producing more false alarm rates in a suppression task [10] and reveal poorer impulse control than normal subjects [11], and these consequences may last for months after heroin withdrawal [5].

The studies presented above highlight the neuropsychological consequences of alcohol and opioid abuse, but the literature is unclear about the effectiveness of neuropsychological rehabilitation in alcohol and heroin addicts. Training and stimulating cognitive functions that have been compromised by the effects of the drugs seems to be one option [12, 13, 14]. Serious games (SG) i.e. games that were designed for other purposes than gaming, also seems to be a sound way to do it. In fact, several have already been designed and applied to stroke and traumatic brain injury rehabilitation [e.g., 15, 16]. However, for addiction related cognitive impairments, studies are still scarce.

On the other hand, the increasing development of both hardware and software has enabled these SG to be played on mobile devices [17]. The feature of mobility would be an added bonus to therapy. It would allow training outside the rehabilitation facilities and the dissemination of these services throughout the rehab community.

Under this light, this paper reports on the preliminary results of a cognitive stimulation program that was devised to improve executive functioning in heroin and alcohol abusers with mobile SG applications.

II. METHOD

A. Participants

Sixty-six patients who were either alcohol or drug addicts participated in this study. Of these, 61 had been diagnosed with alcohol dependence (52 males and 9 females, M^{age} = 45.64 years, SD^{age} = 9.67 with an average of eight years of formal education, with a SD = 4.48), and the remaining were 5 male heroin addicts (M^{age} = 45.00 years-old; SD^{age} = 13.47 and nine years of formal education, with a SD = 4.16). The patients diagnosed with alcohol dependence were randomly distributed between three different groups, namely: (a) traditional paper-and-pencil cognitive stimulation; (b) health mobile cognitive stimulation; and (c) waiting list. The four patients who were heroin addicts were subjected only to health mobile cognitive stimulation.

B. Measures

In order to study the existence of a global cognitive impairment in alcohol and heroin patients, each patient was assessed through a brief screening test: the Mini Mental Examination Test - MMSE [18]. This has been validated for the Portuguese population [19]. The MMSE assesses the aspects of mental function that are related to cognition, allowing an overall assessment of cognitive performance throughout 30 items grouped into 6 categories - Orientation, Retention, Attention and Calculation, Language and Visual-spatial abilities. The maximum score is 30 points and the current cutoff values for the Portuguese population were estimated according to age and education, specifically for people aged over forty years: (a) 0-2 years of schooling – 22; (b) 3-6 years of schooling – 24; and (c) more than 7 years of schooling – 27.

The assessment of frontal brain functioning was carried out with the Frontal Assessment Battery – FAB [20]. The FAB assesses conceptualization, mental flexibility, motor programming, sensitivity to interference, inhibitory control and environmental autonomy. The maximum score is 18 points.

Cognitive flexibility was assessed through the *Wisconsin Card Sorting Test* - WCST [21], which evaluates cognitive functions in several executive domains, namely the ability to develop and maintain appropriate strategies of problem solving and planning and the ability to use environmental feedback to modify a cognitive response. In the current study we used the short-version (WCST-64).

The speed of processing and attentional abilities were also evaluated through the Color Trail Test - CTT [22]. The CTT assesses focused and divided attention, sequencing, mental flexibility, visual search and motor functions.

C. Procedure

The patients were collected from two different institutions for treatment of alcohol and heroin dependence in Lisbon region, Portugal. Each participant was assessed twice with at least 30 days between evaluations. The exercises performed in each of these groups were selected in order to develop cognitive abilities related to executive functioning, which is believed to be impaired in alcohol and heroin addicts. The hardware used to perform the exercises consisted of Samsung Galaxy 10.1" tablets. The study design unfolded throughout 10 sessions (three sessions per week) of 50-60 minutes each. The mobile cognitive stimulation program consisted of several mobile applications running on Android OS that were developed according to traditional paper-and-pencil rationales. The applications were developed using Unity 2.5 (Unity Technologies™). An example of these tasks can be found below (Figure 1).

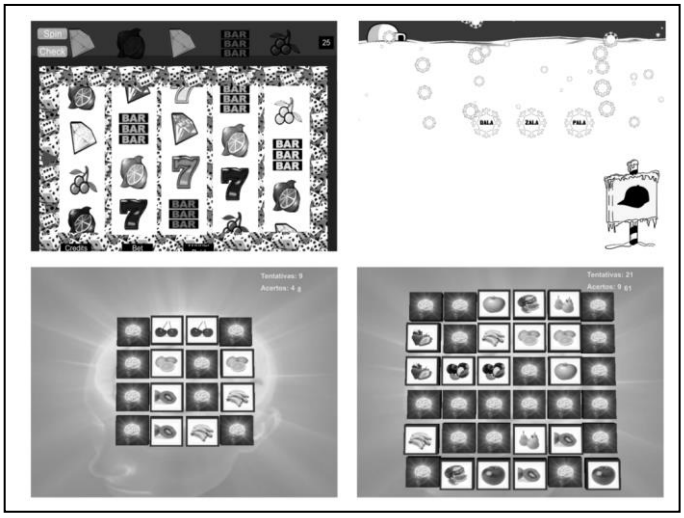

Figure 1. Slot machine (top-left) for attention, visual memory task (bottom-left and bottom-right with increased difficulty) for working memory and the word-object correspondence (top-right) for logical reasoning. These exercices are available from http://labpsicom.ulusofona.pt.

The therapist's role was to explain sessions' procedures and to assess the session outcome. The neuropsychological evaluation was performed in the first session, where the MMSE, FAB, WCST and the CTT were applied to the participants. The following 10 sessions were used for cognitive stimulation (i.e., traditional paper-and-pencil cognitive stimulation vs. health mobile cognitive stimulation). Each session started with a brief training period in which participants were able to acquire interaction skills with the touchscreen devices. Participants' responses were registered using the device input from the touchscreen.

Cognitive stimulation in each session comprised attention, working memory and logical reasoning exercises. The level of difficulty of each task increased progressively throughout the cognitive stimulation rationale. In the last session, the same neuropsychological tests used in the first assessment were again applied (see Table I).

III. Results

The variables assessed during the neuropsychological evaluation were submitted to non-parametric statistical analyses due to non-normal distribution of the dependent variables. The dependent variables were related to the neuropsychological assessment carried out through the overall score of the MMSE and the FAB, the hit percentage in the WCST and mean errors during the execution of the CTT.

Given that alcohol and heroin patients' groups are unbalanced, we avoided any comparison between these two groups. Instead, we performed a comparison of neuropsychological performance in the first assessment within the sample of alcohol patients, namely for the traditional paper-and-pencil cognitive stimulation, the health mobile cognitive stimulation and the waiting list. Independent non-parametric tests based on Kruskal-Wallis H statistic were carried out in order to study differences between these groups for neuropsychological variables. The Table II depicts the mean scores and standard deviations obtained through the neuropsychological assessment between experimental conditions in alcoholics.

The one-way Kruskal-Wallis analysis showed no statistically significant differences between experimental groups in the alcohol patients' sample on general cognitive ability (overall score from the MMSE), frontal functions (overall score from the FAB), cognitive flexibility (hit percentage in the WSCT) and attention (mean errors in the CTT) ($p > 0.05$).

The two neuropsychological assessments were compared independently for traditional, mobile and waiting list groups with two related-samples non-parametric test based on Wilcoxon sign-rank statistic. For alcohol addicts in the traditional paper-and-pencil group, the Wilcoxon statistic revealed a statistical significant increase in hit percentage in the WCST ($Z_W = -2.201$; $p < 0.05$), indicating better cognitive flexibility in the second assessment. No statistically significant differences were found for the overall score of the MMSE and the FAB, or for attention assessed with mean errors in the CTT. As regards the alcohol addicts in the health mobile group, the same procedure identified a statistical significant increase in the overall score from the MMSE ($Z_W = -2.512$; $p < 0.05$), the overall score from the FAB ($Z_W = -3.121$; $p < 0.01$) and in hit percentage from the WSCT ($Z_W = -2.160$; $p < 0.05$). No statistically significant differences were found for mean errors in the CTT ($p > 0.05$). These results suggest an increase in general cognitive ability, executive functioning and flexibility in patients subjected to health mobile cognitive stimulation. The waiting list group revealed an increase in general cognitive ability in the second assessment ($Z_W = -2.488$; $p < 0.05$). No other effects were observed ($p > 0.05$).

As regards the heroin-addicted sample, the comparison between the two neuropsychological assessments showed a marginally significant increase in the overall score from the FAB ($Z_W = -1.786$; $p = 0.07$), which suggests a better executive function following the health mobile cognitive stimulation. No other effects were observed in the remaining neuropsychological domains. The Table III represents the descriptive data from the neuropsychological assessments in heroin addicts.

IV. Conclusions

The current experiment was designed to study the effectiveness of a cognitive stimulation program in heroin and alcohol abusers' executive functioning in mobile SG applications. According to previous studies, alcohol and heroin addiction may impair information processing in the prefrontal areas, such as the dorsolateral prefrontal cortex and the anterior cingulate cortex, that are thought to be related to executive functioning in cognitive domains that range from attention and working memory to higher-order functions of reasoning and decision making. In this study we intended to evaluate the general cognitive ability of alcohol and heroin addicts following different approaches of cognitive stimulation, namely when compared traditional paper-and-pencil vs. health mobile cognitive stimulation using tablets.

The comparison between the three experimental groups of alcoholics suggested that these groups were comparable in the initial stage of the program. However, the comparison between the initial and the final evaluation showed a more pronounced increase of cognitive abilities in the alcoholics subjected to health mobile therapy, with improvements in general cognitive ability and executive functioning. Also, heroin addicts showed better executive functioning following the mobile cognitive stimulation, but probably due to the lack of statistical power, no other effects were observed in this sample.

These findings suggest that the neuropsychological effects of substance abuse on brain structure are reversible and can be rehabilitated following cognitive stimulation approaches. In addition, our study has the hallmark of comparing the effects of a diversity of approaches to cognitive stimulation in alcoholics. Despite the small size of the heroin patients' sample, the overall results are encouraging and suggest an improvement in frontal cognitive functioning in heroin addicts but also in alcoholics, especially those subjected to a cognitive stimulation program with mobile technology. These data support the use of cognitive stimulation approaches outside rehabilitation facilities in order to complement and enhance the capabilities of existing rehabilitation services.

TABLE I. Cognitive Stimulation Program - sessions

Session	Name
1	Slot[4]/Memory[5]/Parking Zone[7]/Under pressure[8]/Snowflakes[2]
2	Slot[4]/Memory[5]/Under pressure[8]/Snowflakes[2]/Right order[3]
3	Slot[4]/Memory[5]/Hanoi Tower[6]/Snowflakes[2]/Right order[3]
4	Slot[4]/Memory[5]Odd-even[3]/Parking Zone[7]/Snowflakes[2]
5	Basket[3]/Odd-even[3]/Hand tricks[8]/Brick[1]/Memory[5]
6	Hanoi Tower[6]/Parking Zone[7]/Under pressure[8]/Memory[5]/Snowflakes[2]
7	Parking Zone[7]/Under pressure[8]/Selective transfer[4]/Memory[5]/Snowflakes[2]
8	Selective transfer[4]/Brick[1]/Hand tricks[8]/Memory[5]
9	Parking Zone[7]/Brick[1]/Hand tricks[8]/Memory[5]
10	Slot[4]/Memory[5]/Parking Zone[7]/Under pressure[8]/Snowflakes[2]

Main domains: 1) perception; 2) processing speed; 3) reasoning; 4) attention; 5) memory; 6) decision making; 7) planning; 8) spatial vision.

TABLE II. NEUROPSYCHOLOGICAL ASSESSMENT BETWEEN EXPERIMENTAL CONDITIONS IN ALCOHOLICS

Neuropsycho-logical data	Initial assessment			Final assessment		
	TCS	***MCS***	***WL***	***TCS***	***MCS***	***WL***
MMSE score	26.9 (1.9)	26.5 (3.0)	26.4 (2.7)	28.1 (1.2)	27.8 (2.0)	27.8 (1.8)
FAB score	15.7 (1.4)	13.9 (2.9)	14.0 (2.9)	15.7 (1.4)	15.5 (2.4)	15.0 (2.4)
WSCT hit%	40.9 (8.6)	52.8 (20.1)	52.5 (17.7)	54.5 (13.5)	64.2 (19.0)	60.1 (19.3)
CTT mean errors	0.1 (0.4)	0.2 (0.6)	0.2 (0.7)	0.0 (0.0)	0.1 (0.2)	0.1 (0.2)

Note: The data are presented as means± standard deviations in brackets. TCS – traditional paper-and-pencil cognitive stimulation; MCS – mobile cognitive stimulation; WL – waiting list.

TABLE III. NEUROPSYCHOLOGICAL ASSESSMENTS IN HEROIN ADDICTS

Neuropsychological data	Initial assessment	Final assessment
	Mean (± SD)	***Mean (± SD)***
MMSE score	29.0 (0.7)	29.4 (0.9)
FAB score	12.8 (2.6)	15.6 (2.5)
WSCT hit%	62.0 (21.2)	78.4 (16.6)
CTT mean errors	0.4 (0.5)	0.0 (0.0)

Note: The data are presented as means± standard deviations (SD).

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