Review

Digital Sensory Phenotyping for Psychiatric Disorders

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ABSTRACT

Today's genome-wide association studies (GWAS) of psychiatric disorders require massive sample sizes and the identification of biologically relevant phenotypes. Sensory phenotypes, assessed by measuring sensorial function, represent early symptoms of psychiatric disorders, and may involve neurobiological pathways in psychiatric disorders. Yet, sensory phenotypes have rarely been studied in large populations for early diagnosis or GWAS. The concept of using digital devices to collect data on disease-related phenotypes is beginning to attract considerable attention. Is it possible to assess sensory phenotypes dynamically by digital devices? And furthermore, is it possible to explain the pathology of psychiatric disorders through those assessments? In this review, we summarize studies investigating sensory phenotypes and digital phenotyping of psychiatric disorders. We discuss the feasibility of digital phenotyping to better capture disease-related sensory phenotypes. We also discussed potential ethical and privacy issues, which require regulation of governments and collaborations of all researchers to solve. While the emergence of digital phenotyping makes the large-scale and moment-by-moment quantification of sensory phenotypes in psychiatric disorders highly scalable, it also introduces tremendous opportunities for genetic research and health improvement.

KEYWORDS: psychiatric; phenotype; sensory phenotype; digital phenotyping

INTRODUCTION

Sensory phenotypes are the sum of complex traits that reflect the
function of the human senses (seeing, hearing, smelling, tasting, and touching) responding to environmental stimuli. Accumulating evidence suggests that sensory defects represent the earliest symptoms of most psychiatric disorders [1–4]. As disease symptoms, sensory phenotypes may help clinical diagnosis and treatment through earlier detection of disease onset, relapse and improvement. Labeled as an endophenotype (having genetically-associated, predictable behavioral symptoms), sensory phenotypes may share some neurophysiological pathways common to psychiatric disorders; additionally, sensory phenotypes may also act as a direct index for neurophysiological effect [1]. Researchers have used sensory phenotypes to identify specific genotypes and to explain psychiatric disorders [5]. However, the existing low-throughput, high-cost methods for measuring sensory phenotypes are also impractical. They are not easily integrated into the massive data sets used in today's genome-wide association studies (GWAS). Therefore, applying convenient and high-throughput digital technologies to measure sensory phenotypes carries great potential for studying psychiatric genetics.

Sensory phenotypes that measured with digital technologies are defined as digital sensory phenotypes. Using common digital technologies such as smartphones and wearable devices to measure and collect personal phenotypic data, termed “digital phenotyping” has tremendous potential [6–8]. Today, researchers are collecting phenotypic data from patients with psychiatric disorders including such parameters as daily mood, physical activities, and social communications using relatively inexpensive digital devices [9,10]. Digital phenotyping is unobtrusive—even a normal smartphone can capture many types of phenotypic data. In psychiatry, objective and continuous quantitation of clinical markers using patients' own devices is useful to refine diagnosis, to tailor treatment strategy or monitor outcomes [11]. Through digital phenotyping, we can capture behavioral and sensor changes, and self-report information. These changes should be distinguishable in nature and clinical status, and detectable by smartphone, wearable devices or other sensors. Among lots of human phenotypes, sensory phenotypes are eligible for the requirements.

In this review, we summarize studies that correlate sensory phenotypes to psychiatric disorders and those that use digital technologies to collect phenotypic data from patients with these psychiatric disorders. We consider both sensory (perceptual) and sensorimotor functions as identifying sensory phenotypes. Sensorial functions refer to the basic abilities of sensory receptors and related neural circuitries, whereas sensorimotor functions refer to both sensory inputs and motor responses, e.g., eye movement or auditory EEG [12]. Abnormalities in sensory or sensorimotor functions suggest defects in the integrity of neural pathways and the nervous system as a whole [13]. Perception involves somewhat
complex subjective judgment and is difficult to measure; therefore, we restricted our discussion in this essay to sensorimotor functions. Involving only limited little cognitive function, sensorimotor functions reflect sensory circuits directly. We are particularly interested in the feasibility of collecting sensory phenotypic data via digital technology and correlating those phenotypes to genetic variants associated with psychiatric disorders (see Figure 1).

![Diagram of sensorimodal phenotypes and digital technology data collection](image)

**Figure 1.** Overview: In this review, we introduce the concepts of the sensory phenotype and digital phenotyping for psychiatric studies. Furthermore, we discuss the feasibility of using digital technology to collect sensory phenotypes of psychiatric disorders.

**PHENOTYPES IN PSYCHIATRIC GENETIC STUDIES**

Diagnosis serves as a categorical phenotype for GWAS [1]; yet, diagnostic validity depends on how diagnosis is defined and whether its criteria are logically and factually reasonable [14–16]. For example, the clinical definition of autism has changed remarkably over the past 75 years. Once thought to be a form of childhood schizophrenia, autism is now considered a neurodevelopment disorder with genetic origins. Diagnoses such as these are conventionally not based on expert observation and objective assessment and not on the physiological etiology [17,18]. Psychiatric disorders are difficult to classify due to their multidimensional phenotypes [16]. This difficulty is compounded by the burden of imprecise phenotyping, which impedes the identification of risk genes that contribute to psychiatric disease susceptibility [19].

The use of endophenotypes is one proposed method for linking disease diagnosis to genetic risk variant detection [20]. Endophenotypes are heritable, objective biological markers that can be measured directly.
Endophenotypes may be categorized as neurophysiological, endocrinological, neuroanatomical, or cognitive [20]. Because they are directly measured and quantifiable, endophenotypes may be superior to traditional methods of diagnoses [20,21]. For example, sensory motor-gating deficits consistently characterize schizophrenia [22–24]. Compared to complex disease behaviors, endophenotypes are governed by fewer genes. These genes may play an important role in the disease. Endophenotypes may bridge disease diagnosis and gene identification, identifying “downstream” clinical phenotype traits as well as “up-stream” genetic output [20]. Endophenotypes may also help to identify aberrant genes in polygenic disease [25]. Furthermore, patients may be subclassified by specific endophenotypes [1]. Multiple endophenotypes could work together to constitute subtypes of the current diagnosis. The biology of endophenotypes contribute a fundamental understanding of the disease process, which has the potential to assist in prevention and more effective treatments [26].

Using endophenotypes offers a quantifiable method for diagnosis. This is plausibly a more precise and reproducible method than the qualitative, subjective categories of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5). Furthermore, as a straightforward biological construct, endophenotypes are likely more accurate than conventional means in pinpointing a specific genetic abnormality and corresponding protein change [23]. Nonetheless, developing a truly high-grade and accurate endophenotype is a critical challenge. Researchers have identified and validated potential endophenotypes typically from disease-linked deficits [27]. Evidence of segregation and heritability in “clinically unaffected” relatives is a genotype-endophenotype correlation that commonly used for individual pedigree members [27]. For example, P50 suppression deficits were found as potential endophenotypes in patients with schizophrenia and unaffected relatives [28], which has been widely replicated and confirmed [26,29–33]. Additionally, an association study identified the chromosomal region of interest [34], which yielded an association of P50 suppression deficits in schizophrenia via the α-7 subunit of the nicotinic receptor [35]. P50 suppression is considered to be one endophenotype of schizophrenia.

Several consortiums are attempting to apply multiple endophenotypes to large samples of patients [36]. Success will attest to the feasibility of endphenotypes for diagnosis within genetic studies [37]. The National Institute of Mental Health initiated the Research Domain Criteria (RDoC) project in 2009 [14]. RDoC focuses on psychological systems including emotion, cognition, motivation, and social behavior, as well as the specific system’s relationship to mental health and illness in general. The Bipolar Schizophrenia Network on Intermediate Phenotypes (BSNIP) project, adherent to RDoC guidelines, aims to systematically investigate
phenotypic components of schizophrenia (SCZ) and bipolar disorder (BD) [38]. BSNIP measures physiological or cognitive traits, such as electroencephalography (EEG), eye movement activity and brain imaging. Likewise, the Enhancing Neuroimaging and Genetics through Meta-Analysis (ENIGMA) Network uses advanced imaging technology to collect complex phenotyping data, identifying genetic influences on brain structure and function [39].

SENSORY PHENOTYPES IN PSYCHIATRIC DISORDERS

Sensory phenotypes are one of endophenotypes for psychiatric disorders. As the technology for collecting sensory measurements improves, interest among mental health professionals is growing. Researchers can now capture previously undetectable sensory phenotypes and test various proposed phenotypes for their correlation to psychiatric characteristics. For example, deficits in the sense of smell are a sensory phenotype linked to negative symptoms in patients with schizophrenia [40]. One meta-analysis showed a deficient sense of smell in patients with schizophrenia and at-risk youth [41]. Whereas, patients with autism spectrum disorder (ASD) show heightened sensorimotor function. ASD prompts atypical sensory reactivity and sensory over-responsivity [42,43], characterized by an extremely negative response to sensory stimuli [44]. ASD's sensory over-responsivity correlates to abnormal changes in the connectivity between the thalamus and the cortex [45]. Furthermore, eye-tracking deficiency in schizophrenia has also been investigated [46]. Chronic pain can be an example of a tactile phenotype of the whole body that is associated with anxiety and depression within epidemiological studies. Individuals with major depressive disorder (MDD) and other psychiatric disorders have an increased risk for chronic pain [47]. Recent research points to overlaps between pain- and depression-related changes in neuroplasticity and neurobiological mechanisms [48]. The sensory pathway of physical pain may involve multiple brain regions, including the insular and prefrontal cortices, associated with mood management [49].

To review the sensory phenotype study in psychiatric disorder, we searched studies of sensory phenotypes in psychiatric disorders in PubMed with the following search builder: (((((((visual) OR olfactory) OR auditory) OR tactile) OR gustatory) OR sensory phenotype)) AND (#DISORDER#). #DISORDER# is one of the major psychiatric disorders: SCZ, BD, MDD, anxiety, obsessive-compulsive disorder (OCD), Alzheimer's disease (AD) and Huntington's disease (HD). We also used the following inclusion criteria: (1) published in English before March 2018; (2) assessed sensory phenotype in at least one of the psychiatric disorders; and (3) case-control studies only. We chose 55 articles for the following tabulation.

In total, we selected 55 case-control studies, involving sensory
phenotype of seven psychiatric disorders, including SCZ, BD, MDD, anxiety, OCD, AD, and HD. Significant differences between the disease and control populations were detected in case-control studies for several sensory phenotypes, e.g., eye-tracking in SCZ, BD, and MDD [50]; auditory event-related potential [51–53] in SCZ, BD, and anxiety; phenylthiocarbamide (PTC) non-taste in SCZ [54,55]; olfactory identification ability in SCZ [56] and AD [57]; and, tactile phenotype in OCD [58]. These studies focused primarily on differences in sensory phenotypes between patients with specific psychiatric disorders and healthy controls; they also reflect an interest in investigating the biological correlates of sensory function and psychiatric disorders. Tabulating the sample size and P-values of sensory phenotypic studies, researchers found that sensory phenotypes do significantly correlate with psychiatric disorders (Table 1). However, sample sizes were relatively small. In fact, most case-control studies had sample sizes under 400, with only two studies that used EEG measurements which included over 1000 participants. Sensory phenotypes are widely studied in the field of psychiatric disorders, however, mostly with small sample sizes.

In genetic studies, sensory phenotype research showed evidence of their correlation to psychiatric disorders. The fact that sensory phenotypes assist in detecting the genetic loci of psychiatric risks also attracts much attention [1]. One GWAS found that the sense of smell shares genetic regions with schizophrenia and Alzheimer’s disease on chromosome 18 (see Table 2). [103] They identified olfactory-related genetic regions using 8561 samples from the Religious Orders Study and Memory and Aging Project (ROSMAP), the Atherosclerosis Risk in Communities (ARIC) and the Health, Aging, and Body Composition (Health ABC) studies [103,104]. The same GWAS identified genetic loci associated with sensory phenotypes previously linked to schizophrenia [103]. One GWAS studying eye movement detected genomic regions also shared with schizophrenia risk loci [105]. Another GWAS of eye movement dysfunction in 128 schizophrenia patients also confirmed schizophrenia-related abnormalities in eye movement tasks. Additionally, 5 SNPs in MAN2A1 were significantly associated with cognitive search scores [106] that estimate the frequency of eyes focusing on the important areas within a figure [107].
Table 1. Summary of sensory phenotypic studies in psychiatric disorders.

<table>
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<tr>
<th>Disease</th>
<th>Sensory type</th>
<th>Phenotype</th>
<th>Phenotype measurement</th>
<th>Total sample</th>
<th>p</th>
<th>Reference</th>
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### Table 1. Cont.

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<th>Phenotype</th>
<th>Phenotype measurement</th>
<th>Total sample</th>
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<tr>
<td>SCZ (First-episode)</td>
<td>Olfactory</td>
<td>Olfactory neuron response</td>
<td>Hydrogen sulfide stimuli</td>
<td>39</td>
<td>0.05</td>
<td>Turetsky2009 [99]</td>
</tr>
<tr>
<td>SCZ (Monzygotic twins)</td>
<td>Olfactory</td>
<td>Olfactory identification ability</td>
<td>UPSIT</td>
<td>112</td>
<td>0.001</td>
<td>Brewer2001 [40]</td>
</tr>
<tr>
<td>SCZ (Monzygotic twins)</td>
<td>Olfactory</td>
<td>Sniffin' Sticks olfactory identification ability</td>
<td>The Sniffin' Sticks test</td>
<td>20</td>
<td>0.01</td>
<td>Ugur2004 [100]</td>
</tr>
</tbody>
</table>
### Table 1. Cont.

<table>
<thead>
<tr>
<th>Disease</th>
<th>Sensory type</th>
<th>Phenotype</th>
<th>Phenotype measurement</th>
<th>Total sample</th>
<th>p</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCZ and TLE</td>
<td>Olfactory</td>
<td>Odor identification ability and detection threshold sensitivity</td>
<td>UPSIT</td>
<td>97</td>
<td>0.008</td>
<td>Kohler2001 [101]</td>
</tr>
<tr>
<td>SCZ and paranoia</td>
<td>Auditory</td>
<td>P50 amplitudes</td>
<td>Electrode recording</td>
<td>46</td>
<td>0.006</td>
<td>Boutros1993 [102]</td>
</tr>
<tr>
<td>SCZ, BD and MDD</td>
<td>Visual</td>
<td>Visual contrast, visual motion integration</td>
<td>Motion detection task</td>
<td>249</td>
<td>0.05</td>
<td>Carter2017 [50]</td>
</tr>
<tr>
<td>SCZ, BD and MDD</td>
<td>Auditory</td>
<td>Auditory tone and auditory tone integration</td>
<td>Auditory integration and response task</td>
<td>249</td>
<td>0.01</td>
<td>Carter2017 [50]</td>
</tr>
</tbody>
</table>

Abbreviations: Electroencephalogram, EEG; event-related potential, ERP; magnetoencephalography, MEG; Magnetic Resonance Imaging, MRI; phenylthiocarbamide, PTC; temporal lobe epilepsy, TLE; significant p-value in the article, p; University of Pennsylvania Smell Identification Test, UPSIT.
Table 2. Genetically overlapped GWAS regions related to the sense of smell in schizophrenia (SCZ), and major depressive disorder (MDD).

<table>
<thead>
<tr>
<th>Phenotype</th>
<th>variant</th>
<th>Chromosome</th>
<th>Start position</th>
<th>End position</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sense of smell</td>
<td>rs115661734</td>
<td>18</td>
<td>52,889,562</td>
<td>53,804,767</td>
<td>Dong2017 [103]</td>
</tr>
<tr>
<td>MD</td>
<td>rs149735550</td>
<td>18</td>
<td>52,866,733</td>
<td>53,440,658</td>
<td>Arnau-Soler2019 [108]</td>
</tr>
<tr>
<td>SCZ</td>
<td>chr18_52749216_D</td>
<td>18</td>
<td>52,747,686</td>
<td>52,752,696</td>
<td>PGC2014 [109]</td>
</tr>
<tr>
<td>SCZ</td>
<td>rs78322266</td>
<td>18</td>
<td>52,987,176</td>
<td>53,172,676</td>
<td>PGC2014 [109]</td>
</tr>
</tbody>
</table>

Technology for measuring sensory phenotypes has developed at a slower pace than DNA sequencing technology. While the cost of DNA sequencing has declined, throughput has increased significantly. DNA extracted from saliva or blood is effective, and sequencing provides coverage of the entire genome. Conversely, aspects of mental health phenotypic measurements such as cost, throughput and some others are lagging compared with the progress made in sequencing technology, for instance. Furthermore, measurement systems are generally inconvenient. The University of Pennsylvania Smell Identification Test (UPSIT) has been used as a gold standard for olfactory sensorial function [110]. Although the method is reliable and practical, researchers are determined to improve its accuracy and convenience [111]. Likewise, measurement systems also are often time-consuming and inaccurate. The auditory event-related potential (ERP) is used to collect auditory phenotypes [52,53,64], measuring brain response related to sensory, cognitive, and motor events [112]. We found that the most frequently used measurement for hearing is the electroencephalogram (EEG) recording of the P50 and P300 waves [113]. Meanwhile, an EEG test requires up to 60 min of a participant’s time, while participants wear a snug electrode cap which must be fitted correctly. Although a smaller, portable EEG has been developed, ambient noise in an uncontrolled environment can be problematic, rendering false test results [114]. Even though ERP is one of the most widely used methods in cognitive neuroscience, the procedures are often complicated and inefficient. Eye movement has been the dominant test for the visual sensorimotor function to date [50,62,67,90]; however, it is another low-throughput method and lacks a unified standard for quality control. The digital recording represented by ERP and eye movement fill the gap of collecting complex phenotype, but the cost of digital recording measurements is still high due to specialized devices and the need for professional operation. In order to collect sensory phenotypes for a conventional study using large populations, high-throughput measurements are required. Embracing the handheld digital technology revolution will allow researchers to generate adequate data needed to establish definitive sensory phenotypes.
DIGITAL PHENOTYPING AS A DEVELOPING PHENOTYPE MEASUREMENT

Digital phenotyping is a method for measuring phenotypes that uses digital technology such as smartphones and wearable devices and allows for a continuous collection of clinical data [115]. As personal technology becomes increasingly embedded in modern society, the possibilities for digital phenotyping have flourished. Patients with psychiatric disorders increasingly own smartphones that could be used to benefit their health [116]. Researchers could collect patient's phenotypic data from smartphone sensors and wearable devices to determine health status [117].

Digital phenotyping encompasses the collection of data for symptoms relevant to psychiatric disorders as either passive or active data. “Passive data” refers to data produced with the patient’s approval but without the patient having to initiate a response; these include GPS and accelerometer data collected by smartphones automatically [8]. Another digital phenotype analysis strategy is the ecological momentary assessment (EMA) [118,119] that uses “active data”. “Active data” requires not only the patient’s approval but also the patient’s active involvement, such as taking surveys or contributing audio samples [8]. For instance, using a smartphone application, patients can keep an accurate diary of their symptoms and behaviors [120].

In the last 5 years, smartphone applications for monitoring psychiatric disorders have proven feasible. We searched studies of digital phenotyping in psychiatric disorders in PubMed with the following search builder: ((((((schizophrenia) OR bipolar disorder) OR major depression disorder) OR suicide) OR neuropsychiatric)) AND (((digital phenotyping) OR smartphone) OR wearable devices). Inclusion criteria contained the following: (1) Published in English before December 2019; (2) Applying digital phenotyping in at least one of the psychiatric disorders; and, (3) Case-control study only. We found digital phenotyping studies of MDD [121–124], BD [125,126], SCZ [120,127–130] and other disorders [131–134]. For example, with the Beiwe smartphone platform [135], Barnett et al. [127] used mobility patterns and social behavior to predict relapse in schizophrenia. They found that the rate of behavioral anomalies was 71% higher within the two weeks preceding relapse. Saeb et al. [123] collected 48 college students’ location sensor data and evaluated their depression symptoms severity using Patient Health Questionnaire 9-item (PHQ-9). They found several digital phenotyping measures significantly correlated with PHQ-9 scores (p-values < 0.05). Beiwinkel et al. [125] monitored social information to track daily mood, physical activity, and social communications in 13 patients with bipolar affective disorder, finding that changes in symptom levels correlated to the smartphone measures. These researchers characterized digital phenotyping as a practical tool for psychiatric-related phenotypic measurement. Their studies reinforce that
the technology revolution and information science can support the field of mental health. Many of these studies tried to prove that digital phenotyping is eligible in routine clinical practice by enhancing clinical diagnosis and treatment through monitoring earlier signs of disease onset, relapse or treatment response. However, practical feasibility is one important consideration. We think that sensory phenotype might be one of the feasible choice.

**USING DIGITAL PHENOTYPING TECHNOLOGIES TO CAPTURE AND ANALYZE SENSORY PHENOTYPES**

The range of available sensor input methods is wide and varied. Taps, clicks, scrolls, and cameras, with human-device interaction information provide multiple measures of sensory function. In regard to tactile phenotype, individuals with OCD, for example, can have abnormal touching patterns captured by a touchscreen [58,77]. For visual phenotypes, individuals with BD may possess inefficient eye-tracking and visual contrast sensitivity [50], which can be captured by a smartphone camera. Improved resolution and refresh frequency of phone cameras will allow the capture of increasingly complex traits related to eye movements that can currently only be analyzed using special devices [136,137]. With regard to auditory phenotypes, it is well known that individuals with BD and MDD can experience auditory verbal hallucinations in response to auditory stimuli. This can be measured by combining the capture of validated auditory stimuli through earphones and the user’s interpretation documented on touchscreen [138]. Quality earphones and advanced audial technology can make studies related to sensitivity and the ability to differentiate direction and tone possible. In terms of smelling, tasting, and tactile phenotypes, individuals with SCZ often lose their ability to distinguish some smells and tastes [76]. While no sensors for measuring smell or taste-related phenotypes exist to date, patient-reporting of symptoms documented through smartphones could provide meaningful data.

The digital measurement of sensory functions represents a powerful tool for capturing a host of sensory phenotypes. Eye tracking can be used to refine diagnostic process or to monitor early signs of disease relapse, but it has yet to become a pervasive technology. Researchers used convolutional neural network to build the eye tracking software that work on commodity hardware such as mobile phones and tablets, without the need for additional sensors or devices. For example, Krafka et al. trained a convolutional neural network for eye tracking, reducing error rate over previous approaches while running on a modern mobile device [139]. This algorithm had been applied to study of ASD patients. Strobl et al. assessed the accuracy of distinguishing between gaze towards the eyes and the mouth with smartphone, providing opportunities for more quantitative
monitoring of ASD patients [140]. Lai et al. also used a deep convolutional neural network, resulting in negligible differences between a smartphone and a high-speed camera in saccade latency, an eye movement measure of reaction time [141]. Comparing to eye tracking measurement, hearing test via smartphone may be easier. Using a smartphone app, Teki et al. evaluated auditory issues by segregating dialogue from background noise, known as the “cocktail party problem” [142]. The researchers evaluated participants’ ability to detect complex figures dictated by multiple voice frequencies against a noisy background. Results highlighted the potential use of smartphone apps in capturing robust large-scale auditory behavioral data from normal healthy volunteers and clinical populations. De Sousa et al. reported a smartphone digits-in-noise hearing test of 24,072 persons in South Africa [143]. Their study indicated that such a hearing test app can address a public health need. However, hearing test using smartphone also have some technical limitations. For example, different type of earphone transducer will influence the accuracy of hearing test [144].

These researchers proved that digital biomarkers can be correlated to gold-standard neurocognitive tests using passively acquired data during daily smartphone use. Digital technology can detect sensory phenotypes in an unobtrusive and economical way, providing data-rich daily assessments of sensory functions and continuous feedback for clinical intervention. To date, the application of digital technology to measure sensory phenotypes was relatively limited, yet this could change in the future. Phenome-wide association studies (PheWAS) could involve a large spectrum of phenotypes captured by digital technologies, useful in pleiotropic genetic associations. Compared with the conventional GWAS design, PheWAS examines a limited set of target genotypes and their association with multiple phenotypes [145,146]. Similar to electronic health records (EHR), digital technologies can also provide a longitudinal and comprehensive phenotypic record of sensory phenotype [147].

Privacy and data security are vital factors that must be considered with the use of digital sensory phenotyping [148,149]. New technologies enlarging upon the meaning of “personal data” necessitate more rigorous data safety and greater privacy protection. It is critical that smartphones do not collect personal data without patients clear understanding what this permission entails compliant with the regulations for patient's rights specific to the country of origin. While researchers may make use of anonymous digital sensory data, maintaining the anonymity of smartphone data is tremendously challenging. Barnett et al. constructed a software platform designed to support the conduct of digital phenotyping for research studies [150]. They protect data using privacy-preserving mechanisms designed to collect only anonymized participant data by default. Their design proves that anonymizing digital data collected on
smartphones is possible. Researchers who study digital sensory phenotype must follow all privacy guidelines established for medical research, including respect for autonomy, beneficence, nonmaleficence, and justice [151]. Unfortunately, inadequate privacy protection has already infested digital health care collections, including estimations of mental health and behavior, as discovered by a 6-month systematic assessment [152]. Privacy issues have often been too narrowly focused, with too few authentications and privacy protocols in place [148]. Only completely up-to-date privacy assessments are likely to uncover these evolving problems. Further attention will be required to ensure that digital health care privacy is adequate.

While smartphones and the Internet may solve specific problems in psychiatry, their clinical use raises new ethical challenges that the collective global society should endeavor to solve. Similar concerns have been raised in other fields. For example, Wand et al. discovered that deep neural network analysis of facial images may threaten the privacy and safety of gay men and women [153]. To solve the problem, Martinez-Martin et al. emphasized that ethical, legal and social implications of digital technology must be addressed. Existing ethical and regulatory frameworks for the provision of mental healthcare clearly do not apply to this field [154]. The authors address transparency, informed consent, privacy, and accountability, aspects that must also require careful consideration in the development of digital sensory phenotype data collection strategies. Shah suggests that smart privacy regulations by governments would be the most effective approach for restricting inappropriate use of personal data [155]. Similarly, the European Union implemented the General Data Protection Regulation, providing those nations with a legal framework to follow should data breaches occur [155]. This regulation might be a starting point for the development of similar regulatory processes for digital sensory phenotype data collection. For academia, it is essential to remember that collecting clinical data on human subjects requires adherence to globally accepted ethical regulations. They require scientific proof and the free volition of participants. Meanwhile, we should also seek ways to make such data generally available. Similar to John Sulston's advocacy that data from the Human Genome Project is openly accessible to the scientific community for common good, researchers should work to ensure that sensory phenotype data are used only for the common good [155].

CONCLUSION AND FUTURE DIRECTION

Digital technology can increase throughput and reduce the cost of measuring human sensory phenotypes. At the same time, digital technology has the potential to capture digital sensory phenotypes in large-scale populations of large genotypic data, such as GWAS. It has been
said that “new directions in science are launched by new tools much more often than by new concepts” [156]. Meanwhile, new measurement technologies can produce new types of data, analysis platforms, data storage, and protection strategies. Likewise, new technologies elicit new security, privacy, and ethical problems that beg adequate resolution. Advances in digital phenotyping technology could represent a new platform for phenotype detection spotlighting new methods of data analysis. Developing novel technologies that can quantitate sensory phenotypes could present a remarkable breakthrough in understanding the genetics of sensory function. Furthermore, such tools could outline the involvement of sensory function in neuropsychiatric disorders and bolster our understanding of the genomic architecture of disease. Moreover, digital sensory phenotypes can ensure objective and continuous assessment in patients’ daily lives, facilitating improved clinical interventions. Further research into the utility of digital sensory phenotypic data, the evaluation of the accuracy of using digital technology to measure sensory phenotypes, and the efficiency of measurements in large samples is needed.

Critically, the ethical issues that face the realization of this technology may be more difficult to overcome than the technical hurdles. Although digital technology holds substantial potential for increasing access to mental healthcare, adequate solutions for safe data transmission and storage are needed to protect participant privacy. Establishing adequate protocols for data collection, data storage, and data process, as well as a framework for securing data usage is critical from the outset. Both the academic and government sectors must endeavor to ensure that data collection and analysis efforts are pursued equitably and transparently in the common interest of humankind. Governments should pass legislation restricting the use of data and protecting participants’ privacy. While some researchers maintain a hopeful view of this new technology [157], its fruition relies upon advances in data security adequate to protect participants’ privacy and to serve our common interests.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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