The Mental Health Quotient: An Online Tool for Population Assessment of Mental Wellbeing

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Abstract

Background: Existing mental health assessment tools provide an incomplete picture of symptom experience creating ambiguity, bias, and inconsistency in mental health outcomes. Furthermore, by focusing on disorders and dysfunction they do not allow a view of mental health and wellbeing across a general population.

Objective: This paper presents a new online assessment tool called the Mental Health Quotient (MHQ) that spans the full range of clinical symptoms and also captures healthy mental functioning to provide a complete profile of an individual's mental health from Clinical to Thriving.

Methods: The MHQ was developed based on coding of symptoms assessed in 126 existing DSM-based psychiatric assessment tools, as well as neuroscientific criteria laid out by RDoC, to arrive at a comprehensive set of semantically distinct mental health symptoms and attributes. These were formulated into questions on a 9-point scale with both positive and negative dimensions and developed into an online tool that takes ~14 minutes to complete. As its output, the assessment provides overall MHQ scores, as well as sub scores for 6 categories of mental health that distinguish clinical and at-risk groups from healthy populations based on a nonlinear scoring algorithm. MHQ items were also mapped to the DSM-5, and clinical diagnostic criteria

for 10 disorders were applied to the MHQ outcomes to cross-validate scores labeled At-risk and Clinical. Initial data was collected from 1665 adult respondents to test the tool.

Results: Scores in the normal healthy range spanned values from 0 to 200 for the overall MHQ with an average score of ~100, and from 0 to 100 with averages between 48 and 55 for sub-scores in each of 6 mental health categories. 2.5% and 13% of respondents were classified as Clinical and At-risk, respectively with negative scores. Validation against DSM-5 diagnostic criteria showed that 95% of those designated "Clinical" were positive for at least one DSM based disorder while only 1% of those with a positive MHQ score met the diagnostic criteria for a mental health disorder.

Conclusions: The MHQ provides a fast, easy and comprehensive way to assess population mental health and wellbeing, identify at-risk individuals and subgroups, and provide diagnosis-relevant information across 10 disorders.

Keywords: psychiatric; population; personalized; clinical; mental health; wellbeing; patient; assessment; DSM; diagnosis; method; screening; mHealth; digital health; ehealth.

1. Introduction

According to the World Health Organization (WHO), mental health is "a state of wellbeing in which the individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community" [1]. According to this definition, any framework of mental health assessment should therefore reflect not just the presence of dysfunction, but also provide insight into positive aspects of mental wellbeing, ensuring it is applicable not only for clinical groups, but also for the wider population [2]. In addition, while personalized approaches to mental health are essential in ensuring effective treatment outcomes at the level of the individual [3-5], population level approaches provide an understanding of the broader geographical, cultural and experiential factors that influence mental health on a macro-scale [6,7]. This latter perspective provides an opportunity to develop interventions that induce large-scale shifts in population wellbeing and is becoming increasingly important to understanding how to improve mental health outcomes [8,9]. However, current approaches to mental health assessment pose considerable challenges to these goals and ideals.

One major challenge is that the clinical heritage of mental health assessment means that the majority of tools are not designed for the general population but instead built around specific psychiatric disorder categories based on the clinical classification systems of the Diagnostic and Statistical Manual of Mental Disorders (DSM) [10] or the International Classification of Diseases (ICD) [11]. In this way an assessment can identify whether an individual exhibits symptoms pertaining to a specific mental health disorder such as depression, attention-deficit/hyperactivity disorder (ADHD) or alcohol addiction but does not readily provide a perspective of their overall mental health. In contrast, the general population falls along a continuum ranging from disordered to thriving, and therefore having a system that is predominantly focused on disorders and dysfunction, without equivalent understanding of wellbeing, presents a challenge to advancing understanding of the borders between "normal" mental health and clinical disorder [12-15], especially as many mental health "symptoms" such as sadness, anxiety and risk-taking also fall within the spectrum of normal mental functioning in the general population. To understand when such "normal" mental functions cross the boundary

to symptoms requires an assessment approach that is designed for the general population and that encompasses the range from clinical dysfunction through to positive mental assets.

A second challenge is that existing mental health assessment tools, despite being broadly based on symptom criteria defined by DSM or ICD classification systems, are highly heterogeneous. Our recent analysis of 126 commonly used mental health screening assessments revealed considerable inconsistency in symptom assessment across different tools focusing on the same disorder, and substantial overlap between disorders [16]. Consequently, two assessments that target the same population group, but which used different tools to assess their experience of mental health problems, may deliver different results because they are assessing a different set of symptoms (see also [17]). This creates ambiguity, bias and inconsistency in mental health determination and confuses the development of effective treatments and interventions to promote wellbeing within the general population. Moreover, when examining assessment tools that span multiple disorders and therefore aim to provide a broader perspective to mental health, Newson et al, [16] found that none of the 16 cross-disorder assessment tools analyzed covered the complete breadth of mental health symptoms (see also [18]), and few considered positive mental assets. This suggests that existing cross-disorder tools fail to provide a complete picture of mental health symptoms and positive assets that would be applicable to both clinical and normal healthy populations.

To address these challenges, we have developed a new online assessment tool called the Mental Health Quotient (MHQ) [19], that is designed for the general population and covers the complete breadth of clinical mental health symptoms as well as positive mental assets. It has been developed based on an extensive review of the way mental health is assessed in clinical and research fields [16] and its purpose is to provide a comprehensive assessment of an individual's mental health profile ranging from Clinical to Thriving that is suitable for both clinical and population based assessment. Here we describe the development of the MHQ and provide preliminary data from a cross section of the population to illustrate its output.

2. Methods

2.1 Design and development of the MHQ

2.1.1 Key design criteria

The key design criteria of the MHQ were that it had to be fast and easy to complete by the general population (take 15 minutes or less), administered such that respondents felt confident to provide honest responses, and reflective of the current perception of the respondent's mental health. The MHQ was therefore designed to provide a view of respondent perception within their individual life context, which is not absolute, i.e. what one person means by a severity rating of 8 could be different from what someone else means in actual life outcomes, and can change over time. This is in line with the manner in which the majority of mental health symptoms are typically assessed. In addition, as an output it would have to provide an overall score of mental health as well as scores along key macro dimensions. Taking these requirements into consideration, the standard version of the MHQ was developed to be taken online anonymously and provide a score and full individual report that encourages honest self-report.

2.1.2 Developing a complete inventory of mental health and wellbeing elements

The MHQ was developed based on a comprehensive review of symptoms assessed across 126 commonly used psychiatric assessment tools (see Figure 1) spanning the disorders of depression, anxiety, bipolar disorder, ADHD, post-traumatic stress disorder, obsessive-compulsive disorder, addiction, schizophrenia, eating disorder and autism spectrum disorder) as well as cross disorder tools (see [16] for a complete list of assessment tools).

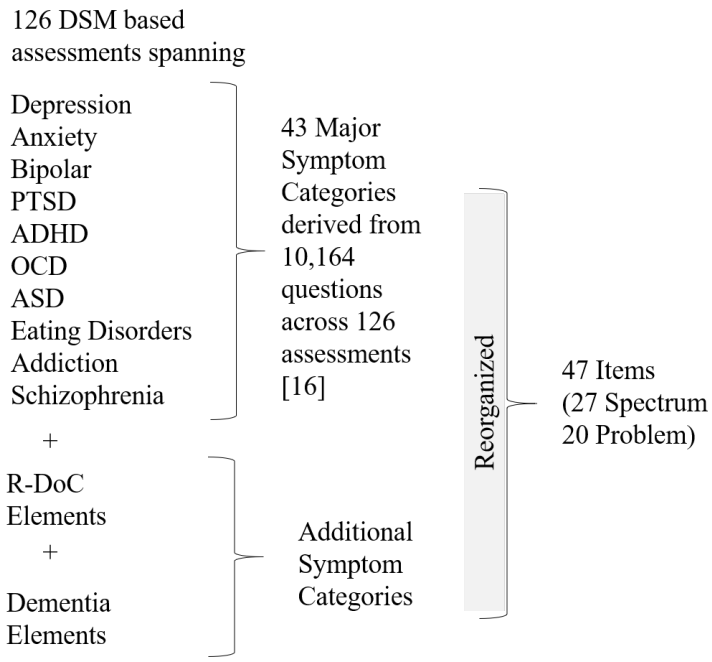

Figure 1. Diagram illustrating the method of development of the MHQ. *126 commonly used psychiatric assessment tools covering 10 disorders (as well as those taking a cross-disorder approach) were reviewed and consolidated into 43 symptom categories. These categories, together with additional symptom categories taken from a review of RDoC constructs and subconstructs as well as dementia elements, were reorganized into a final set of 47 items which were divided into spectrum and problem items for inclusion in the MHQ. Abbreviations: ADHD: Attention Deficit Hyperactivity Disorder; ASD: Autism Spectrum Disorder; OCD: Obsessive Compulsive Disorder; PTSD: Post Traumatic Stress Disorder.*

10,154 questions, taken from these 126 assessment tools were identified and coded based on a judgement of their semantic content and consolidated into a set of 43 symptom categories by grouping together similar preliminary symptom codings (see [16] for a more detailed description). This approach was selected because diagnoses are based on the self-report of symptoms based on their semantic descriptions, rather than underlying biological factors. The objective was not therefore to reduce the scale down into independent items in terms of occurrence, but cover the breadth of symptoms of mental health assessment based on semantic description (as an example of this approach, fever and fatigue are semantically distinct but often co-occur). This set of symptom categories was then reviewed in the context of the Research

Domain Criteria (RDoC) constructs and subconstructs put forward by the National Institute of Mental Health (NIMH) [20-22] and a few additions made to ensure that the list of items reflected the components within this non-DSM framework. We next made sure there were items within the MHQ which reflected symptoms of neurological disorders (e.g. dementia) that were not covered in the original review [16]. The resulting categories were then restructured as follows: First, categories which reflected purely physical symptoms (e.g. urination problems), were consolidated under the generalized item of "physical health concerns". Second, categories that reflected items that a naive respondent might find difficult to differentiate (e.g. delusions and unwanted thoughts) were also consolidated. Third, where a category reflected multiple symptoms or functions, it was split into two (or three) independent items to make it clear to the respondent which function/symptom was being assessed (e.g. sleep quality versus nightmares). This resulted in 47 semantically distinct items (Table 1).

The resultant items from this review and reorganization were then split into two formats –those mental functions that could manifest as a spectrum from positive to negative, which we called spectrum items (27 in all), and those symptoms that purely represented detractions from overall mental health, which we called problem items (20 in all).

Table 1. List of "spectrum" and "problem" items.

Spectrum Questions	**Problem Questions**
Adaptability to Change	Restlessness & Hyperactivity
Self-worth & Confidence	Fear & Anxiety
Creativity & Problem Solving	Susceptibility to Infection
Drive & Motivation	Aggression towards Others
Stability & Calmness	Avoidance & Withdrawal
Sleep Quality	Unwanted, Strange or Obsessive Thoughts
Self-control & Impulsivity	Mood Swings
Ability to Learn	Sense of Being Detached from Reality
Coordination	Nightmares

Relationships with Others	Addictions
Emotional Resilience	Anger & Irritability
Planning and Organisation	Suicidal Thoughts or Intentions
Physical Intimacy	Experience of Pain
Speech & Language	Guilt & Blame
Memory	Hallucinations
Social Interactions and Cooperation	Traumatic Flashbacks
Decision-making & Risk-taking	Repetitive or Compulsive Actions
Curiosity, Interest & Enthusiasm	Feelings of Sadness, Distress & Hopelessness
Energy Level	Physical Health Issues
Emotional Control	Confusion or Slowed Thinking
Focus & Concentration	
Appetite Regulation	
Empathy	
Sensory Sensitivity	
Self-image	
Outlook & Optimism	
Selective Attention	

2.1.3 Question format

Questions were answered based on the current perception of the respondent ("Please choose your answers based on your current perception of yourself") and were formulated on a 9-point scale reflecting the consequence on one's life functioning and performance. Figure 2A shows an example of a spectrum question from the MHQ and figure 2B shows an example of a problem question. Each question included a broad category label, as well as a one sentence description of the item for clarity.

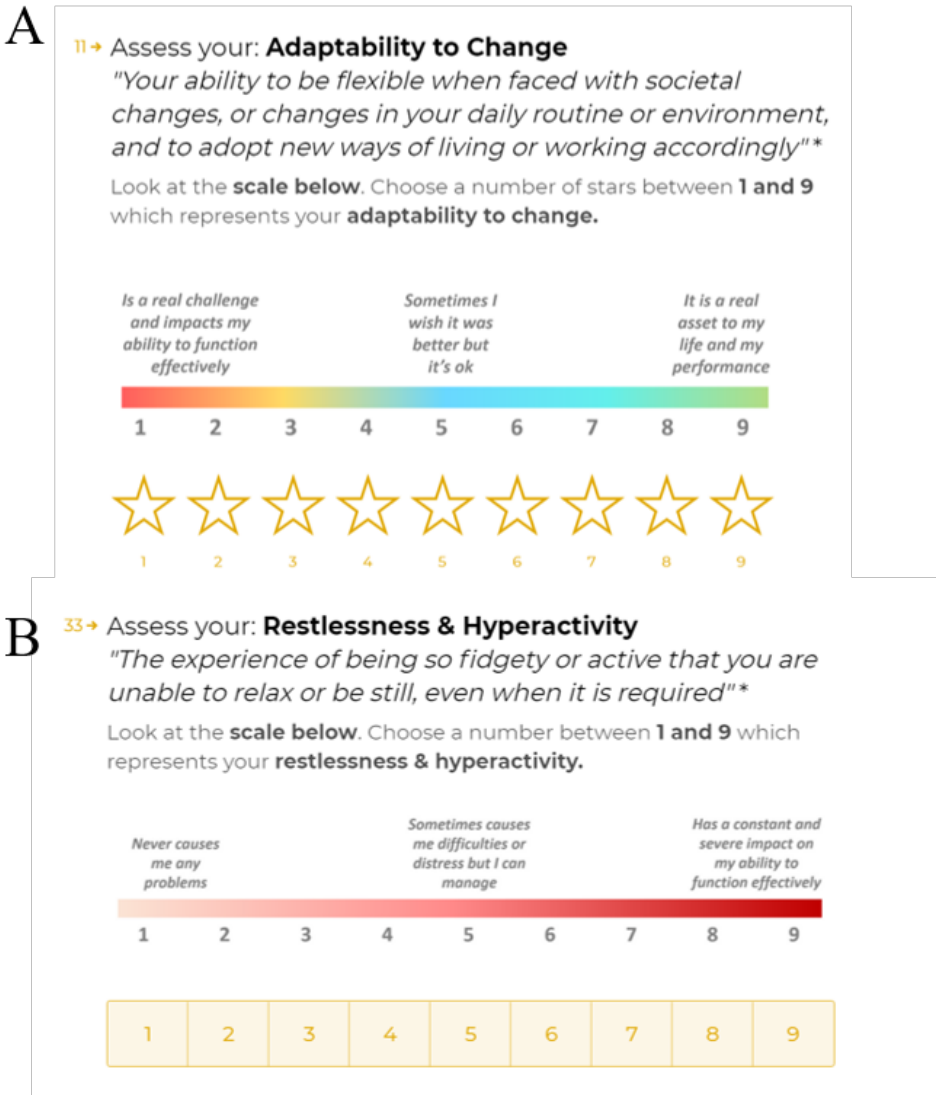

Figure 2. Example questions from the assessment. ***(A)*** *Example of a "spectrum" question. Each question was composed of an item category and a 1 sentence description of that item, as well as a 1 to 9 rating scale with reference labels.* ***(B)*** *Example of a "problem" question. Each question was composed of an item category and a 1 sentence description of that item, as well as a 1 to 9 rating scale with reference labels.*

The scale of "Spectrum" questions was designed to reflect functions which could be an asset for some individuals but a problem for others. In this way, spectrum questions were developed such that they did not relate to the presence or absence of a function/symptom, but instead focused on

the impact that the item had on the individual across a range of positive or negative possibilities. In the 9 point scale of spectrum items 1 referred to “Is a real challenge and impacts my ability to function effectively”, and 9 referred to “It is a real asset to my life and my performance” while 5 referred to “Sometimes I wish it was better, but it’s ok”.

“Problem questions” were designed to reflect functions or dysfunctions that typically had a negative impact on someone’s life and could rarely be seen as a positive asset. Here 1 on the 9 point scale referred to “Never causes me any problems”, and 9 referred to “Has a constant and severe impact on my ability to function effectively” while 5 referred to “Sometimes causes me difficulties or distress but I can manage”.

Within the spectrum and problems sections of the assessment tool, questions were presented in a random order so as not to be leading or priming for the subsequent question.

2.1.4 Demographic, experience and momentary questions

Questions designed to collect demographic, experience and momentary information were also included in the MHQ assessment. These questions aimed to provide insight into the life context and situation of the individual at the time of taking the assessment in order to understand how they influence mental health. Demographic questions were included to ask about the nature of a person’s daily occupation, geography, age and gender. Momentary assessments were designed to determine certain aspects of the individual’s situation, as well as their physical and mental state at the time of taking the assessment including alertness, mood, hours slept the previous night, time since last meal and any current physical symptoms such as headache, nausea or pain. Experience questions were included to ask about life satisfaction, life trauma, whether they had a diagnosed medical disorder or whether they were currently seeking mental health treatment. These questions were answered using multiple choice answer options, 9-point rating scales, or using a text box depending on the specific question type and were included with the purpose of identifying how these factors influence mental health and wellbeing.

2.2 Scoring of the MHQ

2.2.1 Computing the MHQ

The MHQ was not computed as a simple average of raw scores given (1) there were both negative and positive aspects, (2) there are differences in the seriousness of consequences of different symptom types and (3) consequences do not necessarily increase linearly at higher values on the scale. Therefore, the raw scores were transformed in two steps which included a threshold based rescaling of the 9-point scale to a positive-negative scale followed by the application of a differential nonlinear weighting of the negative scores to better distinguish at-risk populations.

For all questions a value *N* was determined as the rescaling threshold to separate the scale into a positive side depicting a normal range and a negative side indicating clinical risk. For problem questions, responses on the rating scale were transformed to *N - [rating response]* where *N* was a threshold number between 2 and 6 that was selected depending on the seriousness of the particular symptom and determined where the scale split between positive and negative. Thus, if *N* was 2, a rating response of 1 (representing the absence of the problem) would be rescaled to a 1 and a rating response of 9 (representing a constant and severe impact on the ability to function effectively) would be rescaled to -7. If *N* was 4, a rating response of 1 would be rescaled to a 3 and a rating response of 9 to -5. For spectrum questions the scores were rescaled as *[rating response] – N* where *N* was a number between 2 and 6. Thus if *N* was 3, a rating response of 1 (representing a constant and severe impact on the ability to function effectively) would be rescaled to a -2 and a rating response of 9 (representing an asset to life and performance) to 6. The specific values of *N* form part of a proprietary MHQ algorithm where lower numbers depict items which have a greater negative consequence either to the patient, or those around them when experienced at severe levels (e.g. Suicidal Thoughts or Intentions; Aggression Towards Others). In contrast, higher *N* values depict items which were evaluated as having a less negative consequence to the patient, or which are often found within a healthy population (e.g. Guilt & Blame; Adaptability to Change).

Subsequent to this positive-negative rescaling, a differential nonlinear weighting was applied to negative scores of different symptoms to create greater distinction in the at-risk group. This weighting value also forms part of the proprietary MHQ algorithm and, similar to *N,* was determined based on an evaluation of the negative consequence of each symptom. For example, a rescaled negative score of -7 for Suicidal Thoughts or Intentions would be weighted more negatively than a -7 for Restlessness and Hyperactivity and therefore result in a greater negative amplification of the MHQ score. Similarly, a rescaled negative score of -2 for Energy Levels would be weighted more negatively than a -2 for Creativity and Problem-Solving, and result in a greater negative amplification of the MHQ score.

The resulting rescaled and non-linearly weighted scores across all problem and spectrum items were then summed to provide an aggregate intermediate score. This intermediate score could be either a negative or positive score where negative scores identified those respondents who had or were at risk for a clinical mental health issue, while positive scores represented a normal or healthy range of mental health. To compute the MHQ, positive scores were then normalized to a scale between 0 and 200 while negative scores were normalized across a smaller window of -1 to -100. The negative scale was chosen to be smaller in order to provide a mitigated number to minimize any psychological distress that could be induced by receiving a highly negative score. Thus, the overall MHQ score spans a possible range from -100 to +200 where negative scores reflect clinical or clinically at-risk populations, while positive scores reflect the distribution of the normal healthy population (Figure 4A). This score range was also chosen so as to be similar to the way that intelligent quotient (IQ) scores are computed where scores are centralized around 100.

2.2.2 MHQ sub scores

Sub scores were also computed for 6 broad subcategories of mental health. These 6 categories included Core Cognition, Complex Cognition, Mood and Outlook, Drive and Motivation, Social Self and Mind Body (Table 2).

Table 2. Descriptions of the 6 categories of mental health.

Category	Description
Core Cognition	The ability to function effectively and independently on a moment to moment basis. Includes brain functions such as attention, memory, learning and self-control. Abnormal aspects of core cognition include severe or extreme forms of mental confusion, obsessive thoughts, sensory sensitivity, compulsive behaviors, psychosis and hallucinations.
Complex Cognition	The ability to synthesize and make sense of complex sets of events and situations and display a longer-term perspective in thoughts and behavior. Includes brain functions such as decision-making, creativity, problem-solving, planning and adaptability to change. Abnormal forms of complex cognition are associated with extreme risk-taking and a severe intolerance to change.
Mood and Outlook	The ability to manage and regulate emotions effectively and encompasses feelings of distress such as fear, anxiety, anger, irritability, guilt and sadness. It also includes the ability to have a constructive or optimistic outlook for the future. Abnormal forms of emotional functioning include uncontrollable crying, night terrors, severe temper outbursts, extreme phobias, uncontrollable panic attacks, highly traumatic flashbacks, intense mania or suicidal intentions.
Drive and Motivation	The ability to work towards desired goals and to initiate, persevere and complete activities in daily life. It is associated with interest, curiosity, motivation, and is also related to overall energy levels. Abnormal forms of drive and motivation include severe addictions which cause harm, or extreme withdrawal from activities or social interaction.
Social Self	The ability to interact with, relate to and see oneself with respect to others. It includes factors such as confidence, communication skills, self-worth, body image, empathy, and relationship building. Abnormal forms of social functioning include excessive unprovoked aggression, a strong sense of being detached from reality or suicidal intentions.
Mind Body	The regulation of balance between mind and body to ensure that any mental concerns do not manifest themselves as physical symptoms in the body in a chronic

	or severe way. It includes functions such as sleep, appetite, coordination, physical intimacy and fatigue. Abnormal forms of mind-body balance can include insomnia or chronic and severe pain, as well as a propensity for infection or frequent physical symptoms (e.g. digestive issues) with no obvious physical cause.

To compute the subcategory scores, a weighted average of items for each subcategory was calculated by weighting as "1" items core to the subcategory and as "0.5" items secondary to the subcategory. This weighting algorithm was developed based on a review of cognitive and neuroscience models of brain functioning, and forms part of the proprietary MHQ algorithm. For example the item "Stability and Calmness" was coded with a primary "1" weighting in the Mood & Outlook subcategory and a secondary "0.5" weighting in the Mind & Body subcategory to reflect its dual components of emotion and physiological response, while the item "Unwanted, Strange or Obsessive Thoughts" was dual coded with a primary weighting in the Core Cognition subcategory and a secondary weighting in the Mood & Outlook subcategory, to reflect both the cognitive and emotional elements of this item. In this regard an item could be assigned to two different subcategories and occasionally three. Overall, each subcategory comprised anywhere from 10 to 24 items. The subcategory scores were then normalized to constrain them to a smaller scale than the overall MHQ to distinguish them from the overall score. Positive scores were normalized to the range of 0 to 100 while negative scores were normalized to the range of -1 to -50.

2.3 Mapping of the MHQ against DSM-5 Criteria.

Given that the MHQ items were derived out of validated DSM-based assessments and span the breadth of symptoms assessed across 10 DSM-derived disorders, they can be readily mapped to DSM criteria. Thus, to determine DSM diagnostic status in relation to MHQ score ranges, each of the 47 MHQ question items were first mapped to the diagnostic criteria of 10 mental health disorders (depression, bipolar disorder, anxiety, OCD, PTSD, schizophrenia, eating disorder, addiction, ADHD and ASD), as defined by the DSM-5. For example, the MHQ items of "Feelings of Sadness, Distress & Hopelessness" and "Outlook & Optimism" were mapped onto

the "depressed mood" criteria for depression while the MHQ items of "Unwanted, Strange or Obsessive Thoughts", "Self-control & Impulsivity" and "Emotional Control" were mapped onto the "obsession" criteria for OCD. Those below the negative threshold *N* on the spectrum rating scale, and above the negative threshold *N* on the problem rating scale were considered to meet the severity criteria of the DSM-5.

To arrive at the diagnostic indication, we then applied the diagnostic criteria of the DSM-5 for these 10 disorders to the MHQ responses. These criteria stated the type of symptom (e.g. interest, fear), the number of symptoms required (e.g. must have at least 3) and whether any specific symptoms must be present (e.g. depression must have either a depressed mood or markedly diminished interest) for a diagnosis of a clinical disorder. Together this provided a view of (i) the percentage of symptoms for a particular disorder that the individual exhibits (i.e. the number of severe symptoms associated with that disorder they report/ total number of symptoms associated with that disorder), (ii) the percentage of an individual's symptoms associated to each of the 10 DSM-5 based disorder classifications (i.e. the number of severe symptoms they exhibit associated with that disorder / total number of severe symptoms they report) and (iii) a diagnostic indication for each disorder based on criteria-derived algorithms. An example MHQ output for the DSM mapping of symptoms for one individual is shown in Table 3.

Table 3: Example MHQ output for DSM mapping across 10 different mental health disorders for one individual.

Disorder	% Of Disorder Symptoms	% Of Individual's Symptoms	Diagnostic indication
Depression	71	50	Positive
Anxiety	55	30	Negative
Bipolar	73	55	Negative
PTSD	45	45	Negative
OCD	67	20	Negative
Schizophrenia	50	20	Negative
Eating Disorder	100	15	Positive

Addiction	25	5	Negative
ADHD	50	20	Negative
ASD	22	10	Negative

We note that the diagnosis is based on criteria of symptom severity but excludes specifics of frequency and duration of symptoms not captured in the MHQ which are sometimes part of the DSM-5 diagnostic criteria.

2.4 Reporting of the MHQ

The output of the MHQ was summarized both as scores as well as into an optional detailed report with recommendations for action that could be obtained by the respondent. Providing a detailed report ensured greater interest of the respondent to answer questions thoughtfully and accurately. Figure 3 shows an extract of an example MHQ results report detailing the MHQ score and sub scores. The first section offers an overall MHQ score and a recommendation based on that score. The following sections offer scores for each of the 6 categories (Table 2) and recommendations based on each of those scores (see [19] for further details).

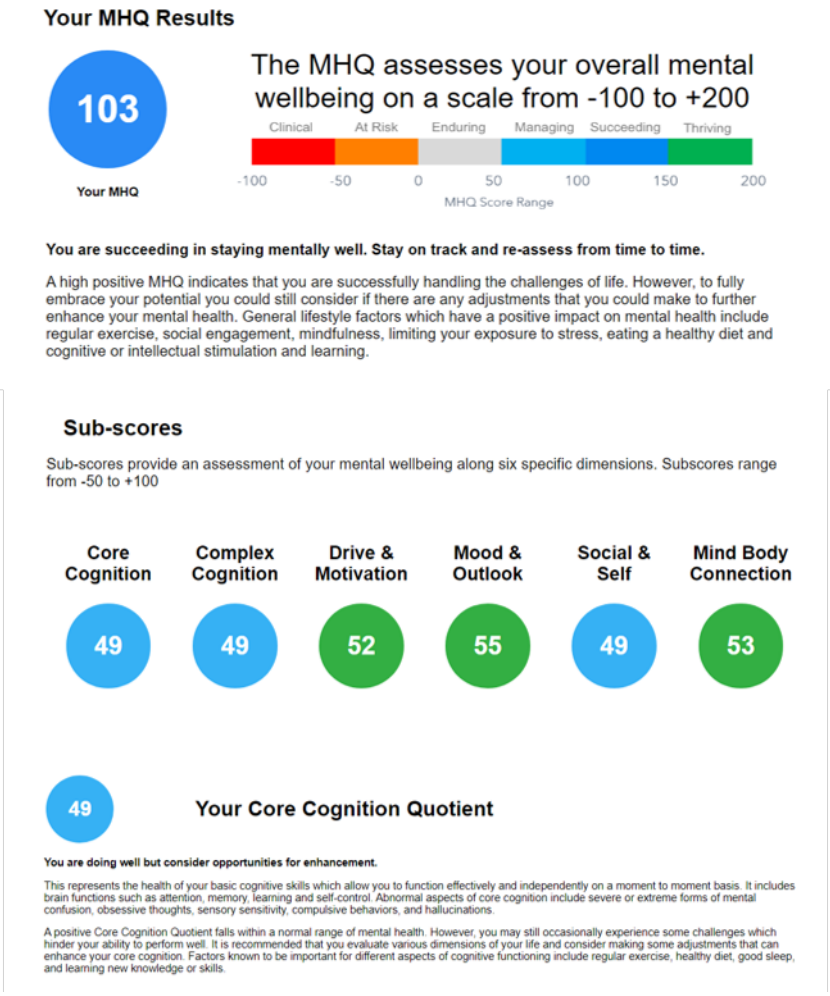

Figure 3. Extract of an example MHQ results report. *The report details the overall MHQ score and recommendations based on that score. It also details each of the 6 subcategory scores as well as descriptions and recommendations based on each of those subcategory scores (see [19]).*

DSM-based mapping (e.g. as shown in Table 3) is not included in the current iteration of the individual output report, although may be included in the future. When the MHQ is used in a clinical setting, for instance, the DSM mapping can be provided to an individual's physician to provide transdiagnostic insight.

3. Testing of the MHQ in the general population

3.1 Participant and protocol for data collection

1,961 responses were collected in the study. Respondents were recruited from the online websites of Psychology Today and Sapien Labs using a series of blog articles targeted at adults during July 2019-February 2020 providing links to the study. The study received ethics approval from Health Media Lab Institutional Review Board. Respondents took part by accessing the MHQ online [19] and completing the assessment. Those under 18 years old were not eligible to take part. On average, the assessment took 14 minutes to complete with the typical time taken for completion being between 8 and 20 minutes (79% of respondents). In addition, 98% of those taking part said the assessment was easy to understand.

3.2 Data cleaning and exclusion criteria

The following exclusion criteria were applied to the responses for data cleaning purposes. Firstly, the exclusion of all but the first of multiple assessments from the same IP address. Secondly, those respondents who took under 7 minutes (an indication the questions were not actually read), or over 1 hour to complete the assessment (suggesting the individual was not focused on the response). Thirdly, individuals who found the assessment hard to understand (i.e. responded "No" to the question "Did you find this assessment easy to understand?"). Fourthly, respondents who made unusual or unrealistic responses (e.g. those who stated they had not eaten for 16+ hours, or who stated that they had slept for +16 hours). We reasoned that while one might sleep longer than 16 hours or fast for a day or more under unique circumstances, these responses might be considered to be under distressed circumstances where thinking is physiologically impaired and therefore not valid. This resulted in the exclusion of 15% of responses (see Table 4) and a total of 1665 responses available for the final analysis.

Table 4: A breakdown of the percentage of responses excluded for each exclusion criteria.

Exclusion Criteria	% of Responses Excluded
Repeat responses from same respondent	3%
Time to complete < 7 minutes (range 2-7 minutes)	6%
Time to complete > 1 hour (range 1-23 hours)	2%

Poor understanding of assessment	2%
Over 16 hours since their last meal (range 17-52)	2%
Over 16 hours sleep the previous night (range 31-888)	0.5%

3.3 Respondent profile

Sixty-one percent of respondents were female, 37% of respondents were male and 1% responded as non-binary/third gender. One percent of respondents preferred not to reveal their gender. The age distribution of respondents ranged from 18 to above 65 with the highest number in the 25-34 age bracket (see Figure 5B legend for *n* values by age group). Only seven percent of respondents were aged 65 or above. These specific age ranges were selected to reflect major life periods above age 18. For example, 18-25 years reflects early adulthood, and the period when many people are students, single and are unlikely to have children, while 65 years and above reflects the age at which many people retire from work.

Respondents from 90 different countries completed the survey. The majority of respondents were from the United States (48%), whilst a notable proportion from UK (9%), Canada (6%) and India (5%) also responded.

3.4 Overall MHQ scores

Firstly, we examined overall MHQ scores across the group of 1665 respondents. MHQ scores ranged from -99 to +191 (on a scale of -100 to +200) where 84% of scores fell within the positive or normal healthy range and 16% fell within the negative range indicating clinical risk. The distribution is shown in Figure 4A. The overall MHQ scores had an average of 81 (median 94) while the positive MHQ scores had an average of 101 (median 105, mode 139) and the negative MHQ scores had an average of -24 (median -15). To obtain an interpretative picture of these scores, we further grouped MHQ scores into six levels according to their score window (Figure 4B) where, in the positive score range +151 to +200 was labeled Thriving (11% of respondents), +101 to +150 was labeled Succeeding (35% of respondents), +51 to +100 was labeled Managing (25% of respondents) and 0 to +50 was labeled Enduring (13.5% of

respondents). In the negative range 13% of respondents fell in the -1 to -50 score range labeled At risk for a mental health disorder while 2.5% of respondents fell in the -51 to -100 range, representing those who would likely require immediate clinical intervention (labeled Clinical). The proportion of respondents reporting negative scores is therefore in line with annual prevalence rates of mental health disorders reported from other sources [23-25].

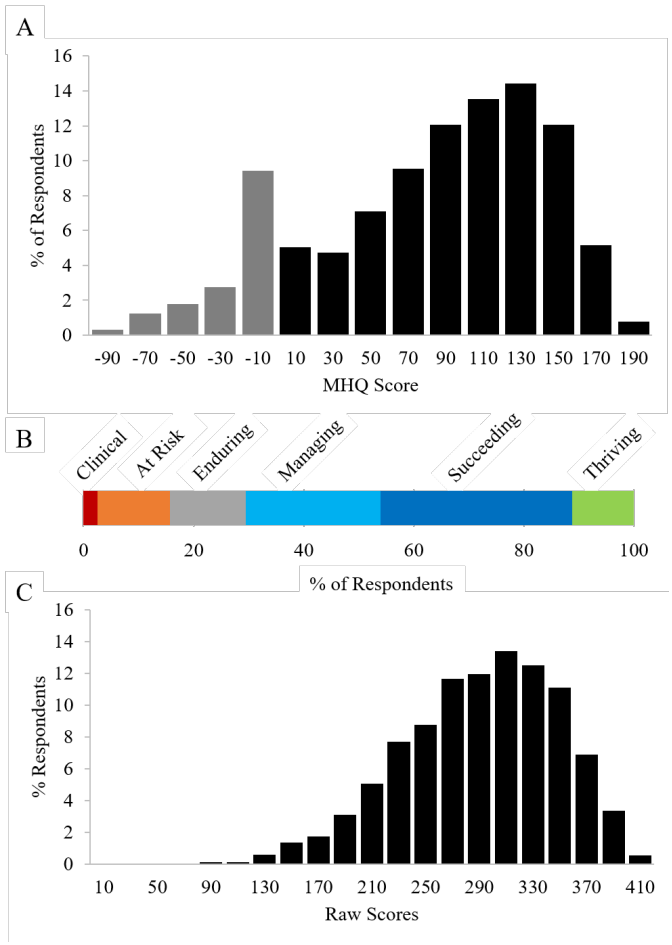

Figure 4. Distribution of MHQ scores across 1665 respondents. ***(A)*** *Percentage of respondents falling into MHQ score windows ranging from -100 to +200. Grey bars denote negative scores, black bars denote positive scores.* ***(B)*** *Percentage of respondents falling into each of 6 levels of MHQ scores. These levels are (from left to right) Clinical (Score range: -100 to -51), At Risk (-50 to -1), Enduring (0 to 50), Managing (51 to 100), Succeeding (101 to 150) and Thriving (151 to 200).* ***(C)*** *Distribution of raw scores depicting percentage of respondents falling into different raw score brackets. Raw scores calculated as the average of spectrum question rating*

responses and reverse scored problem question rating responses (i.e. where 1 is converted to a 9 and vice versa to maintain a consistent positive-negative direction).

There were certain important characteristics of the distribution of MHQ scores. First, the scale spanned both positive and negative numbers and the distribution was more heavily skewed to the left compared to a simple average of the raw scores (Figure 4A in comparison to Figure 4C). This reflects the characteristics of the algorithm (negative thresholding and nonlinear weighting, see Methods section 2.2) which serves to create greater distinction between people who have negative symptoms of different levels of seriousness and life consequence. Second, there was a peak in the negative range in the bin immediately to the left of the zero. This arises on account of the compression of the negative scores to a smaller scale of 50% of the positive scale such that each bin would be double what it would otherwise be. The rationale for this differential was to mitigate stress to the respondent.

3.5 Validation of MHQ Score Labels against DSM-5 Diagnostic Criteria.

To determine the validity of the MHQ scoring approach, we applied DSM mapped diagnostic criteria from 10 different mental health disorders to the MHQ responses (see Methods). This rule-based algorithm identified respondents who met the criteria for a diagnosis for at least 1 mental health disorder, out of a possible 10. We then examined the pattern of diagnoses across the different MHQ levels from Clinical to Thriving. 95% of those individuals with an MHQ score in the "Clinical" range had a diagnosis for at least one mental health disorder and 31% of those in the "At risk" range had a diagnosis for at least one mental health disorder. Those in the 'Clinical' and 'At risk' categories who did not meet DSM criteria for a disorder diagnosis nonetheless had a large number of severe symptoms that spanned multiple disorders (an average of 6 severe symptoms compared to an average of 1 in the positive MHQ score group).

Within the positive score range (from 0 to 200), only 1% of respondents met the DSM criteria equivalent to a disorder diagnosis, with 90% of these being in the Enduring category. Thus, the MHQ scoring exhibits both a low false positive rate within the Clinical score range, and a low false negative rate within the positive score range.

3.6 MHQ by age and gender

We next show the initial results of overall MHQ scores by age and gender (Figure 5). The distribution for males and females showed that a greater proportion of females reported negative MHQ scores compared to males (17% for females compared to 13% for males, Figure 5A) with the greatest difference being in Mood and Outlook (20% of female respondents At risk/Clinical compared to 15% of male respondents), and Mind Body (17% of female respondents At risk/Clinical compared to 7% of male respondents) subcategories. Both subcategories contain a large proportion of depressive symptoms and therefore this finding is in line with gender differences reported elsewhere [26-28]. In addition, MHQ scores differed substantially by age, with older age brackets having increasingly positive scores overall (Figure 5B). MHQ scores of respondents in the 18-24 age range were sharply lower, with 24% in the negative At-risk/Clinical range and only 27% Succeeding or Thriving (Figure 5C). The proportion At-risk/Clinical declined with age from 25% to just 9% in the 65+ age group and the proportion Succeeding or Thriving (i.e. scores above 100) increased with age from 27% to 69%. This pattern is in line with data from other sources [29]. This view by age and gender was not significantly different between respondents from the USA alone versus respondents from all other countries together. However, at this stage due to the small representation from other countries (max of 9% for any individual country) a country wise comparison was not possible.

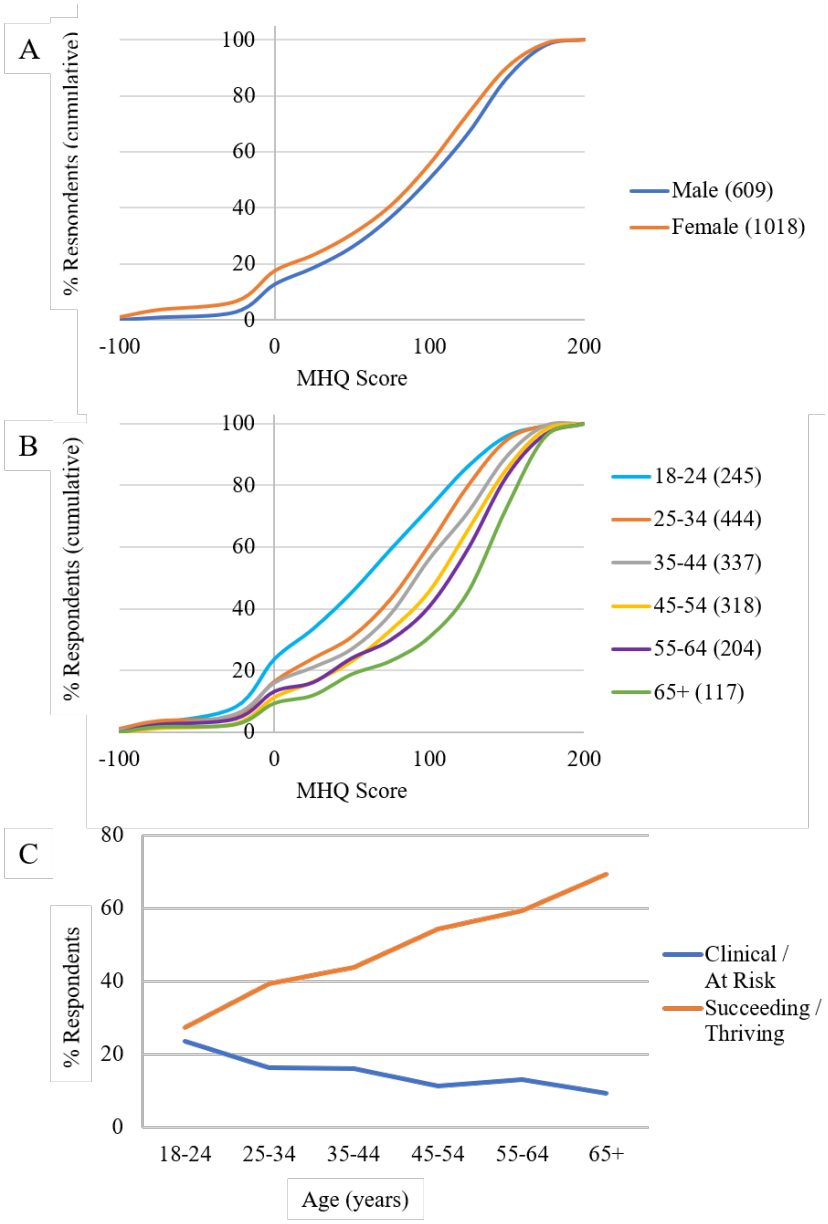

Figure 5. Distribution of MHQ scores across gender and age. (A) *Cumulative percentage of respondents across the MHQ score range for male and female groups. N values for male and female groups shown in legend.* ***(B)*** *Cumulative percentage of respondents across the MHQ score range for each age bracket. N values for each age bracket shown in legend.* ***(C)*** *Linear increase in proportion of Succeeding/Thriving (MHQ scores above 100) and decrease in proportion of At-Risk/Clinical (MHQ scores below 0) from younger to older age groups.*

3.7 MHQ subcategory scores

We next show the distribution of MHQ subcategory scores across each of the 6 subcategories of mental health (Figure 6). The distribution structure has high similarity to the overall MHQ across all categories with a normal distribution in the positive range and a skew in the negative range (Figure 6A). The average values across the entire score range for each subcategory were as follows: Core Cognition: 46 (median 54); Complex Cognition: 49 (median 53); Drive and Motivation: 47 (median 54); Mood and Outlook: 39 (median 43); Social Self: 39 (median 46); Mind Body: 40 (median 45). Within the positive score range the average, median and modal values were as follows: Core Cognition: 54 (median 57/mode 63); Complex cognition: 54 (median 56/mode 51); Drive and Motivation: 55 (median 57/mode 74); Mood and Outlook: 49 (median 51/mode 80); Social Self: 53 (median 56/mode 75); Mind Body: 48 (median 49/mode 65). A few key aspects warrant mention: the Social Self category in particular had a comparatively large proportion of people in the negative range (22.5% overall, 1.4% in Clinical range) followed by Mood and Outlook (18% overall, 1.1% in Clinical range) indicating that challenges relating to these aspects of mental health were most highly prevalent in the population of respondents (Figure 6B). In contrast the proportion of respondents facing serious challenges in their Cognition (Core and Complex), Drive and Motivation and Mind Body were comparatively smaller.

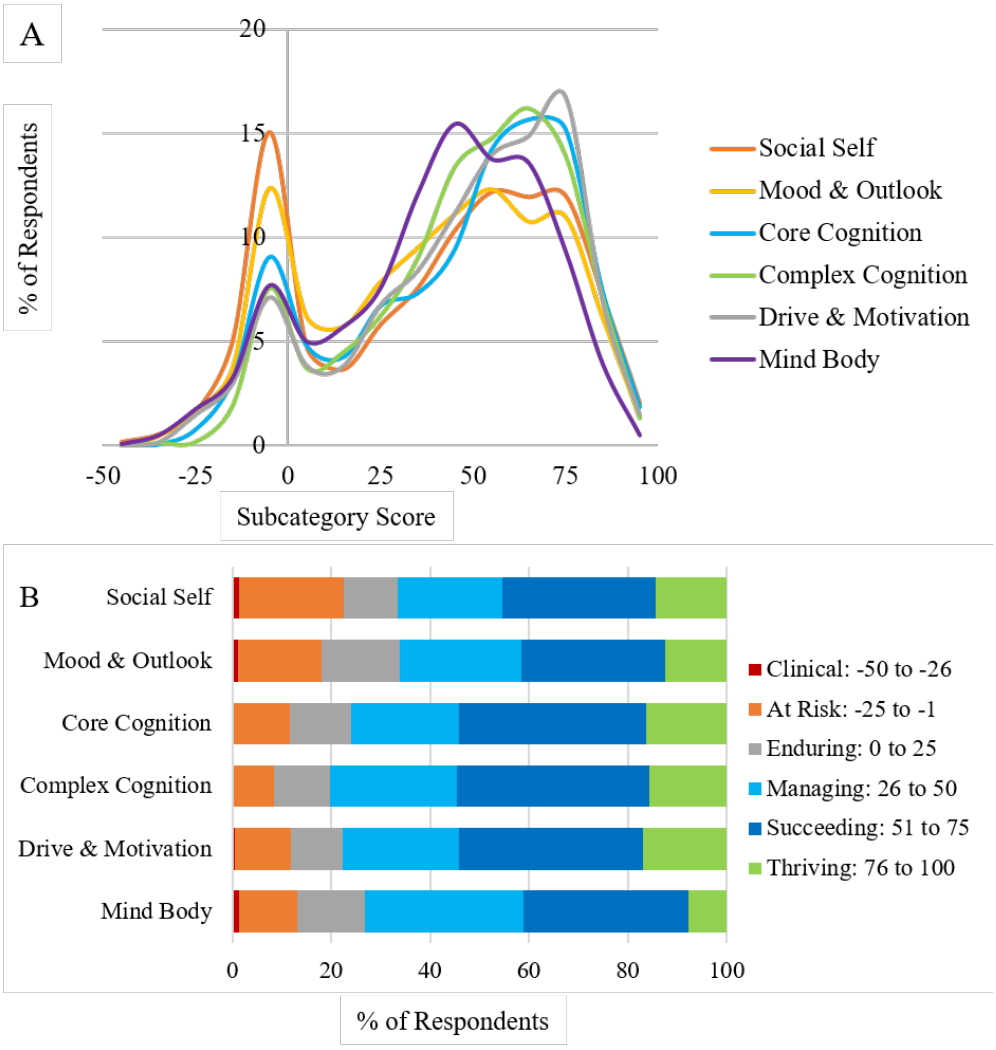

Figure 6. Distribution of MHQ subcategory scores. (A) *Distribution of MHQ sub scores for each of the 6 subcategories of mental health.* ***(B)*** *Percentage of respondents for each of the 6 subcategories of mental health for each MHQ score level. These levels are (from left to right) Clinical, At Risk, Enduring, Managing, Succeeding and Thriving. Numbers in legend denote MHQ score range for each level.*

4. Discussion

Assessment is the first step in identifying individuals and groups who are most at risk from mental health challenges as well as understanding the overall mental wellbeing of a population.

However, existing mental health assessment tools exhibit a number of limitations [16] which hinder both effective trans-disorder diagnosis and their application to the general population. Here we present the MHQ, a uniquely designed online assessment tool, that provides both an individual view of mental health and clinical risk and, when aggregated, a population view of overall mental wellbeing.

4.1 MHQ as a unique and comprehensive view of both symptoms and assets

The MHQ spans the breadth of mental health symptoms associated with major psychiatric disorders in a standardized and unbiased manner as well as assets and abilities important for overall mental wellbeing. The fact that 98% of respondents found the MHQ easy to understand, and that it took, on average, only 14 minutes to complete, indicates that the tool is highly accessible to the general population.

The MHQ was uniquely developed based on an extensive review of symptoms from 126 assessment tools across 10 different mental health disorders, as well as taking into account disorder agnostic approaches to mental health such as RDoC [20-22]). In this regard it represents the most comprehensive symptom profiling available, overcoming many limitations and biases of existing tools that include only partial lists of symptoms and are often skewed towards feelings or behaviors [16]. The MHQ also goes beyond a disorder-based approach (i.e. a focus on negative symptoms alone) with the inclusion of "spectrum" items that give consideration to a person's mental abilities and assets. This aspect, rarely considered by existing mental health assessment tools, is critical to established views of mental wellbeing [1] and captures the growing realization that positive aspects of mental health are essential for an integrated view of health [2,30].

Together, this design approach allows respondents, on an individual level, to obtain a holistic picture of both concerns and abilities across their results profile while, from a population level, it ensures that insights are not based on an incomplete or biased picture of reported symptoms and functions.

4.2 Insights into individual mental health

On one hand, the MHQ can be used to provide a personalized insight into an individual's mental health in a manner that is disorder agnostic and avoids the ambiguity of disorder classification [18]. These insights are accompanied by feedback generated based on the scoring profile of the individual. This allows at-risk individuals to self-identify so that they can seek appropriate support before reaching clinical levels of distress or impairment. For example, in this preliminary dataset, 13% of respondents were identified as being At risk, while 2.5% likely required immediate clinical intervention of which 95% met the DSM-5 criteria for a mental health disorder. It also provides a mechanism for individuals within a normal healthy range to evaluate dimensions of their mental health and identify challenge areas so that they can take action (e.g. make adjustments to their lifestyle) to strengthen and preserve their wellbeing even if they are not considered clinically at-risk. Due to its close equivalence to diagnostic outcomes based on DSM-5 criteria, the MHQ can also be used as a fast patient screen on admittance to a hospital clinic where individual scores and mappings to DSM disorder classifications, as shown in Table 3, can provide an initial impression of a patient's symptoms and diagnosis to guide faster paths to treatment.

4.3 Validation of MHQ against DSM-5 diagnostic criteria and known epidemiology

The preliminary data presented here from just 1665 adult respondents, demonstrated that, overall, 15.5% of respondents were identified as being At risk (13%), or requiring immediate clinical intervention (2.5%). Comparisons of MHQ scores against DSM criteria also revealed a low false positive rate (5%) within the "Clinical" score range, where 95% of respondents met the criteria for a diagnosis for at least one mental health disorder. There was also a low false negative rate (1%) within the positive score range (from Enduring to Thriving) indicating that 99% of respondents with a positive MHQ score did not meet the criteria for a mental health disorder diagnosis. The close alignment between MHQ scores and the degree to which people meet DSM-5 diagnostic criteria demonstrates its validity as a mental health assessment tool capable of identifying at risk individuals within a population, as well as providing a comprehensive cross-disorder clinical view.

The one limitation was that the MHQ mapping to the DSM, and subsequent diagnostic indication, only took into account the severity of symptoms and not the duration or frequency of symptoms required for some disorders, as these aspects do not form part of the MHQ. On the other hand, the MHQ is also able to identify those people with a large number of severe clinical symptoms in need of help whose symptoms do not fall specifically into any particular disorder classification.

At a population level, the proportion of respondents reporting negative scores is in line with annual prevalence rates of mental health disorders reported from other sources [23-25]. In addition, female respondents scored slightly more poorly, especially in the Mood and Outlook and Mind Body subcategories, both subcategories with a large proportion of depressive symptoms, in line with gender differences reported elsewhere [26-28]. Finally, the data showed that individuals within the youngest age bracket (18-24 years) were most at risk from experiencing mental health challenges, also in line with data from other sources [29]. Thus, the overall results of the MHQ are in line with other epidemiological estimates along various dimensions, demonstrating its validity as an epidemiological mental health assessment tool.

4.4 Potential applications of the MHQ

The MHQ was designed to be easy to implement in research initiatives employing large populations of individuals to obtain insights into the profile of mental health challenges and positive wellbeing. When used in a large-scale epidemiological context, relating MHQ scores to a range of demographic, experiential and situational variables can support the development of relevant interventions or policies that could induce larger-scale shifts in population wellbeing. Furthermore, the MHQ can be used within specific organizations such as companies or universities to measure and track the overall mental health and wellbeing of their workforce or student body respectively, and to support the design of tailored interventions suited to that specific group, identify at risk individuals or subgroups, and assess the impact of any support programs. The MHQ can also be used in a clinical context as a first line screening tool within both primary care and psychiatric clinics. From a research perspective, the results obtained from

the MHQ can also enable better understanding of the relationship of individual symptoms and symptom profiles to underlying biomarkers and efficacy of new treatment regimes.

4.5 Identifying the borders between "abnormal" and "normal" mental health

The development of an assessment tool covering the breadth of mental ill-health through to positive functioning that is accessible to the general population is also relevant for one of the major discussion points pertaining to the diagnosis and classification of mental disorders, namely the distinction between "normal" and "abnormal" mental health [12,14,15]. As most negative mental states, such as sadness, despair, anxiety, fear, agitation, and anger, are not abnormalities per se but normal responses to life's ups and downs, being able to decipher whether a person is responding normally to difficult circumstances, or experiencing pathological levels of distress or impairment, is not straightforward [13]. One challenge underpinning this debate, relates to the fact that, currently, there is a poor understanding of the state and diversity of mental health across a "normal" population. Thus, if there is a poor understanding of what the continuum of "normal" mental health looks like, how can we understand when it is starting to slide into "abnormal". Such a distinction is necessary not only to prevent false positives in diagnosis, a label that can be unduly associated with stigma, but also to ensure that people receive appropriate treatment, and that clinical research studies investigating underlying etiologies select from appropriate sample pools. The MHQ assessment tool has been constructed to capture this breadth of function from positive assets to extreme distress in order to establish these distinctions.

With psychiatric disorders being among the most disabling health conditions worldwide and creating significant burdens on individuals and societies [31], assessments of mental health that are accessible to the general population support the early identification of at risk individuals or subgroups and reveal relevant risk factors. This, in turn, can help to reduce the burden of suffering by facilitating the development of relevant and effective interventions and policies before symptoms escalate to clinical levels. The importance of population-accessible tools is further emphasized by the reported gap between those suffering from severe distress and impairment, and those receiving the help and support they need [32]. The MHQ aims to help realize the vital goals of mental health prevention and support by providing a means to measure

and track population mental health. Going beyond this, the MHQ ultimately seeks to enable a paradigm that can manage and improve the lives and wellbeing of all people, and not just of those with disorder or dysfunction.

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JN and TT developed the assessment tool. JN drafted the manuscript. TT and JN revised the manuscript, approved the final version, and agreed to be accountable for all aspects of the work. This work was supported by internal funding from Sapien Labs.

6. Conflicts of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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