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Research paper

Commonly available activity tracker apps and wearables as a mental health outcome indicator: A prospective observational cohort study among young adults with psychological distress

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ABSTRACT

Background: Monitoring is integral to adequately recognise and track mental health indicators of symptoms and functioning. Early identification of warning signs from digital footprints could facilitate adaptive and dynamic just in-time monitoring and care for individuals with common mental disorders.
Methods: Self-report data on mental health and lifestyle behaviour from 120 male and female Australian young adults experiencing psychological distress were collected online. API software was used to download participant's daily activity duration measurements over eight months from linked commercial activity tracker apps and wearables in real time. An independent samples *t*-test was conducted to compare the differences in daily durations of recorded physical activity between wearable devises and smartphone apps. Entropy techniques using R interpol package were used to analyse volatility in daily activity duration.
Results: DASS-21 depression, stress and anxiety sub-scale scores indicated the study sample on average, had a moderate level of psychological distress. Daily activity duration was significantly greater from wearable devices when compared with smartphone apps (t-test = 25.4, $p < 0.001$). Entropy indices were not related with any of the DASS-21 measures. However, significant correlation between DASS-21 anxiety subscale scores and entropy of those with over 45 days measurements ($r = 0.58$, $p = 0.02$) was observed.
Limitations: The observational nature of this study prohibits causal inference. As a convenience sample was used, the results may lack generalisability to the wider population.
Conclusions: Continuous monitoring using commercial apps and wearables as a resource to help clinicians augment clinical care for common mental disorders appears viable.

1. Introduction

Common mental disorders including depression, generalised anxiety disorder (GAD), panic disorder, phobias, social anxiety disorder, obsessive-compulsive disorder (OCD) and post-traumatic stress disorder (PTSD) affect approximately 8% of the world population (WHO, 2017). Historically, emphasis of burden has been placed on severe, organic mental disorders such as schizophrenia and bipolar disorder. In parallel to these types of neurological-based, chronic mental diseases, mental conditions considered to be more common in the community, while not typically considered 'severe', are by no means 'mild' (Goldberg, 1994). In fact, numerous studies have documented the immense suffering and disability associated with common mental disorders, as well as the broad, substantial social and economic detriment they generate. Indeed, a new study by the World Health Organization (WHO, 2016) estimated that the cost of depression and anxiety in over 36 countries around the world will amount to around $147 billion by 2030. Thus, there appears an urgent need to reshape the way common mental illnesses are foreseen and acted upon, including a multidisciplinary approach.

In 2002, the Australian Government attempted to address the impending mental illness epidemic with a new policy of 'monitoring' for all state-based community mental health services; instated in the Second National Mental Health Plan (DoHA, 2005). Indeed, monitoring is integral to adequately recognise and track mental health indicators of symptoms and functioning (Carlier, 2012). However, people with mental disorders are unprecedently difficult to monitor. For the most part, this is due to the fact that a substantial proportion of sufferers with common mental disorders do not often seek medical treatment (Pratt and Brody, 2014; Mojtabai et al., 2002). Hence, attempting to monitor

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such people in a way that facilitates the opportunity for early intervention, is particularly challenging (Collins et al., 2014).

Digital-based, continuous monitoring, has recently been documented as a responsive strategy that holds potential to target individuals suffering with common mental disorders in the community. Specifically, new research has shown that early identification of warning signs from digital footprints (i.e. passive data traces arising as a by-product of individuals' day-to-day interactions with mobile and/or Internet-connected technologies) could facilitate adaptive and dynamic just in-time monitoring and care for individuals with psychological distress (Bidargaddi et al., 2016).

Fixed-time monitoring systems, which are currently used in Australian public mental health services, are limited in their capacity to achieve this goal. In this approach, functional and symptomatic assessments are conducted only at fixed time points using traditional self-report and expert rated assessment measures. Typically, these approaches lack ecological validity as they are subject to recall biases, can only be administered at limited time points in controlled settings, and often require individuals to travel to medical settings to receive the assessment (Trull and Ebner-Priemer, 2013). This inability to assess the impact of environmental interactions with mental state in real-time, has hindered progress towards understanding and classifying mental disorders, as well as treating them. A more nuanced method for monitoring and detecting remote behavioural changes, which transports traditional clinic-based assessment into the naturalistic environments of individuals, may provide a better received therapeutic context that leads to early intervention and improved health outcomes.

Sensor signals automatically captured in smartphones and wearables may serve as an avenue to achieving such holistic view of patients' mental health trajectories in real-time (Patel et al., 2012). Indeed, there is much scope for incorporating consumer technologies into mental healthcare. Today, the vast majority of people today have "smartphones," a new advanced class of mobile phones. In fact, an estimated 62% of the population worldwide owned a mobile phone in 2016 (4.61 billion), and is expected to increase to over 67% by 2019 (5.07 billion). This estimate includes usage among lower socioeconomic groups and minority populations (Statistica, 2015). Smartphones are a global positioning system (GPS), equipped with advanced computing and sensing capabilities, and host a number of sophisticated programs that can easily be installed on the phones (i.e. "apps"). These features, together with the unobtrusiveness of sensor data gathering and demonstrated evidence of popularity and acceptability, represents a potential information resource for epidemiological-based research in common mental disorders (Bidargaddi et al., 2016).

To date, the primary approach used by studies involves providing dedicated mobile phones to participants and developing custom apps to extract raw sensor signals (Capela et al., 2015). The advantage of this approach is better reliability and quality of data (del Rosario et al., 2015). However using dedicated devices has limited translational potential due to scalability issues arising from costs associated with providing devices. Introducing a new technology is also likely to alter participants default behaviour and environment, and thus the measurements might not reflect truest sense of the observant. An alternative approach is to derive indicators from sensors contained in smartphone apps or wearables that participants may already be using in their daily lives (Grunerbl et al., 2015). Collecting data via the use of smartphone apps in this way may reduce the likelihood of cofounders and/or bias typically associated with traditional forms of measuring behaviour. Furthermore, economically, the use of individually owned smartphones offers the potential of conducting assessment and providing intervention at immense scalability worldwide at little to no cost.

Activity tracker apps and wearables in particular, are uniquely positioned to capture the granular and temporal behavioural characteristics in natural settings, and reveal underlying objective indicators of a person's moment-to-moment functioning (Grunerbl et al., 2015; Osmani, 2015). Indeed, studies have begun to show the efficacy of this capability among serious and severe mental illness populations. Grunerbl et al. (2015) were among the first to investigate whether physical activity, smartphone-sensing accelerometers could detect state changes (i.e. depressive and manic states) that could signal the onset of an episode in patients suffering from bipolar disorder. Results showed a strong correlation between physical activity daily interval (morning, afternoon, evening, night) scores and patients' states ($r = 0.63$, $p < 0.05$). Furthermore, within-patient Naïve Bayes classification results revealed 81% mean accuracy in recognising patients' state, and 82% recall. Further recent studies have begun to emerge, supporting these findings for serious and severe mental illness populations (Grunerbl et al., 2015; Alvarez-Lozano et al., 2014; Mayora et al., 2013; Beiwinkel et al., 2016).

However, to date, scarce evidence from research supporting the use of activity tracker apps and wearables as a valid mental health assessment tool for common mental disorder populations exists. Therefore, the primary aim of the current study was to elicit a descriptive overview of young adults with common mental disorders using and sharing physical activity tracker app and wearable device data. Characteristics of this data, including processes of collection, ways to reconcile measurements from different activity tracker sources, missing data patterns, and approaches of deriving indicators for common mental disorder risk identification and potential interventional pathways are explored and discussed.

2. Method

2.1. Study design and recruitment

This study utilised a prospective observational cohort trial design over eight months conducted in Australia. A total of 120 male and female young Australian adults aged between 18 and 25 years old were initially recruited between July 2016 and September 2016 from the mental health web site ReachOut.com; an online mental health support platform targeted at Australian young adults between 13 and 25 (Vogl et al., 2016). A rolling recruitment strategy was used over a course of three months, involving two approaches: 1. emailing participants directly who had registered interest with ReachOut.com due to reported depressive, anxious or stressful psychological distress to participate in the study, and 2. placing popup banners about the study at the bottom right corner of some sections of the ReachOut website. Participation in the study was completely voluntary, and participants were informed at the beginning of the study they were free to withdraw at any stage.

2.2. Participant screening, selection and study procedure

The initial recruited sample of 120 volunteers who expressed interest in the study by either responding to email invitations or study advertisements were sent a detailed information pack about the study. Eligibility criteria for participation were: (1) aged between 18 and 25 years old, (2) currently using or had willingness to install activity tracker apps on a smartphone or wearable device, and (3) provided informed consent. From an initial sample of 120 volunteers who were assessed for eligibility, 67 were excluded due to not meeting one or more of the outlined eligibility criteria, leaving 53 potential participants. As such, those 53 participants completed a detailed online survey about their health and lifestyle profile, provided authorised access to measurements recorded in their activity trackers apps through online API software, of which enabled data to be analysed. A flow diagram of participant's progress throughout the duration of the study is illustrated below in Fig. 1.