Probing distraction to cognitive control using real-time fMRI

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Introduction. Real-time functional MRI (rtfMRI) feedback has been used in preliminary studies to help individuals learn to gain greater voluntary control of their brain activity in the context of chronic pain [1], tinnitus [2], emotion [3], movement [4], and a variety of other applications. The design of each particular neurofeedback paradigm involves choices such as which brain region(s) to target, how and when to provide visual feedback (e.g. intermittent vs. continuous), the fMRI task instructions, and whether or not to use visual cues. In the case of addiction therapy, these choices are particularly challenging. For example, it is unclear which brain regions could be targeted to help patients gain increased control of craving modulation. Among the candidates are the deep limbic structures (e.g. amygdala) which are known to be particularly susceptible to noise. Furthermore, frequent modulation of craving (e.g. with 30 second task intervals typical for fMRI) is inherently difficult for drug abuse patients. For these reasons (and after unsuccessfully attempts of direct neurofeedback paradigms with treatment-seeking cocaine patients) we have developed an indirect method for using real-time neurofeedback to probe cognitive control in real-time in a non-craving task, and then to measure the disruption of control in the face of various distractions cues, including pictures with drug content.

Methods. We used whole-brain classifier-based real-time fMRI feedback [5] to provide participants (6 cocaine abuse patients and 15 healthy controls) with a continuous measure of how well they were able to stay focused on a cue-aided cognitive task. Subjects were instructed to imagine navigating when scene pictures were visible, and to rest when pictures were hidden (See figs. 1 and 2). Each condition lasted 6 seconds (comprising 3 repetitions in the pulse sequence). During three 36-period s during each scan, distraction pictures (of various types) appeared on the periphery of the screen (fig. 1), and subjects were instructed to continue focusing on the instructed task despite the disruption. Three categories of distraction pictures were used as depicted in fig. 2. Subjects were scanned four times with this protocol within a single 1-hour session.

All fMRI data was acquired on a Siemens 3T scanner with a standard BOLD imaging protocol (TR=2 sec, 32 slices), and processed in real time using custom software (partial least squares was used for developing the multi-voxel classifiers). A sliding window technique was used to calculate the feedback score as a continuous function of the classification data such that more accurate classification yielded a higher score. In retrospective analysis the classifier was restricted to each brain lobe separately (see figs. 3,4).

Results and Discussion. Figs. 3 and 4 show the average performance scores throughout the first and last scans, separated by brain region and by subject type. For the first scan (fig. 3), the cocaine patients showed a distraction (decrease in feedback score) for both the drug and aversive distraction types, whereas healthy controls showed a distraction effect for aversive, but not drug distractions. Distractions were particularly evident in the Limbic lobe (shown in red). By the fourth scan (fig. 4), however, these distraction dips were much less evident suggesting that the subjects may have learned, over the course of the session, to stay focused despite distraction. Further studies (e.g. with sham feedback) are needed to test this hypothesis of feedback efficacy.

Conclusion. These data illustrate a new real-time fMRI paradigm in which we can characterize “loss of control” in addicted individuals and in healthy comparison subjects. We also see evidence of learning to overcome the distractions, which may be a therapeutic consequence of feedback exposure.

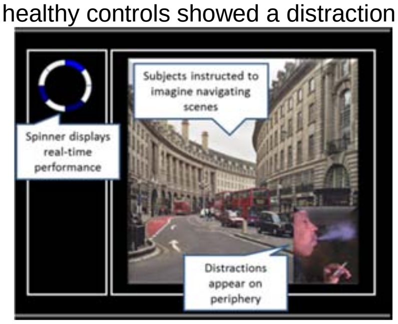

Figure 1. Screenshot of the real-time feedback display including the feedback spinner, cue picture, and distraction image.

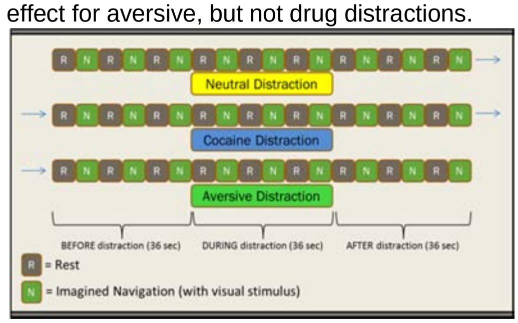

Figure 2. Diagram for the distraction scan protocol in which cognitive control is tracked in real time in the face of various distractions.

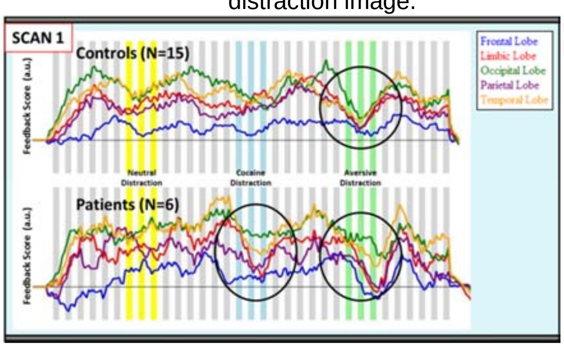

Figure 3. In the first scan, both patients and controls were distracted by the aversive pictures, whereas only patients had a notable distraction dip for drug cues.

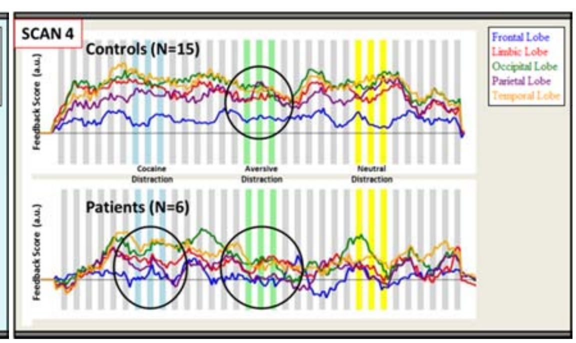

Figure 4. Patients and controls may have learned to overcome the distractions by the fourth scan. However, patients had an overall worse performance suggesting fatigue effects.

References

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