Digital phenotyping and mobile sensing in addiction psychiatry

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Improving prognosis and treatment response to substance use disorder (SUD) remains a challenge. Such an aspiration, however, is confronted by a reality that psychiatry lacks reliable tests that predict illness risk, treatment response, remission, or recurrence likelihood. Here, we consider potential advantages in addressing these shortcomings bestowed by the digital revolution. The overarching challenge is to realise an integration of digital phenotyping and mobile sensing into SUD diagnostic assessments, coupled to discovery of underlying mechanisms and delivery of targeted interventions. The attraction of digital personalized medicine arises out of a deployment capability within a clinical environment, one that addresses the challenge of scalability.

New digital technologies, including digital phenotyping and mobile sensing [1], provide a platform for ecological momentary assessments (EMA) and interventions (EMI) that have the capability to assess and change health-related behaviour patterns [2]. These technologies can capture diverse variables spanning psychomotor activity, mood state, geolocation, and movement in real time, with a potential to assess specific covert antecedents (e.g., urges and cravings, lifestyle factors) and environmental determinants (e.g., high-risk situations) of addictive behaviours. Such metrics, among others, provide inputs for algorithmic analyses to enable immediate automated risk-evaluation coupled with an evaluation of candidate predictive models. Once valid predictive models are established, specific and timely interventions can be triggered to prevent addictive behaviour relapse [2,3].

Smartphone-based platforms (e.g., *movisensXS*, *ESm Capture*, and *LifeData*) provide examples of digital phenotyping tools. While SUDs are marked by multiple physiologic changes (e.g., high arousal) in response to cue exposures, mobile sensing tools can capture physiological indices of cue-elicited craving, for example those that involve a change in physiological (e.g., heart rate and skin conductance) reactivity, that can feed into predictive models of relapse [4].

Digital technologies have many advantages over conventional laboratory assessments [1,2], including an enhanced ecological validity consequent upon their deployment in everyday settings, coupled to an absence requirement for intrusive specialized equipment. Indeed, targeted intervention programs (e.g., mindfulness meditation and psychoeducation) can be digitalized and incorporated into smartphone application (app). Furthermore, through use of analytic approaches (e.g., machine learning) interventions can adaptively tailor to the precise phase of the disorder and characteristics of at-risk subjects. To improve patient treatment outcomes., the use of digital technologies can be part of a global patient follow-up scheme [5]. By providing a robust functionality, these tools can aid a reduction in stigma, particularly embarrassment experiences through help seeking that involve traditional face-to-face communication interventions [2]. Finally, it does not escape our attention that an added impact of digital technologies on substance use treatment arises in an age of unforeseen enforced isolation, quarantine and social distancing [6].

We consider an outline realisation of the above-mentioned aims in greater detail. Substance-associated cues (e.g., alcohol and cigarette advertisements) are known to often elicit craving and promote substance-seeking responses, particularly in a context of diminished cognitive control [3]. Unique person-specific cues (e.g., the presence of a specific friend or object / context that is commonly paired with an individual own substance use) encountered on a daily basis in a manner that enhances momentary substance craving intensity [4]. The latter highlights that an individual's unique history of substance use provides important predictive inputs for quantifying a risk of relapse. Indeed, future studies that rely on digital technologies can reap a rich harvest of data based upon dense sampling of dynamic features of an individual's experience, environments, or social contexts in real time. In this way digital technologies enable new opportunities to understand and act upon these person-specific risk factors and individual lifestyle features, at a level that facilitates individually tailored interventions.

Another example of a leverage point for digital technologies is the likelihood of momentary daily fluctuations in inhibitory control, sensation-seeking, and urgency. Thus, as changes in working memory function, have been associated with momentary enhancements in craving that can lead to subsequent SUDs [3,4]. Substance-associated expectancies and availabilities also mediate cognitive and behavioural impairment in real life [4]. Capturing such fluctuations in momentary SUD behaviours and experiences across time and in everyday settings hold potential for informative inputs to predictive models and prevention strategies.

Gamified mobile cognitive tests have emerged as powerful tools to advance a mechanistic interpretability of SUDs. Embedding a standard experimental task, within an engaging, fun-to-play game is an increasingly popular experimental strategy not least as it improves both participant engagement and retention. Thus, use of an app enables delivery of a gamified battery of cognitive tests that measure circadian rhythm and time-of-day variations in cognitive function in SUDs. A pertinent pioneering example is *The Great Brain Experiment* (http://www.thegreatbrainexperiment.com), which supports a gamified app that transforms otherwise mundane tasks into an engaging activity. It provides access to cognitive mechanisms that encompass inhibitory control, working memory, risk taking and Pavlovian bias. Of note all these processes have potential relevance for understanding SUDs. Another example is a newly launched *Brain Explorer* app (https://brainexplorer.net) which provides a basis for exploring associations between adolescent cognitive and brain development with a disposition to substance use.

Tracing the trajectory of SUD via EMA and unpicking underlying mechanisms via gamified cognitive tests, enable researchers to embed EMI into SUD patients' daily lives. EMI can be delivered in many ways ranging from unstructured recommendations (e.g., requesting a SUD patient practice relaxation technique when showing an increased stress-induced craving) to more formalized and structured interventions (e.g., patients participating in a substance use cessation intervention receive a prompt via an app with tips for dealing with cravings during a time when they typically use substances). Notably, EMI can supplement existing interventions including standard ongoing medical and psychological treatments or can be implemented as stand-alone interventions. Additionally, these technologies take well-developed therapeutic interventions (e.g., cognitive behavioural therapy and guided self-help) and apply them in a potentially engaging format as, for example, through exploitation of music and gamified features. Smartphone-based interventions are not limited to a particular setting and can be delivered while a SUD patient sits at home, reducing patient-flow delays and easing human resources burden [7]. An interventional example is a smartphone-based *Addiction – Comprehensive Health Enhancement Support System* (A-CHESS, http://chess.wisc.edu/achess-archive/). A-CHESS provides monitoring and support services to SUD patients. Shanghai Mental Health Centre recently developed an app *Community-based Addiction Rehabilitation Electronic System* (CAREs), that offers personalized recovery monitoring and enables SUD patients get easier access to social support in community.

There are several implementation barriers in utilisation of digital technologies that deserve mention [1,2,6]. First is a general concern around data protection and privacy. This can be addressed via an anonymization of data and a thorough quality evaluation of apps as to enact the highest data standards and adherence to regulatory requirements. Second is the question as to whether digital tools will be feasible for use and acceptable to SUD patients, as app efficacy depends largely on user engagement. Third is a challenge in building simple, elegant, and intuitive user interface designs especially for patients with low digital literacy. Moreover, many digital tools remain inaccessible to rural underserved areas and vulnerable populations (e.g., patients who are elderly, living with some form of disability). Finally, the full potential of digital health can only be realised in a world where digital technology is democratically accessible to everyone.

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