

A system of classifying and measuring personality, emotion, and behaviour

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Abstract

This thesis addresses two long-standing dilemmas in personality psychology. The first dilemma is that of identifying the latent dimensions of personality. The second is to identify how best to measure psychological constructs. Novel solutions to both of these problems are presented in two articles. The first article (published), 'An atlas of personality, emotion, and behaviour' proposes a two-dimensional taxonomy, with strictly orthogonal dimensions affiliation and dominance. The second article (submitted for publication), 'Metrology applied to personality, emotion, and behaviour', proposes two quantitative measures. The measures are consistent with both the lexical hypothesis and metrology, the science of measurement.

In study 1, methods included cataloguing adjectival descriptors of personality, abstract noun descriptors of feelings and emotion, and verb descriptors of behaviour. Sociobiological and neurobiological evidence was further used to identify two orthogonal dimensions, each of which was divided into five ordinal categories. Using the Delphi Method, 20% of the catalogued words were scored by clinical psychologists, whilst the remaining 80% of words were scored using a tailored network approach. A technique was then developed to visualise a wide range of existing psychological and social constructs in two dimensions. Finally, a simulation technique was then developed to identify an alternative approach to psychological testing.

Results: The identified dimensions of affiliation and dominance were derived from the cataloguing of over 20,000 English language words, including 7,000 adjectival descriptors of personality, 3,000 abstract noun descriptors of emotion, and 8,000 verb descriptors of behaviour. All 20,000 catalogued words were able to be classified according to the ordinal scale. A wide range of psychological and social constructs was visualised and delineated, including the Dark Triad, Five-Factor Model, leadership, criminality, and many DSM-5 personality disorders. The simulation approach facilitated the formation of a psychological testing methodology that minimises the number of questions that must be asked to encompass a broad spectrum of personality, whilst minimising confounding and maximising statistical power.

In study 2, two quantitative psychological measures were proposed that strictly conform to metrological standards and the lexical hypothesis. The first measures semantic distance, inspired by the small world problem more popularly known as 'six degrees of separation'. The second measures the geometric distance between constructs according to the atlas. Both

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measures are theory realistic and address known issues with existing measures of psychological constructs, such as definitional circularity and reification.

The method involved a crowdsourcing study of all 1,506 IPIP items. Respondents (N=1,814) were asked to identify the single best adjectival descriptor relevant to each item. The responses were then measured according to both newly proposed quantitative measures. It was found that participant responses were significantly heterogeneous across many IPIP items, calling into question these items' suitability for psychological testing purposes. The crowdsourcing responses were further used to test the hypothesis that five-factor models are hierarchical. Results did not support the notion that the five-factor model is hierarchical, contrary to popular opinion.

Considered together, the conclusion of both studies is that a two factor model of personality may have advantages over the prevailing five-factor model.

Declaration of Originality

The works found within this thesis are original and have not been written by another person, nor submitted for a higher degree to any other university or institution. The empirical research contained within this thesis was approved by the Human Research Ethics Committee at Macquarie University on 17/05/2019 (Reference No: 5201953908793, Project ID: 5390).

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I thank my supervisor, Simon Boag, for his gracious perseverance in assisting me transition from commerce and return to my first love of learning. Every interaction has served to increase my appreciation of the depth of Simon's wisdom and expertise.

I thank my family for the many hours they have suffered my inability to focus on much other than categorisation, taxonomies, orthogonality and measurement.

Publications

1. Mobbs AED. An atlas of personality, emotion, and behaviour. PLoS One. 2020;15: e0227877. doi:10.1371/journal.pone.0227877
2. Mobbs AED, Boag S. Metrology applied to personality, emotion, and behaviour. 2021 (submitted)

Vancouver Referencing

Publications constitute two chapters of this thesis. Both articles adhered to the Vancouver referring style as required by the publisher. To maintain consistency with the publications, the entire thesis has been prepared using the Vancouver referencing style.

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Introduction

Systems of classification and measurement are prevalent throughout science, industry, commerce, and the arts. The psychological sciences are primarily interested in mind and behaviour[1], and there are many recognised approaches for classifying and measuring psychological personality constructs and behaviour. One of these approaches was developed by Raymond Cattell, who, inspired by the periodic table of elements, pioneered factorisation methods to propose sixteen fundamental personality factors[2]. Since Cattell, models with five and six factors have been developed[3]. Five-factor personality models are arguably the most popular[4]; however, they are not without criticism[5–13]. In addition to factor personality models, many other models exist, such as hierarchical forms of five-factor models[14], the interpersonal circumplex[15], attachment theory[16], unipolar models such as the Dark Triad[17,18], and categorical models such as DSM personality disorders[19]. This plethora of psychological models and constructs has resulted in calls for overarching personality constructs that encompass the entirety of personality[20–25]. One aim of this thesis is to develop an overarching system of classifying existing personality constructs.

Psychology has been described as a social science, and shares certain interests with other social sciences, including law, economics, anthropology, education, politics, and sociology[26]. Each of these social sciences investigates, classifies and measures domain-specific behaviours. For example, the law classifies and measures criminal behaviours[27], and education classifies and measures learning behaviours[28]. In addition to the social sciences, there are life sciences and humanities that also investigate, categorise and measure domain-specific facets of personality, emotion, and behaviour. These humanities and sciences typically utilise domain-specific vocabulary to describe and communicate matters of interest. The same applies to personality psychology, as seen in approaches adopting the lexical hypothesis. The lexical hypothesis suggests that ‘All aspects of human personality, which are or have been of importance, interest or utility, have already become recorded in the substance of language’ [29]. Personality psychology has traditionally applied the lexical hypothesis to adjectival descriptors of personality, and given the aforementioned shared interest and similarity between social sciences and humanities, the hypothesis should equally apply to these as well. Thus, an exciting possibility exists that an overarching categorisation system could encompass the domain-specific language of personality, emotion, and behaviour relevant to other social sciences and humanities. To address this, chapter two of this thesis undertakes extensive cataloguing of all verbs, nouns

and adjectives descriptive of personality, emotion, and behaviour relevant to other sciences and humanities.

Taxonomic classification, itself, is the empirical process of identifying the minimum number of homogeneous groups necessary to cluster similar phenomena and differentiate dissimilar phenomena[30,31]. As an empirical process, classification is improved by measurement instrument accuracy and precision. Accuracy and precision help improve delineation and reduce misclassification between groups[32], resulting in greater homogeneity of within-group phenomena and heterogeneity of between-group phenomena[33]. One promising direction to help improve taxonomic classification is the introduction of metrology[34]. Metrology is the science of measurement and its application[35]. Metrology emerged in response to the internationally recognised need for uniform measures and standardised measurement vocabulary[36]. Metrology is ubiquitous in the physical sciences, commerce, and industry but has not as yet been introduced into the social sciences[37–40]. This is somewhat unfortunate since metrology potentially imparts a number of advantages for social science research. For instance, several researchers have claimed that adopting metrology will improve science replicability[41,42]. Furthermore, metrology may address specific previously identified concerns with personality theories, such as reification and definitional circularity[13]. Chapter two of this thesis introduces a novel empirical approach to measuring personality, emotion, and behaviour. Chapter three then extends this analysis to make the measures introduced metrologically compliant.

Dynamic models are also increasingly used to identify causal interactions and predict behaviour[43–45]. Such dynamic models aim to specify the sensory inputs, algorithmic processes, and resultant behavioural outputs[46]. Also, dynamic modelling recognises that along with ever-changing perceptual inputs, the model's prior internal states and output responses may create feedback loops that affect subsequent responses[46]. Such complex modelling requires definitional specificity of each input, output and algorithmic process. Metrology's requirement for precise specification and delineation of phenomena from their measurable attributes is potentially beneficial for accurate specification and disambiguating a dynamic model's components. Chapter three of this thesis proposes a set of algorithmic components and congruent latent variables that potentially specify the causal relationships between personality, emotions, and behaviour.

In summary, this thesis aimed to develop a proposal for an overarching system of categorising and measuring personality, emotion, and behaviour. Chapters two and three of this thesis describe the process of achieving this objective. Firstly, words relevant to

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personality, emotion, and behaviour were comprehensively catalogued. Secondly, a metrologically compliant measurement system was developed with the minimum number of dimensions and categories necessary to score and measure all catalogued words. Finally, the thesis develops a dynamic model of personality, emotion, and behaviour that potentially identifies the latent variables required to explain the causal relationships between and manifestations of personality, emotion, and behaviour.

Chapter 2: An atlas of personality, emotion, and behaviour

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Abstract

A novel two-dimensional matrix taxonomy, or atlas, of personality, emotion, and behaviour is presented. The two dimensions of the atlas, affiliation and dominance, are demonstrated to have theoretical foundations in neurobiology and social psychology. Both dimensions are divided into five ordinal categories, creating a square matrix of 25 cells. A new catalogue of 20,669 English words descriptive of personality, emotion, behaviour, and power is also presented. The catalogue is more comprehensive than previous catalogues, and is novel in its inclusion of intrapersonal, group, and societal behaviours. All words in the catalogue were scored according to the atlas, facilitating visualisation in two dimensions. This enabled a contiguous and novel comparison of existing psychological taxonomies, as well as broader societal concepts such as leadership, ethics, and crime. Using the atlas, a novel psychological test is developed with improved sensitivity and specificity.

Key words

Personality, Emotion, Behaviour, Affiliation, Dominance

Introduction

Since antiquity, humans have sought to identify a framework for understanding the whole person, encompassing personality, emotion, and behaviour[20,22,23]. Raymond Cattell, who introduced factor analysis to personality research, originally trained as a chemist and stated that his lifelong ambition was to identify a model of personality with similar explanatory power as the periodic table of elements[47]. Taxonomies are systems of measuring or classifying phenomena that facilitate precise communication and common understanding. The law of

parsimony states that 'the simplest explanation of an event or observation is the preferred explanation'[1], or in other words, 'Everything should be made as simple as possible, but not simpler.'[48]. Taxonomies may be said to be parsimonious if they precisely describe a broad range of phenomena with the minimum number of independent variables[49]. The characteristics of a parsimonious model of personality are well understood[20,21,30], yet no 'periodic table' or grand theory of the whole person currently exists[20,21]. There remains disagreement about the number or nature of personality factors[50] giving rise to the diverse variety of personality constructs[21]. Identifying a grand theory has been deemed one of the most important goals of personality research[51] with impact for both diagnostic and therapeutic understanding. Psychological connections have been observed between the concepts of emotion, behaviour and personality[52–59]. It was therefore hypothesised that a taxonomy may encompass all three concepts of emotion, behaviour and personality. A unifying taxonomy encompassing personality, emotions and behaviour would be more parsimonious than three separate taxonomies. It was hypothesised that the lexical approach could be utilised to identify an overarching taxonomy of personality, emotion, and behaviour.

Lexical analysis

The lexical hypothesis states that, 'All aspects of human personality, which are or have been of importance, interest or utility, have already become recorded in the substance of language'[29] and, 'When an idea is important, people are likely to have a word for it ... the more important something is, ... the more words there are likely to be'[60]. Lexical analysis is typically performed in two phases. Firstly, the words relevant to a topic are catalogued. Secondly, the catalogue is analysed to identify a parsimonious taxonomy that reduces complexity, simplifies categorisation and enhances communication. The completeness of the catalogue is desirable to ensure optimal selection of the form and parameterisation of the taxonomy. Conversely, an incomplete catalogue may lead to inappropriate selection of the taxonomic form or incorrect parameterisation.

Previous taxonomies of personality derived from lexical analysis, such as 16PF[61], HEXACO[62] and five-factor models[5] have largely focussed upon adjectival descriptors of personality. Verbs and nouns have largely been excluded[63], with notable exceptions[64,65], therefore leading to incomplete catalogues. In the context of lexical analysis, there are a range of verbs and nouns that are related to adjectival descriptors of personality traits. For example, verbs are used to describe interpersonal interactions (e.g. hit, hug, and harmonize) whereas abstract nouns may be used to describe emotions (e.g. hate, happiness and

helplessness) and other nouns may be used to describe power (e.g. celebrity, chief, rich and poor).

Interpersonal circumplex

For thousands of years, circles have been used in various ways to map the breadth of the human experience[66]. For instance, ancient Greek astrology divided the sky into twelve equal portions of a circle, and from that derived the star-signs which are still discussed in popular culture today. The Interpersonal Circumplex was born out of this tradition. In the early-mid twentieth century, the American psychoanalyst, Harry Stack Sullivan, began mapping theories of interpersonal dynamics in circular forms. One sketch from 1948 was similar to the subsequent Interpersonal Circumplex; it depicts two individuals in an interpersonal interaction, connected by one arc representing a disaffiliative force, and two arcs representing affiliative forces. After Sullivan's death, the Kaiser Foundation Group, which included Timothy Leary, operationalised Sullivan's concepts and were credited with discovering the circumplex. Leary continued developing the Interpersonal Circumplex, which gained international recognition through his seminal text, 'The Interpersonal Diagnosis of Personality'[23]. The Interpersonal Circumplex became a watershed theory in personality psychology, and although it is not often used in contemporary application, it remains a foundational influence.

Interpersonal Circumplex taxonomies[23,67,68] are characterised by radially divided concentric circles superimposed over two orthogonal axes (Fig 1A). When used as a taxonomy of personality, affiliation and dominance have commonly been used as the orthogonal dimensions[23,69–72]. Other researchers have used a range of synonymic terms for affiliation and dominance including: agency/communion[73], getting-ahead/getting along[74], ambitious/agreeable[75], assertiveness/compassion[76], dominant/friendly[67,77] and domineering/nurturant[78]. The superimposed concentric circles measure intensity, with the least intensity at the origin and gaining intensity in proportion to the radius. The most extreme behaviours and personality descriptors are located on the perimeter of the outermost concentric circle. Many psychological constructs have previously been mapped onto Interpersonal Circumplex models; for example, Fig 1B shows the components of the Dark Triad mapped onto the Circumplex[79]. The circumplex has also been used as a taxonomy of emotion in which case the valence/affect and intensity/activation are often used as the orthogonal dimensions[80–82].

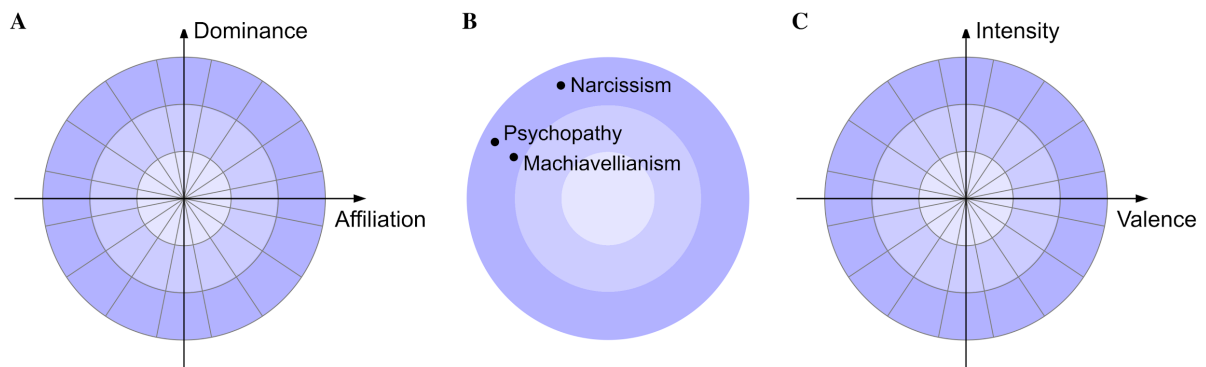


Fig 1. The Interpersonal Circumplex

(A) Interpersonal Circumplex used as a taxonomy of personality[23,68,83] with radially divided concentric circles superimposed over the two orthogonal dimensions of affiliation and dominance. (B) The Interpersonal Circumplex used to represent the Dark Triad[79]. (C) The Interpersonal Circumplex used as a taxonomy of emotion.

Criticisms of the circumplex approach have included the apparent subjectivity of item placement[84], difficulty in operationalising due to overly numerical application[85], the superior performance of alternative taxonomies[86] and the inability to place personality disorders[87]. Proponents of the Interpersonal Circumplex have used methodological devices such as rotations in an apparent effort to overcome its inherent limitations[88]. In addition to these criticisms observed by others, three additional deficiencies of the Interpersonal Circumplex were identified in the present research. Firstly, that the constraints imposed by the use of concentric circles to measure intensity, impose correlation between otherwise orthogonal axes. Secondly, the Interpersonal Circumplex does not make allowance for behaviours and traits of neutral dominance (Fig 2A) or neutral affiliation (Fig 2B). Finally, Interpersonal Circumplex taxonomies are ambiguous as to the placement of extreme behaviours. For example, a behaviour that is both maximally dominant and maximally disaffiliative, such as killing, is unable to be mapped onto the Interpersonal Circumplex models with precision due to the concentricity constraint (Fig 2C).

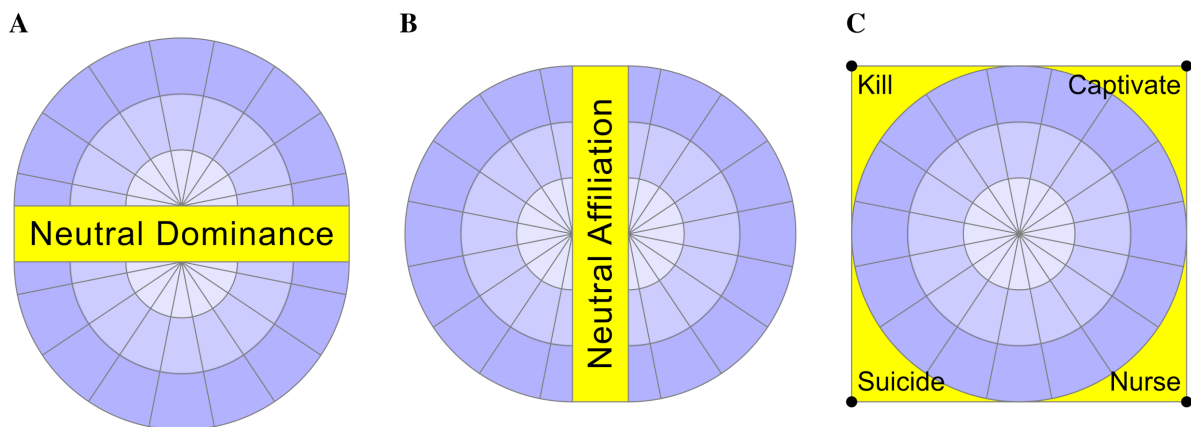


Fig 2. Deficiencies of the Interpersonal Circumplex

(A) Adominant behaviours (neutral dominance) not specifically identified on previous versions of the Interpersonal Circumplex, for example: ‘separate’, ‘gamble’ and ‘cooperate’. (B) Intrapersonal behaviours (neutral affiliation) not described on previous versions of the Interpersonal Circumplex[89] ‘innovate’, ‘learn’ and ‘stagnate’. (C) Maximally dominant and disaffiliative behaviours, such as killing, fall beyond the limits of the outermost concentric circle of the Interpersonal Circumplex.

The Abridged Big Five-Dimensional Circumplex (AB5C)[90,91] advances the Interpersonal Circumplex and measures many additional traits, thus overcoming some of the identified deficiencies. Although the Abridged Big Five-Dimensional Circumplex incorporates behaviours and traits of neutral affiliation and dominance, it retains the requirement for intensity to be measured by concentric circles, perpetuating the imposed correlation between axes and the ambiguous placement of extreme behaviours.

Proposing a unifying taxonomy

The characteristics of a parsimonious taxonomy of personality have previously been described[20,21,30], four of which are:

1. **Comprehensive:** Encompassing all of what psychologists mean by ‘personality’[20,21].
2. **Synthetic:** Integrating knowledge of the various components of personality within a single coherent framework[20].

3. **Mechanistic:** Encompassing the biological basis of the mechanisms responsible for personality[20,21].
4. **Specific:** The dimensions of the taxonomy should be orthogonal and divisible into non-overlapping categories so that phenomena may be uniquely placed within the taxonomy[30].

No current taxonomy appears to satisfy all these criteria. Narrow taxonomies, such as the Dark Triad[79] are neither comprehensive nor synthetic, as they specifically limit their scope to a particular subset of behaviours (e.g. Psychopathy, Narcissism, and Machiavellianism). Factor taxonomies, such as 16PF[61], HEXACO[62] and five-factor models[5] are derived using dimensional reduction techniques such as principal components analysis or factorisation. Although there is clear evidence of heritability of personality characteristics[92], there is currently no accepted theory as to the neurological mechanisms that support the dimensions of factor models[93]. Other criticisms of five-factor models include the unexplained correlations between dimensions[5–10] and that factor models have been assessed as being insufficiently comprehensive[94]. For these reasons, both narrow and factor taxonomies were excluded from consideration as the foundation of a parsimonious taxonomy.

In contrast to five-factor models of personality, the dimensions of the Interpersonal Circumplex, affiliation and dominance, have strong biological support. Functional neuroimaging has identified independent neural pathways for affiliation and dominance (see Fig 3)[95]. These neural pathways have been identified in non-mammalian vertebrates[96] and are evident across five major vertebrate lineages of mammals, birds, reptiles, amphibians, and teleost fish[97]. The psychoactive hormones of oxytocin and testosterone have also been correlated with affiliation and dominance[98,99]. Additionally, the evolutionary bases of affiliation and dominance have been extensively investigated and established[100–102]. Given the comprehensive usage and biological basis for the selection of affiliation and dominance, we conclude that affiliation and dominance satisfy the criteria for being mechanistic and are therefore suitable candidates for the dimensions of a parsimonious taxonomy of personality.

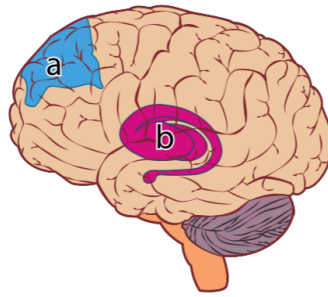


Fig 3. Areas associated with Affiliation and Dominance in the human brain.

(A) The dorsolateral prefrontal cortex is related to dominance and submissiveness. (B) The Putamen is related to affiliation.

To avoid ambiguity of trait placement and achieve the requisite level of specificity required for parsimony, two structural modifications to the Interpersonal Circumplex are proposed. Firstly, to overcome the imposed correlation between dimensions, it was proposed to remove the concentric circles. Therefore, behaviours and personality traits may be measured independently by reference to each orthogonal axis. Secondly, to allow for the categorisation of behaviours and traits of neutral dominance and affiliation, one of the ordinal categories for each dimension must be created to specifically allow for neutral behaviours. In keeping with the concept of neutrality, this category will be assigned the value of 0.

In order to categorise phenomena according to the taxonomy with specificity, each dimension must be divided into non-overlapping categories[30]. Ordinal categories are proposed that measure the enduring effect of behaviour on observers (Table 1). Behaviours that have negligible effect on observers were scored towards the centre of the scale. Behaviours that have an enduring impact on the observer were scored towards the extremity of the scale. Affiliation was scored as positive and disaffiliative behaviours as negative. Dominant behaviours were scored positive and submissive behaviours, negative.

	Affiliation	Dominance
2	The actor asserts, proffers, evokes or induces enduring affiliation with others	The actor asserts, proffers, evokes or induces enduring dominance over others
1	The actor asserts, proffers, evokes or induces transient affiliation with others	The actor asserts, proffers, evokes or induces transient dominance over others
0	The actor's behaviour is neutral	The actor's behaviour is neutral
-1	The actor asserts, proffers, evokes or induces transient disaffiliation with others	The actor asserts, proffers, evokes or induces transient submission to others
-2	The actor asserts, proffers, evokes or induces enduring disaffiliation with others	The actor asserts, proffers, evokes or induces enduring submission to others

Table 1. Temporal scale of enduring effect an actor's behaviour has on observers.

An actor may attempt to assert, proffer, evoke or induce states of affiliation and/or dominance with respect to an observer; however, the response of the observer is inherently influenced by their perception of the actor's behaviour/emotion. These perceptions may be dependent upon many factors, such as individual neurobiological variation in personality, cognitive states including attentional networks, power status, context, and the cultural milieu. For these reasons, the proposed classification scale does not specify or infer causal relations, rather, it identifies correlations rated typical of general cases.

Representative examples of the application of this table include:

1. Behaviours that are maximally disaffiliative and maximally dominant (-2,2) include 'maim', 'attack', as well as the absolute behaviour, 'kill'. Observers of these behaviours may label the actor as 'cruel', 'violent' or 'criminal'. Antecedent emotions to such behaviours and traits include 'rage', 'anger' or 'wrath'.
2. Behaviours that are maximally disaffiliative and maximally submissive (-2,-2) include 'self-harm' and the absolute behaviour, 'suicide'. Observers of these behaviours may

label the actor as 'dejected', 'morose' or 'melancholic'. Antecedent emotions to such behaviours and traits include 'despair', 'emptiness' or 'futility'.

3. Behaviours that are maximally affiliative and maximally submissive (2,-2) include 'worship', 'honour' and 'adore', and the absolute behaviour, 'martyrdom'. Observers of these behaviours may label the actor as 'reverent' or 'devoted'. Antecedent emotions to such behaviours and traits include 'love', 'veneration' and 'devotion'.
4. Behaviours that are maximally affiliative and maximally dominant (2,2) include 'charm', 'excite' and 'inspire'. Observers of these behaviours may label the actor as 'exuberant', 'dynamic' or 'charismatic', and the absolute behaviour, 'perfection'. Antecedent emotions to such behaviours and traits include 'ecstasy', 'passion' or 'triumph'.
5. Behaviours that are of neutral dominance and affiliation (0,0) will be rarely noticed by either the actor or observer(s). These neutral emotions and behaviours include the awareness of our basic senses and involuntary behaviours such as 'digestion' and 'respiration'.

The atlas taxonomy addresses the deficiencies of the Interpersonal Circumplex, thus forming a parsimonious taxonomy of human personality. By removing the radial and concentric constraints and dividing each axis into ordinal divisions, a matrix structure is created, see Fig 4. The matrix's standard taxonomic form[30] resembles other parsimonious taxonomies, such as the periodic table of elements and cartographic maps. This enables the full spectrum of interpersonal, intrapersonal, dominant, submissive and adominant behaviours to be precisely measured.

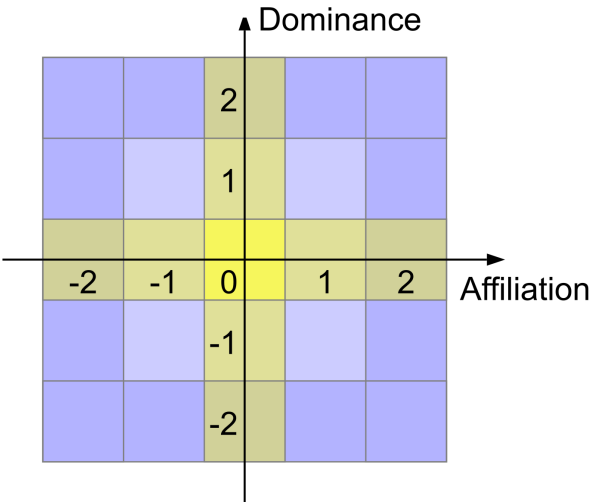


Fig 4. Atlas of personality, emotion, and behaviour.

Matrix taxonomy of personality created by ordinal division of the affiliation and dominance dimensions. Neutrally affiliative and dominant behaviours and traits are shown in yellow. Behaviours may be independently classified by reference to each orthogonal axis.

Studies 1 to 4 in the present research seek to confirm that the proposed atlas taxonomy is both comprehensive and synthetic. If so confirmed, the atlas taxonomy will be demonstrated to be comprehensive, synthetic, mechanistic and specific, and will therefore satisfy the criterion for being a parsimonious taxonomy of personality. Study 5 in the present research develops a pilot psychological test founded upon the atlas that may be used as the basis for future research using the atlas.

Study 1

The objective of this Study was to catalogue all English language words descriptive of human interaction and emotion.

Method

WordNet[103] was identified as a reputable lexical database for the English language developed within the Princeton University Department of Psychology. Multiple scans of the

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WordNet repository cataloguing all words descriptive of emotions, behaviour, personality and power. The Oxford and Merriam Webster thesauri[104,105] were used to identify synonyms and antonyms for all catalogued words. The synonyms and antonyms descriptive of emotions, behaviour, personality and power were added to the catalogue. This process was repeated until no further words were identified. The Oxford English Dictionary[104] was used to classify the part of speech for each word.

To achieve consistent categorisation, the four concepts were defined as follows: behaviour is an observable action (typically verbs), emotion is the perception of a neurological impulse that initiates behaviour (typically abstract nouns)[106], personality traits are descriptors of characteristic behaviours (typically adjectives), and power is the capacity to influence another, or the capacity to avoid being influenced by another (typically nouns)[107–110]. The concepts of power and the trait of dominance are often conflated, yet others have sought to differentiate these concepts[111]. Power has been observed to have a significant moderating effect on personality and emotion. Given the moderating effect of power on personality and emotion, the present research distinguished power from other concepts where possible.

Results

20,669 words were identified as being descriptive of personality, emotion, behaviour and power. A summary of the words is shown in Table 2.

<i>Part of Speech</i>	<i>Domain</i>				
	Behaviour	Emotion	Personality	Power	Total
Adjectives	-	-	4,356	171	4,527
Idioms	3,675	532	1,915	464	6,586
Nouns	1,345	2,705	1,047	1,335	6,432
Verbs	3,124	-	-	-	3,124
Total	8,144	3,237	7,318	1,970	20,669

Table 2. Summary of words denoting personality, emotion, and behaviour and power.

Examples of the 1,970 words descriptive of power, included ‘rich’, ‘poor’, ‘skilled’, ‘unskilled’, ‘employed’, ‘unemployed’, ‘king’ and ‘servant’.

Discussion

Previous catalogues of adjectives are in the range of 1,710 to 4,500 words[65,112–114]. The limited size of previous catalogues casts doubt on the completeness of taxonomies derived from them. Reconciliations of the new catalogue were performed with previous catalogues where available. The reconciliations showed that previous catalogues included archaic words that are uncommon in modern dictionaries, such as ‘indeliberate’, ‘granousier’, ‘eremitic’ and ‘scientistic’. The reconciliation showed that currently popular words, such as ‘adaptable’, ‘charismatic’, ‘perfectionist’ and, ‘withdrawn’, had been omitted from earlier catalogues. This is demonstrative of the ability of the catalogue to be culturally sensitive. The existence of modern online word catalogues, dictionaries and thesauri greatly assisted the compilation of the catalogue, and thus formed the most comprehensive catalogue of English-language words in personality research to date. The procedures adopted, as well as the absolute number of words identified, formed a catalogue that was considered to be unbiased and sufficient for the purposes of identifying a comprehensive taxonomy.

Despite the comprehensiveness of the catalogue, without replication, it is possible that important descriptors of personality, emotion or behaviour may have been overlooked.

Study 2

The objective of this study was: firstly, to confirm that the words in the catalogue can be classified according to the atlas matrix taxonomy, and secondly, to score a subset of up to 20% of the catalogued words.

Method

A Delphi approach was utilised to obtain a reliable consensus of opinions of a small group of health professionals[115]. The Delphi approach requires a group of experts to independently record their professional opinion and then achieve consensus through discussion. A cognitive and behavioural neurologist and three registered clinical psychologists assisted as linguistic judges. It was determined that a relatively small subset of the catalogue could be manually scored and therefore a five phase Delphi approach with sampling was used.

Phase one: To ensure the Delphi process covered all of the 25 cells of the atlas, the author performed an initial scoring of the entire catalogue. From this initial scoring, 10 nouns, 10 verbs and 10 adjectives were selected from each of the 25 cells of the atlas (750 words in total).

Phase two: Without being informed of the scoring performed in Phase one, the judges were asked to independently score each word. The judges then discussed their scores, during which, the judges were encouraged to revise their individual scoring until consensus was achieved.

Phase three: Synonyms of words scored in Phase two were identified from which were selected 35 nouns, 35 verbs and 35 adjectives from each cell (1,925 words in total). These word lists were collectively discussed by the judges. The scoring of each word was reviewed by exception until consensus was achieved. It was observed in this phase that the judges referred to synonyms and antonyms of other words selected to achieve a level of consistency in their scoring. Subsequent to the group process, the author and neurologist rescored the remainder of the catalogue.

Phase four: The author selected 1,620 antonymic word pairs. The word pairs consisted of words made opposite by prefix or suffix, such as 'observant/unobservant', 'engaged/unengaged' and 'merciless/merciful', and word pairs identified as antonyms in either or both of the reference thesauri. If both words had previously been scored as

diametrically opposite in earlier phases, the scoring was retained. If both words had not been previously scored as diametrically opposite, a manual revision of their scoring was performed to achieve exact opposite scoring. These word pairs were then independently reviewed by three judges. In cases where at least two of the three judges had assigned identical scoring to word pairs, these word pairs were considered to be archetypal. The remaining words scored by the judges in Phase three were also deemed to be archetypal.

Phase five: The author reviewed the scored archetypal words and made minor amendments to ensure that synonyms, conjugates and inflections were proximately located where appropriate. The judges then performed an overarching review of a summary of 1,800 archetypal words until consensus was achieved by all judges (see S1 Poster).

It was identified that there are examples of English language words that can be used in multiple contexts. In these situations, the words are usually classified as different parts of speech. For example, 'bully', 'calm' or 'tidy' all of which can all be descriptive of a behaviour (verb) or personality trait (adjective). In these instances, the words were categorised by the judging panel in the same cell irrespective of the context. An example of a word that can be used in different contexts but would be categorised in different cells is 'humble'. 'Humble' used as an adjective was scored by the reviewers as having affiliation of 1 and dominance of -2. When used as a verb, 'humble' was scored as having affiliation of -2 and dominance of 1. When such instances were detected, the word was excluded as being candidate archetypal words. However, due to there being relatively few words in the cell (1,-2) and the word 'humble' was retained as an archetypal word for this cell.

Results

Of the 1,620 antonymically opposite word pairs, 27 were rejected by two or more judges leaving 1,593 word pairs remaining. Of the remaining 1,593 word pairs, 150 were opposite due to a prefix or suffix, 711 were identified as antonyms in both reference thesauri and 731 were identified as antonyms in one of the reference thesauri. Consensus amongst the four judges was achieved for 96% of word pairs, with a single dissenting judge on 4% of word pairs. The near complete consensus was viewed as confirming that the catalogued words can be successfully classified using the atlas. Table 3 shows an example of a personality trait, emotion and behaviour for each cell in the atlas taxonomy.

Dominance	Domain	Affiliation				
		-2	-1	0	1	2
2	Emotion	hate	arrogance	enthusiasm	courage	euphoria
	Behaviour	attack	defy	pioneer	advance	captivate
	Personality	cruel	arrogant	energetic	brave	charismatic
1	Emotion	contempt	frustration	interest	confidence	happiness
	Behaviour	slander	argue	action	negotiate	laugh
	Personality	nasty	inflexible	efficient	confident	joyful
0	Emotion	detachment	instability	consciousness	stability	harmony
	Behaviour	dissociate	neglect	sense	attend	attach
	Personality	unfriendly	vague	alive	clear	friendly
-1	Emotion	sadness	anxiety	disinterest	appreciation	admiration
	Behaviour	lament	complain	inaction	relent	endorse
	Personality	joyless	worried	inefficient	flexible	nice
-2	Emotion	dread	cowardice	fatigue	humility	love
	Behaviour	deflate	surrender	stagnate	obey	nurse
	Personality	morose	coward	apathetic	humble	tender

Table 3. Example personality traits, emotions and behaviour applicable to each cell in the atlas.

Colouration applied to assist interpretation. See S1 Poster for an expanded version of this table with 25 words for each combination of affiliation, dominance and domain.

Discussion

The thesauri did not frequently identify synonymic associations between the words descriptive of personality, emotion, and behaviour; for example, the words 'kill' (behaviour) and 'murderer' (personality) were not synonymously related. The reference thesauri did however nominate 'killer' (personality) and 'murderer' (personality) as synonyms. 'Kill' and 'killer' can be linked by virtue of having the same linguistic stem. The linking of stem words was performed manually in the present research; however, it could be automated in future. By supplementing the thesauri derived synonyms with manually linked stem words, a robust association between personality, emotions and behaviours was achieved.

Some emotions are known to give rise to physiological changes[116], such as happiness, love, pride, anger, fear, anxiety, shame, sadness, depression, disgust, contempt, and envy. It was noted that these emotions are located on the outer edge of the atlas. Strong emotions promote high levels of arousal, and the associated physiological changes are thought to lead to an evolutionary advantage by creating a state of readiness for action[117,118]. Conversely, emotions and behaviours at the centre of the atlas are largely occult or involuntary without any sense of urgency. Emotional intensity and readiness for action appear to be correlated concepts, and future analysis with the aid of the atlas may establish causality between these concepts.

Historically, it has been acknowledged that relationships exist between personality, emotions and behaviour, although the nature of these relationships is yet unclear. The present research has illustrated the linguistic associations between the catalogued words. Building upon this, future research may use the atlas as a tool to clarify the nature of the causal relationships between personality, emotion, and behaviour.

Extensive research has been conducted on the human and non-human ability to recognise emotion through facial expression[58,59,119–121]. Several studies have used the Interpersonal Circumplex as a taxonomy for arranging the biological spectrum of facial expressions[72,122–124]. The atlas' inclusion of emotions prompted the categorisation of facial expressions according to the atlas. An artist's impression of the emotions represented in Table 3 is shown in Fig 5. Emoji, which have become ubiquitous forms of electronic communication, have been arranged according to the atlas as shown in Fig 6. The facial expressions shown in Fig 5 demonstrate smooth gradients of expression according to the orthogonal dimensions of affiliation and dominance. The ability of the atlas to represent facial expressions lends support to the efficacy of the two-dimensional model of personality and emotion, as well as the selection of affiliation and dominance as the two orthogonal dimensions.



Fig 5. Artist's impression of emotional expressions according to the atlas.

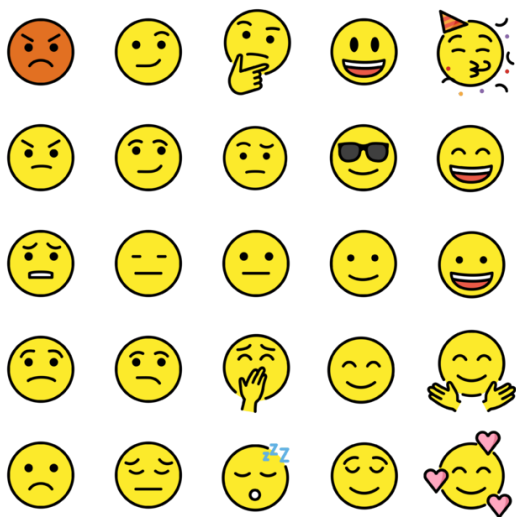


Fig 6. Emoji arranged according to the atlas.

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A limitation of this study is that a large number of words were categorised by a small number of judges and that only 20% of the catalogue was manually scored. These limitations give rise to the possibility of bias. These limitations may be overcome by independent replication with additional judges and greater sample sizes.

Study 3

The objective of this Study was to automate the scoring of words in the catalogue using a spring-based[125] network analysis.

Method

Network theory has been used to visualise and analyse related concepts, including affiliation and dominance. Network theory has previously been applied to both psychological [126,127] and lexical [60,128,129] concepts. Networks consist of 'nodes' joined together by 'edges'. In some network visualisations, such as transport networks, the stations (nodes) are connected, for example by tracks or roads (edges). For such networks, the location of the nodes and edges are physically fixed, and the network visualisation serves as a representation to assist commuters expeditiously travel between locations. Social networks are based on the connection of individual users (nodes) within a relationship network (edges). Networks may be concisely visualised by allowing the nodes to move freely on a two-dimensional surface. Nodes are joined together by edges that either attract or repel other connected nodes.

The equilibrium position of the nodes is determined when the combined attracting and repelling forces are minimised. When equilibrium is achieved, nodes connected by an attracting force are often proximate and nodes joined by a repelling force are normally distant from each other. A hybrid visualisation of networks is one in which some nodes are fixed and other nodes move freely. The attracting and repelling forces of each edge are typically modelled using the physical forces of Maxwell's equations of electromagnetic fields or Hooke's Law of springs[125]. Network representations of related words have been demonstrated by connecting words (nodes) by their synonymic and antonymic (edges) relationships[130,131].

In this Study, a network approach was used to categorise the affiliation and dominance for words not previously scored in Study 2, totalling approximately 80% of catalogue (nodes). Edges representing synonymic links were modelled as an attracting force and antonymic

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links modelled as repelling forces. The use of Hooke's Law to model the attracting and repelling forces ensured that synonyms were closely proximate and antonyms were disparate when visualised using the atlas.

A Python computer program was developed to implement the following steps:

1. The synonyms and antonyms for all catalogued words were obtained from the Oxford and Merriam-Webster thesauri[104,105].
2. First iteration
 - a. For unscored words in the catalogue with 100% (threshold) of their synonyms previously unscored, the equilibrium position was calculated such that the forces of attraction between synonymic words and repulsion between antonymic words were minimised. Hooke's Law was used to calculate the forces of attraction and repulsion. Hooke's Law states that the force needed to extend or compress a spring is proportional to the extension or compression from the resting position. Synonyms that are distant from each other will experience a strong force of attraction whereas synonyms that are close together will experience no force. Conversely, antonyms that are close together will experience a strong repulsive force and antonyms that are distant from each other will experience no repulsive force.
 - b. Step a. was repeated by successively reducing the threshold (initially set at 100%) by 1% until all words in the catalogue were scored.
3. Subsequent iterations
 - a. The equilibrium position for each word in the catalogue was re-calculated in alphabetical order using the location of previously modified word scoring. This process allowed each word to freely move in the atlas, until equilibrium was reached and the words ceased to move.
 - b. This process was repeated until all words achieved their equilibrium position and no further word movements occurred.

Results

A total of 543,830 synonymic pairs and 97,394 antonymic pairs were identified between words in the catalogue. Eight iterations of Step 3. were required until equilibrium was achieved. Table 4 shows the number of words within each cell of the atlas.

<i>domain</i>	<i>dominance</i>	<i>affiliation</i>					Total
		-2	-1	0	1	2	
behaviour	2	449	142	79	66	67	803
	1	343	992	1,514	497	99	3,445
	0	132	1,108	30	1,483	175	2,928
	-1	58	91	164	246	70	629
	-2	32	55	40	52	109	288
emotion	2	135	133	78	60	74	480
	1	189	318	256	169	58	990
	0	83	410	7	282	168	950
	-1	66	243	72	60	73	514
	-2	51	58	47	43	85	284
personality	2	220	279	133	229	79	940
	1	492	755	525	342	108	2,222
	0	267	1,390	10	816	177	2,660
	-1	127	227	374	84	108	920
	-2	39	102	183	115	80	519
Total		2,683	6,303	3,512	4,544	1,530	18,572

Table 4. Frequency of words in each cell of the atlas.

A qualitative review of the word placement by the spring-based network method confirmed that the method accurately placed the majority of words.

Discussion

The spring-based network approach was able to efficiently score all words in the catalogue not previously scored in Study 2. A review of the scored words suggested that the process was accurate and satisfactory for the purpose of analysing existing psychological and social constructs.

Study 4

The objective of this Study was to visualise in two dimensions a wide range of existing psychological, psychiatric and social constructs using the atlas.

Method

A benefit of the atlas is that it is two-dimensional, consequently, a wide range of existing visualisation tools are readily available. One such method of visualisation is based on kernel density estimates[132,133]. Kernel density estimate plots were selected as they may easily visualise the relative density of items in particular regions of the atlas as compared to other regions.

The DSM-5 and ICD-11 were selected as the foremost texts on psychiatric disorders. The five-factor model and Dark Triad were selected as representative personality scales. Leadership, ethics and criminality were selected as important social constructs.

A Python library was developed that processes a list of words. The words were then mapped to their affiliation and dominance scores obtained in Studies 2 and 3. For example, the word 'ordinary' was scored with affiliation of 1 and dominance of 0, or (1,0), similarly 'kill' is translated to (-2,2) and 'love' (2,-2). Points on the atlas were then visualised in two-dimensions using the matplotlib Python library[134].

For each personality construct, a clinical psychologist assigned the most representative single word adjective to each question constituting the construct. For example, the clinical psychologist assigned the word 'extroverted' as being the most appropriate single word adjective to the question 'I am the life of the party'. The DSM-5 and ICD-11 constructs were defined in terms of single word personality traits, emotions and behaviour, and were subsequently compiled into a list for each construct. For good and bad leadership behaviours, leading texts[135–137] were reviewed and the personality traits, emotions and behaviours were catalogued. For criminal behaviours, the criminal codes of several jurisdictions[138–143] were reviewed and the associated behaviours catalogued. For the concepts of good, bad, ethical and unethical, the synonyms in the reference thesauri[104,105] were catalogued for each term.

Results

The results of this Study are visualised in Fig 7.

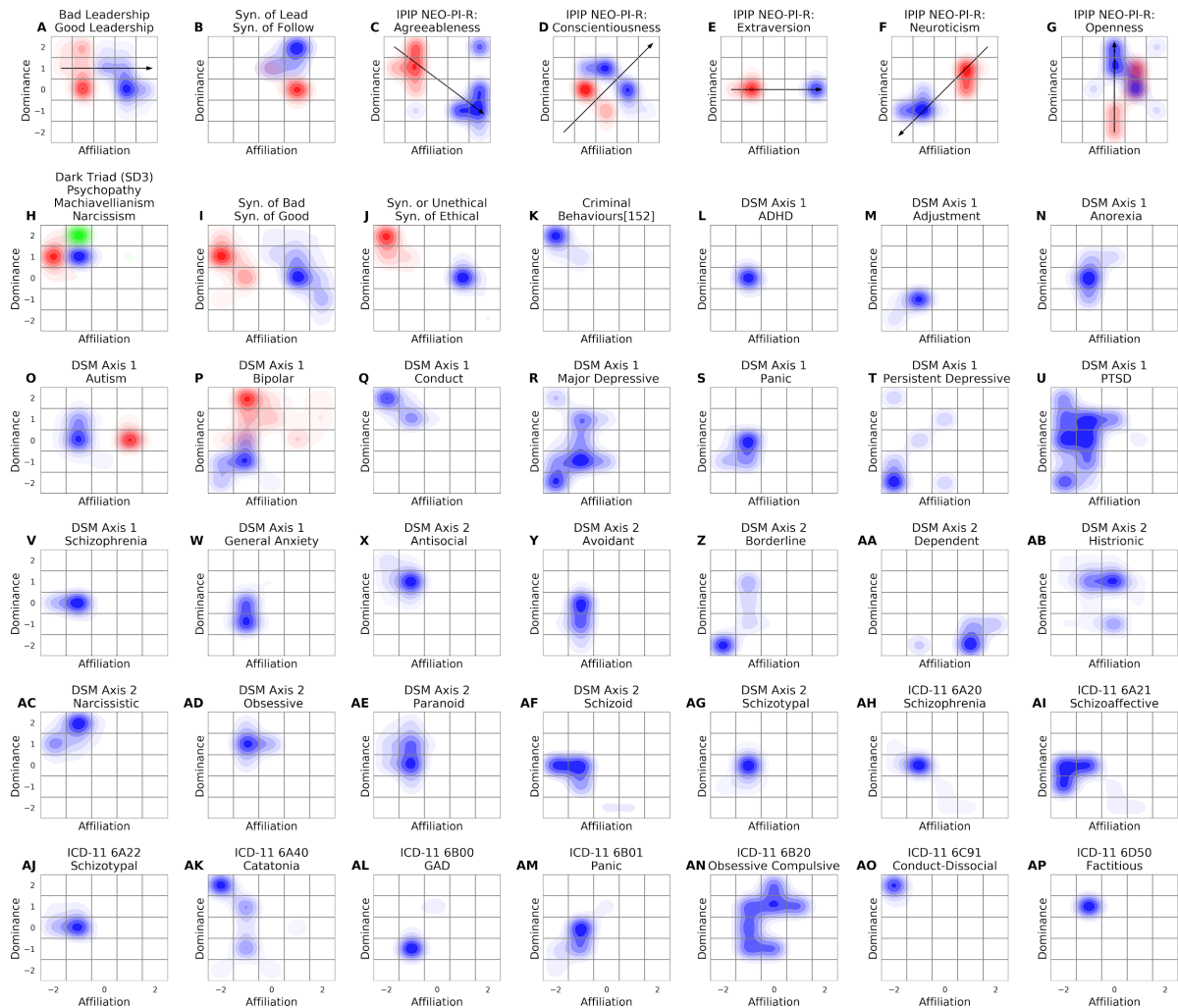


Fig 7. Visualisation of social and psychological constructs and personality disorders.

(A) Good leadership (Blue) and bad leadership (Red)[135–137]. (B) Synonyms of Lead (Blue) and Follow (Red). (C-G) IPIP-NEO-120 Five Factor Model[144,145]. Positive valence (Blue), Negative valence (Red). (H) Dark Triad[79]. Narcissism (Green), Machiavellianism (Blue), Psychopathy (Red). (I) Synonyms of Good (Blue) and Bad (Red). (J) Synonyms of Ethical (Blue) and Unethical (Red). (K) Criminal behaviours[138–143] DSM-5 personality disorders[19]. Positive valence (Blue), Negative valence (Red). (AH-AP) ICD-11 Mental, behavioural or neurodevelopmental disorders[146].

Discussion

It was demonstrated that the atlas can be used to visualise a range of important psychological and social taxonomies (Fig 7). The Dark Triad[79] was visualised by its authors using the Interpersonal Circumplex (Fig 1B). The similarity of the representation between the circumplex and atlas (Fig 7H) suggests convergent validity to the atlas in this instance. Other examples of convergence include psychopathy (Fig 7H), agreeableness (Fig 7C - negative valence), DSM-5 conduct disorder (Fig 7Q), ICD-11 Conduct-dissocial Disorder (Fig 7AO) and criminality (Fig 7AO) which converge in cell (-2,2) of the taxonomy. Similarly, the related concepts of good (Fig 7I), ethical behaviours (Fig 7J) and agreeableness (Fig 7C - positive valence) converge in the cells adjacent to (2,0). These findings match intuitive expectations about the co-location of certain constructs, and provide preliminary evidence for the convergent validity of the atlas.

The atlas was able to visually demonstrate and differentiate the poles of multi-pole concepts, such as concepts defined by poles of positive and negative valence. For example, the subsidiary concepts constituting the Dark Triad (Fig 7H), Autism (Fig 7O), Bipolar (Fig 7P), Five Factor Models (Fig 7C-G) and social concepts such as leadership (Figs 7A and 7B) and ethics (Figs 7I and 7J). Of these multi-pole concepts, the visual delineation was least distinct between the two poles of openness (Fig 7G). Social concepts such as good and bad leadership (Fig 7A), leading and following (Fig 7B), good and bad (Fig 7I), and ethical/unethical (Fig 7J) do not appear to have been previously visualised using the Interpersonal Circumplex, yet were easily plotted and differentiated when visualised using the atlas. This may have implications for the practical application of the taxonomy to group and cultural dynamics.

The observed correlations between the five factors of five-factor models has hitherto evaded theoretical explanation[6,10,147,148]. However, the representation of the vectors facilitated by the atlas appears to provide a basis for understanding the observed correlations. The correlation between vectors may be calculated by determining the cosine of the angle between vectors at the point of intersection[149]. For example, neuroticism has been consistently observed to be negatively correlated with the other factors of five-factor models, which is consistent with the calculated correlation using the vector approach. Further confirmation of this result would represent strong evidence of there being two fundamental dimensions of personality.

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The proposed atlas introduces a novel approach to visualising psychological and social concepts. There are, however, several hundred existing psychological constructs in existence and one limitation of this study is that only a small number have been visualised. The atlas could be further validated by visualising additional psychological constructs.

Study 5

The purpose of this Study was to develop a pilot psychological test that may form the basis of future research based on the atlas.

Method

To be comprehensive, it was determined that the psychological test must ask questions from all cells of the atlas. However, the centre cell of the taxonomy (0,0) identifies basic functions of living, such as occult emotions and involuntary and reflexive behaviours. Measuring involuntary and reflexive behaviours is unlikely to be of interest to individuals or personality researchers, and therefore the (0,0) cell was excluded from the test. After excluding the centre cell, 24 cells remained. It was determined that a single question could compare two cells simultaneously by asking dipole questions, where each option is sourced from a different cell, for example 'Are you more often happy or unhappy?'. From this it was inferred that the minimum number of questions required for the proposed psychological test was 12.

Sensitivity and specificity are statistical measures often used to assess the performance of binary classification tests, and were presently used to determine the optimal configuration of the 12 dipole questions. The concept of sensitivity measures the proportion of correctly identified positives, and specificity measures the proportion of correctly identified negatives. To achieve high levels of sensitivity and specificity, a parsimonious test must ask questions that maximally distinguish the concepts under consideration. Greater distinction was hypothesised for antonymic binary choice questions as opposed to near synonymic binary choice questions. For example, antonymic binary choice questions such as 'Are you usually friendly or unfriendly?' are likely to have greater sensitivity and specificity when compared with near synonymic binary choice questions such as, 'Are you usually friendly or polite?'. Therefore, the 12 dipole questions were restricted to antonymic binary choices.

In a matrix of 24 cells, there are ${}_{24}P_{24} \approx 10^{23}$ permutations of binary questions that could be asked of the respondent. It is not possible with modern computational techniques to test all

10^{23} permutations in order to identify the combinations that maximise the overall contrast, therefore, a simulation and alpha-beta pruning[150] approach was used to determine which combinations maximise the average distance between the possible antonymic binary pairs.

Three measures were developed to compare the efficacy of various psychological tests and constructs. The first measure was termed 'Completeness' and defined as the proportion of cells in the atlas at which one side of a dipole was located. Tests with higher levels of completeness are likely to be efficacious for a diverse range of diagnostic applications. The second measure was termed 'Diffusion' and defined as the proportion of questions in the test that are represented by the atlas outside of the modal cell containing one side of the dipole. Tests with lower levels of diffusion are likely to have higher levels of sensitivity and specificity. The third measure was termed 'Discrimination' and defined as the average distance between the poles of a dipole as represented by the atlas. Tests with higher levels of discrimination are likely to have higher levels of sensitivity and specificity. A limitation of these measures is that they are only relevant if the research approach is predicated on the use of the atlas.

Results

In total, 4 billion simulations were run, revealing that the average distance between antonymic pairs was maximised when antonymic pairs were selected from opposite sides of the matrix and reflected through the origin (Fig 8). For example, the selection of antonymic word pairs such as blissful (2,2) and despondent (-2,-2) have maximal contrast, and are located on opposite sides of the matrix (Fig 8E). The catalogue contained approximately 3,400 antonymic adjectival word pairs that were maximally contrasting. The alpha-beta pruning refinement revealed that 16 of the 10^{23} permutations maximised the average distance between the possible antonymic binary pairs (see Fig 8). Of these 16 combinations, only one had sufficient antonymic word pairs catalogued to facilitate a psychological test (Fig 8). Therefore, this combination was selected as the basis of the new psychological test. The simulation confirmed that the centre cell (0,0) is theoretically inappropriate for inclusion in the test, as it has no maximally distant pairing. Additionally, there were few antonymic pairs with an endpoint at (0,0).

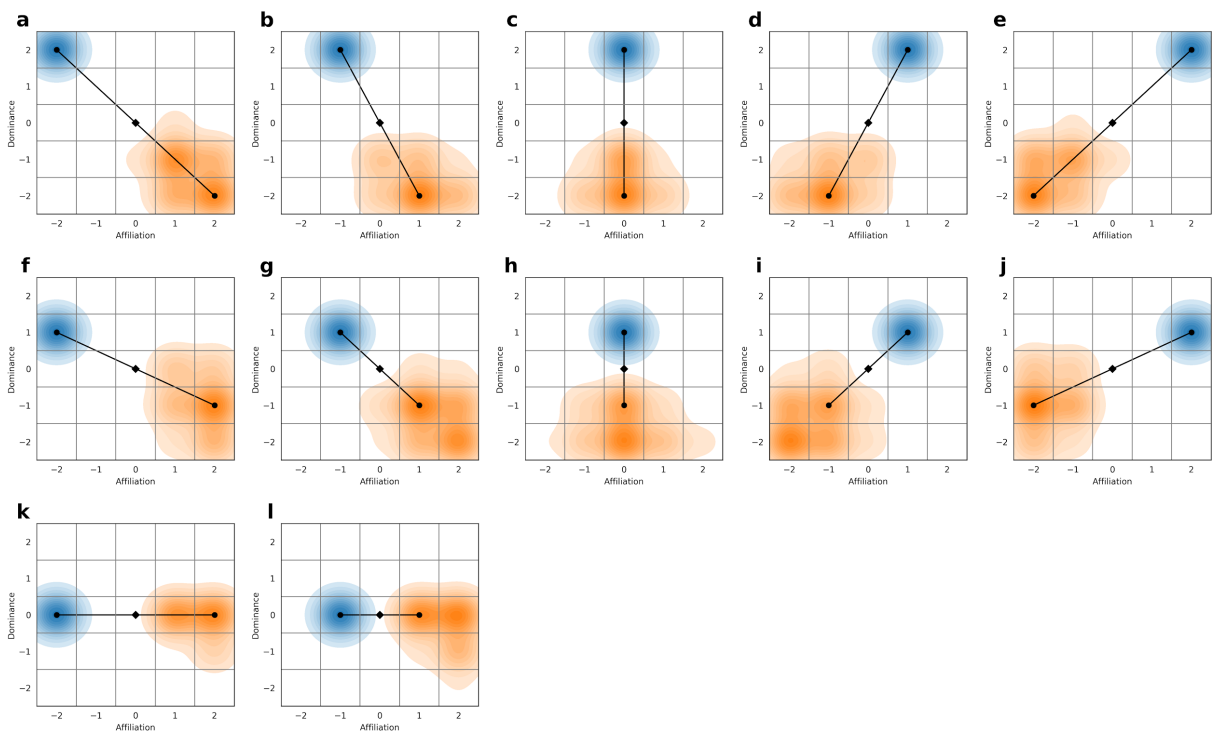


Fig 8. Binary pairs maximising overall contrast of the psychological test.

For each of the 12 graphs, the blue and orange kernel density plots represent each side of the antonymic dipole. The kernel density plots are representative of the 299 observations (99.999999th percentile) out of 4 billion simulations that average distance between the 12 pairs, maximising the overall contrast of the psychological test. The lines shown on each graph represent the binary pairs that have a sufficient number of antonyms identified in the reference thesauri to allow the construction of a psychological test. The diamond at location (0,0) represents the point of reflection about which the antonymic pairs are reflected.

The psychological test derived from the atlas was compared with pre-existing tests and the results are shown in Table 5.

Construct	Diffusion	Discrimination	Completeness	Dipoles
Criminal behaviours	47%	N/A	4%	0
DSM Schizophrenia	61%	0.0	4%	0
DSM Conduct	66%	0.0	4%	0
Dark Triad	33%	N/A	13%	0
DSM Autism Average	63%	1.4	8%	1
DSM Bipolar Average	78%	2.1	8%	1
Lead/Follow	68%	1.1	8%	1
Leadership	74%	1.8	8%	1
Ethical/Unethical	53%	3.3	8%	1
IPIP NEO	64%	1.6	42%	5
Atlas	0%	3.9	100%	12

Table 5. Facets of Psychological Test Efficacy for several psychological tests and constructs

A 12 question test based on the antonyms using the identified antonyms pairs is demonstrated in Table 6. Complete coverage of the atlas is obtained by selecting words located in cells from opposite sides of the atlas. This test may be used as either self-report or observer-report. S2 Dataset lists the antonymic word pairs from which the 12 questions in Table 6 were selected. S3 Questionnaires provides an example of a personality (adjective) and emotion (abstract noun) questionnaires with 48 questions.

ID	Word		Antonym	Cells
1	despondent <input type="checkbox"/>	n/a <input type="checkbox"/>	hopeful <input type="checkbox"/>	(-2,-2) - (2,2)
2	sad <input type="checkbox"/>	n/a <input type="checkbox"/>	happy <input type="checkbox"/>	(-2,-1) - (2,1)
3	uncooperative <input type="checkbox"/>	n/a <input type="checkbox"/>	cooperative <input type="checkbox"/>	(-2,0) - (2,0)
4	disagreeable <input type="checkbox"/>	n/a <input type="checkbox"/>	agreeable <input type="checkbox"/>	(-2,1) - (2,-1)
5	unkind <input type="checkbox"/>	n/a <input type="checkbox"/>	kind <input type="checkbox"/>	(-2,2) - (2,-2)
6	cowardly <input type="checkbox"/>	n/a <input type="checkbox"/>	courageous <input type="checkbox"/>	(-1,-2) - (1,2)
7	discontent <input type="checkbox"/>	n/a <input type="checkbox"/>	content <input type="checkbox"/>	(-1,-1) - (1,1)
8	untalkative <input type="checkbox"/>	n/a <input type="checkbox"/>	talkative <input type="checkbox"/>	(-1,0) - (1,0)
9	unhelpful <input type="checkbox"/>	n/a <input type="checkbox"/>	helpful <input type="checkbox"/>	(-1,1) - (1,-1)
10	selfish <input type="checkbox"/>	n/a <input type="checkbox"/>	unselfish <input type="checkbox"/>	(-1,2) - (1,-2)
11	unambitious <input type="checkbox"/>	n/a <input type="checkbox"/>	ambitious <input type="checkbox"/>	(0,-2) - (0,2)
12	inactive <input type="checkbox"/>	n/a <input type="checkbox"/>	active <input type="checkbox"/>	(0,-1) - (0,1)

Table 6. Example 12 question test based on the atlas.

Discussion

It has been demonstrated that for a psychological taxonomy consisting of a square matrix of 25 cells, the minimum number of questions required for a comprehensive psychological test is 12. It has also been shown that a psychological test consisting of antonymic dipoles taken from opposite sides of the atlas, when reflected about the origin, minimises test diffusion and maximises test discrimination and completeness. Study 2 derived a list of 1,620 antonymic dipoles suitable for such a psychological test (see S2 Dataset). Examples of questions constructed from these antonymic word pairs include: 'Are you generally friendly or unfriendly?', 'Are you generally kind or unkind?', and, 'Are you generally anxious or calm?'. Such questions are unambiguous and succinct.

Whilst such a test would be highly efficient, it is likely that a survey limited to 12 questions will have insufficient statistical power required for discriminatory testing. To achieve the requisite level of statistical power, it is suggested that multiple iterations of the 12 questions will be required (as in S3 Questionnaires). Future empirical studies will be required to determine the number of iterations required to achieve the level of statistical power suitable for particular applications. The atlas facilitated the development of a new form of psychological test that appears more comprehensive and effective than previous tests. However, a major limitation

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of this proposed test is that it has not been subject to normative testing and that the atlas taxonomy requires further validation.

General discussion

The need for a parsimonious taxonomy of human personality, emotion, and behaviour has been repeatedly identified[20,22,51] and is satisfied by the proposed atlas. The dimensions of the taxonomy, affiliation and dominance, have theoretical foundations in neurobiology, zoology and evolution[95–102]. A wide range of existing psychological and social taxonomies and constructs have been quantitatively visualised in these two dimensions. When visualised, the components of these taxonomies and constructs are clearly distinguished. The proposed psychological test, if validated, may offer new insights into personality psychology and other fields when compared to previous psychological tests.

The atlas provides a theoretical basis upon which to redefine concepts such as emotional and social intelligence. Emotional intelligence might now be understood to mean an individual's self-awareness of their emotional state relative to the atlas, and the subsequent ability to favourably alter their emotions. Similarly, it is hypothesised that social intelligence may newly be interpreted as the ability to accurately perceive one's own and other's behaviour relative to their positions within the atlas, to demonstrate competence in a wide range of social behaviours, and to navigate social interactions according to the atlas.

Cattell sought a periodic table. The structure of the atlas bears similarity to a periodic table; however, the dimensions are continuous, and is therefore best classified as an atlas. The atlas has the capacity for multilingual validation of this continuum.

In summary, the present research has introduced a common methodological tool by which the linguistic associations between personality, emotion, and behaviour can be understood, facilitating future research into their causal relationships. A new and internet accessible catalogue of words is presented, substantially larger than previous catalogues, inclusive of verbs, nouns, and adjectives. This two-dimensional atlas has been demonstrated to be theoretically based, and offers empirical advantages over other taxonomies. The advantages of the atlas include its parsimony and unique ability to visualise psychological and social constructs in two dimensions. The applications of these findings potentially extend to translational applications in clinical testing, workplace selection, social and emotional education, and research in the fields of sociology and psychology. Philosophically, the atlas

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offers a potential greater understanding as to how we might better understand both ourselves and others.

Additional information

Code and data availability

All Python code and datasets are available at doi.org/10.6084/m9.figshare.c.4792323 with the exception of data obtained under licence from Oxford and Merriam-Webster Dictionary. The Python code will not operate without the data licenced by Oxford and/or Merriam-Webster. Subsequent to obtaining a licence(s), the Python code automatically downloads the licenced data enabling the Python code to fully operate.

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Competing interests

Anthony E.D. Mobbs has submitted Patent Cooperation Treaty Application Number PCT/AU2019/051233 titled 'An Improved Psychometric Testing System'. This does not alter our adherence to PLOS ONE policies on sharing data and materials.

Chapter 3: Metrology applied to personality, emotion, and behaviour

This chapter has been submitted for publication as a manuscript in December 2020 with the following authors and roles:

- Anthony E. D. Mobbs: Conceptualisation, Methodology, Formal analysis, Software, Visualisation, Writing – original draft, Writing – review & editing
- Simon Boag: Supervision, Writing - Review & Editing, Revising the paper critically for important intellectual content.

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Keywords: metrology, dynamic modelling, Bayesian inference, Game theory, consciousness, measurement, trust, personality, emotion, behaviour, Five-Factor Theory, semantic relatedness.

Abstract

A dynamic model of personality, emotion, and behaviour is proposed with latent variables trust-in-self and trust-in-other(s). Personality traits (characteristic behaviours) are newly explained as an equilibrium of each relationship's dynamics. Metrological measures of trust-in-self and trust-in-other(s) were developed, and a measure of semantic relatedness. These quantitative measures were used to assess the accuracy and precision of popular psychological test questions and the hierarchical nature of faceted taxonomies. Three significant findings were identified. Firstly, psychological test questions appear to be inconsistently interpreted, suggesting their limited efficacy for testing purposes. Secondly, facets commonly associated with the Five-Factor Model are not always hierarchically related to the five major dimensions. Thirdly, the Five-Factor Model's dimensions of neuroticism and conscientiousness should be amalgamated into a single dimension. The proposed dynamic model unifies several prior personality theories, including attachment theory, interpersonal circumplex, and a revised Five-Factor Theory.

Introduction

The Five-Factor Theory of personality is an influential personality model that asserts a biological basis for five orthogonal factors[151]. However, the absence of supporting biological evidence[152,153], the absence of theoretical support[154,155], the absence of a robust evolutionary account[7,156], and unexplained correlations between the five factors[7] cast doubt as to the theory's accuracy. Additionally, trait theories, including Five-Factor Theory, have been criticised for both definitional circularity and reification[13]. These deficits amount to what has been described as a 'crisis of theory'[157]. Two alternative but congruent proposals have been made to overcome this crisis and advance psychological personality science. Firstly, it has been proposed that novel, causal, dynamic, process-driven, more realistic theories of personality must be developed[25,45,158,159], and secondly, psychological theories and measures adopt the vocabulary and strictures of metrology[37,38,160]. This article addresses these proposals by introducing a novel theory of personality that adopts the vocabulary of metrology. Newly defined quantitative measures are then used to assess the accuracy and precision of existing psychological tests.

Metrology is the science of measurement ubiquitously used in the natural sciences and industry[35]. Metrology emerged in response to the internationally recognised need for uniform measures and a common language of measurement. Metrology considers phenomena, bodies, or substances with one or more quantifiable attributes; each quantifiable attribute is known as a measurand. Metrology has been successfully used to develop accurate and precise measures of scalars, vectors and tensors, such as time, distance, location, temperature, power, velocity, force, weight, and space-time[161]. The first internationally agreed measures were length (metre) and mass (kilogram)[36]. Metrology requires a clear definition of the phenomenon being measured (e.g. gravity), the measurands (e.g. force of attraction), the measuring instrument (e.g. spring scale), and measurement units (e.g. Newton). The adoption of metrological frameworks has further been recommended to improve replicability in science[41,42]. The claimed definitional circularity and reification of psychological measures may have been avoided had metrology been adopted sooner. For example, the Five-Factor Theory of personality appears to conflate the phenomena with the phenomena's measurand (e.g. extraversion), leading to claims circularity[13].

Both accuracy and precision are consistently defined by metrology and the social sciences (see Fig 1). Accuracy is the closeness of agreement between a measured quantity value and the true quantity value. Precision is the inverse of the statistical variance and represents the

closeness of replicate measurements. Unlike accuracy and precision, metrology and the social sciences ascribe different meanings to the word 'validity'. Although the definitions used are not entirely inconsistent, the distinction is important. In the social sciences, validity refers to 'the characteristic of being founded on truth, accuracy, fact, or law'[1]. Psychological measurement is often considered valid if the measurement purports to measure what it claims to measure[162].

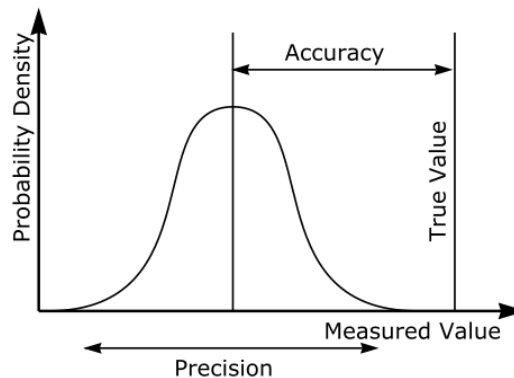


Fig 1: Metrological definitions of accuracy and precision

Accuracy is the closeness of agreement between a measured quantity value and the true quantity value. Precision is the inverse of the statistical variance and represents the closeness of replicate measurements. Metrological validity requires the accuracy and precision to be sufficient for the intended purpose of measurement.

The social sciences identify a hierarchy of validity, with content, criterion, and construct validity being at the peak. Within criterion validity are the concepts of predictive and discriminant validity[163]. These concepts of predictive and discriminant validity are most closely aligned with metrology's construction of validity. From the perspective of metrology, measurement is valid if both the measurement accuracy and precision are adequate for the intended purpose of measurement[35]. Such purpose may include description, classification, discrimination or prediction. More recent social science conceptualisations of validity align with metrology by requiring the purpose of measurement to be specified, to ascertain whether the test is valid[164]. This article adopts the metrological perspective of validity, that is, to evaluate whether both the accuracy and precision of measurement are sufficient for an intended purpose[35]. By way of example, a student's ruler may be sufficiently accurate and precise for describing classroom objects but less valid for building construction, where the accuracy and precision of theodolites may be necessary to achieve validity. More relevant

social science examples may include evaluating whether both the accuracy and precision of psychological measurement is sufficient for the purpose of employment selection or clinical diagnosis of personality disorders.

As metrology requires clear articulation and distinction between a phenomenon and its measurable attributes, known as measurands[35], personality traits must either be the phenomenon itself or the measurands of the phenomenon. Extant personality theory has been criticised for reifying personality traits such that they are both the phenomenon and the measurable attribute[13]. Addressing this inconsistency between extant personality theory and metrology requires identifying the phenomenon with measurable personality, emotion, and behaviour attributes. In a broad sense, personality, emotion, and behaviour arise from the operation of the brain's network of billions of neurons and interconnecting synapses. The phenomenon of consciousness is a function of the brain credited as 'the state of being aware of and responsive to one's surroundings'[104]. Beyond this ordinary meaning of consciousness lies a complex and controversial philosophical debate concerning the nature of consciousness[165–168]. This philosophical debate lies beyond the scope of this article. However, some conceptualisations of consciousness limit consideration to the practicalities of attention to sensory inputs, evaluation, awareness of emotion, goal setting, and the instigation of resultant action[169,170]. This reduced and practical conceptualisation of consciousness is adopted in this article. Consciousness has been extensively associated with sensory processing[171–173], personality[174], emotion[175,176], and behaviour[177,178]. Therefore, consciousness was hypothesised to be the phenomenon that gives rise to personality, emotion, and behaviour.

If, as assumed in this article, consciousness is the phenomenon that gives rise to personality, emotion, and behaviour, the corollary is that consciousness is made up of several interdependent components that operate cohesively as a dynamic neurobiological process[179]. The dynamic processes of consciousness may be interpreted to include sensory inputs that are measurable by, as yet, unidentified latent variables (measurands). Identifying these latent variables has been a dominant topic of interest for several decades[180,181]. This article aims to identify the latent variables by first considering the most likely algorithms that potentially give rise to consciousness (as defined herein).

Game theory[182–184] and Bayesian inference[185,186] are extensively used to model human and animal behaviour and, therefore, likely to be algorithmic components of consciousness. Where incomplete information is available, game theory and Bayesian inference are often combined to model stable equilibriums, known as Bayes-Nash

equilibria[187,188]. Despite the incompleteness of information, stable behavioural equilibria can be achieved that bear a striking resemblance to personality. For example, if an equilibrium condition results in an individual repeatedly engaging in slandering behaviour, their personality may be labelled rude. Game theory analysis is relatively simple from an algorithmic perspective, requiring only a matrix identifying the behavioural choices available to each individual and the payoff from each behavioural combination. Game theory initially defined the payoff using the term 'utility', which is often translated as profit in dynamic economic models. It is presumed that consciousness's purpose is to promote evolutionary survival; therefore, evolutionary survival would be the payoff to be used in dynamic modelling[189,190]. It is proposed to consider Bayesian inference and game theory as successive interdependent algorithmic components of a dynamic model.

Bayesian inference posits that information gathering is an incremental process. Individuals start with an initial, a priori belief or trust in a hypothesis. As information is incrementally received and processed, trust in the hypothesis is revised (the a posteriori belief). For example, an individual may reasonably assume (a priori) that a counterpart is trustworthy. Successive interactions between the individual and their counterpart will strengthen or weaken this belief (a posteriori). Individuals make decisions based on their current a posteriori belief. The atlas of personality, emotion, and behaviour is a recently proposed parsimonious two-dimensional taxonomy with axes affiliation and dominance[191]. The atlas taxonomy was developed using a novel network approach utilising synonyms and antonyms. The atlas taxonomised traits (adjectives), emotions (abstract nouns), and behaviours (verbs) according to the same two-dimensions, affiliation and dominance, and the same five-point integer approximation of a continuous scale. The atlas was able to visualise and differentiate a wide range of social and psychological constructs in two-dimensions. The atlas identifies several thousand adjectival descriptors of personality[191]. Similarly, the parsimonious process of evolution results in tremendous variation in speciation and biological complexity. System dynamics can describe behavioural complexity generated by parsimonious algorithmic processes[192]. An evolutionary explanation of personality suggests that personality would arise from the most parsimonious dynamic processes reliant upon the least possible number of latent variables[193,194]. The language elements from which these latent variables can be deduced are adjectives, nouns, verbs descriptive of personality, emotion, and behaviour.

The atlas identified two orthogonal dimensions, affiliation and dominance, by which the adjectival descriptors of personality could be mapped to a specific location or area[191]. The

atlas' dimensions of affiliation and dominance may be used as the basis for the Bayesian algorithm, provided they are made referable to belief or trust. With reference to Bakan's concepts of agency and communion[195], the atlas' concept of affiliation could be reframed as trust-in-other(s), and dominance could be reframed as trust-in-self (see Fig 2). Reframed in this manner, it is immediately observable that this model parallels and bears a striking resemblance to attachment theory, that uses the two orthogonal dimensions view-of-self and view-of-other(s)[196,197]. The atlas reframed with latent orthogonal dimensions trust-in-self and trust-in-other(s) forms a parsimonious basis for modelling personality using Bayesian inference and Game theory.

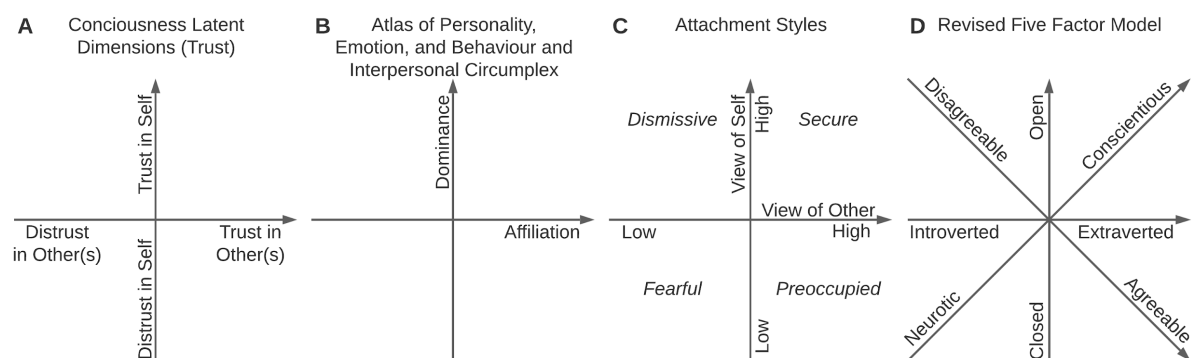


Fig 2. Comparison of Models of Personality.

(A) The latent variables of consciousness: Trust-In-Self and Trust-In-Other(s). Trust being trust of evolutionary survival. These orthogonal variables are predicted to account for personality, emotion, and behaviour. (B) The atlas of personality, emotion, and behaviour[191] and interpersonal circumplex[71] describe the orthogonal dimensions of affiliation and dominance. (C) Attachment Styles. View-of-self and view-of-other are closely aligned with trust-in-self and trust-in-other(s)[196]. (D) The revised Five-Factor Model (with four factors) proposes that neuroticism and conscientiousness are opposite poles of a single dimension. With four factors, the revised model bears a striking resemblance to other two-dimensional models of personality.

Thus far, the latent variables of trust-in-self and trust-in-other(s) have been postulated as giving rise to consciousness. Also postulated has been the Bayesian and game theory algorithmic processes that operate on the latent variables trust-in-self and trust-in-other(s). These components can be arranged, as shown in Fig 3. To operationalise this consciousness model, the brain needs only to store a minimal amount of information, trust-in-self, trust-in-other(s), and the behavioural options available to the self and counterparts. This

minimalist information requirement and algorithmic simplicity are congruent with the evolutionary need for speed and efficiency[198,199].

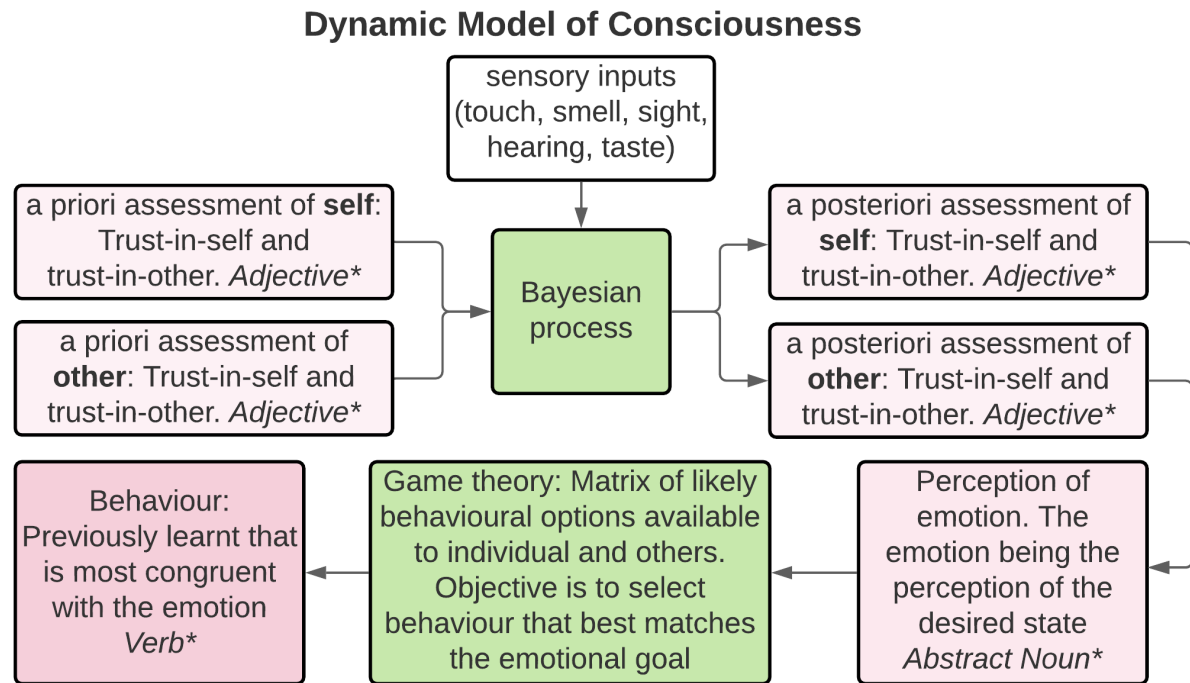


Fig 3. Dynamic Model of the Phenomenon of Consciousness.

The items coloured green are the algorithmic processes of Bayesian inference and game theory. The items in pink are measurable according to the latent variables trust-in-self and trust-in-other(s). Game theory equilibria result in repetitive behavioural patterns that resemble personality traits. An asterisk (*) identifies measurable items. A future enhancement of this model will be the inclusion of power.

Given powers moderating effect on personality, it is likely that behavioural options may best be modelled by power[107,109]. Power has been defined as the capacity for action[200]. According to this conceptualisation of power, a person(s) or object(s) with power have the capacity to perform behaviours congruent with the source of power[201]. An unexpected advantage of this consciousness model is that it appears to apply equally to an individual's interaction with inanimate objects and conceptual, cultural, religious and political beliefs. For example, our willingness to sit on a chair depends on our trust in the chair's capacity (or power) to hold our weight. The evaluation of capacity in this context is presumably an aspect of consciousness that usually occurs without explicit awareness. Secondly, our willingness to subscribe to a cultural, religious or political group depends on how much we trust the group

to assist our evolutionary survival, and our trust in whether the group has the capacity (power) to assist our evolutionary survival. The postulated model of behaviour is dynamic and therefore aligns, at least to some extent, with the conception of situationism rather than individuals having fixed or stable personality traits[202–205]. This implies that an individual may have stable behaviour patterns relative to a particular counterpart(s) but may have entirely different stable behaviour patterns with other counterparts. From the above analysis, it appears that the Bayesian evaluation process occurs mechanistically and without explicit awareness. Conversely, the resultant perception of emotions and states of action readiness are aspects of consciousness, of which there is awareness.

This article proposes two novel measures relevant to personality, emotion, and behaviour. The first relates to the phenomenon of consciousness, and the second relates to the phenomenon of language. For each phenomenon, the measurands, measurement instruments, and measurement units are summarised in Table 1. An extant measure of personality is provided for reference. For the phenomenon of consciousness, the measurands are trust-in-self and trust-in-other(s), the measurement instruments are the elements of language descriptive of personality (adjectives), emotion (abstract nouns) and behaviour (verbs). Over 20,000 such words were catalogued by the atlas and scored according to five-point integer scales of affiliation and dominance[191]. The atlas introduced the dimensions of affiliation and dominance as continuous scales; however, integer approximations were used as a first approximation of the continuous scale. It is now theorised that the latent variables giving rise to affiliation and dominance are trust-in-self and trust-in-other(s). Therefore, it is proposed that the atlas' integer approximation of continuous scales of affiliation and dominance are suitable proxies for the newly recognised latent variables of trust-in-self and trust-in-other(s). No extant quantitative scale of trust was identified; therefore, it was proposed that the measurement units for trust-in-self and trust-in-other(s) be 'psychological trust units'. Psychological trust units are derived from the atlas' integer scales of affiliation and dominance and, therefore, quantitative. Being quantitative units, they are suitable for descriptive and inferential statistics. Therefore, psychological trust units can assess the accuracy and precision of measurement instruments relevant to consciousness.

Phenomenon	Personality traits	Consciousness	Language
Measurands	Personality traits (e.g. extraversion)	Trust-in-self, and trust-in-other(s)	Semantic relatedness
Measurement instrument	Questionnaires with Likert-type scale responses[206,207]	Adjectives, abstract nouns, and verbs catalogued by the atlas[191]	Word lists and a Thesaurus[104,105].
Measurement units	Unspecified	Psychological trust units	Degrees of separation
Unit type	Integer	Integer approximation of real number in the range [-2,2]	Positive integer

Table 1. Measures of personality, emotion, and behaviour using the vocabulary of metrology.

Language is the second phenomenon considered in this article. The lexical hypothesis acknowledges that the phenomenon of language is a primary source of human communication[208]. For taxonomising language, methods of measuring the homogeneity of groups of words are required. The atlas introduced a network analysis method using synonyms and antonyms to arrange catalogued words in two dimensions. Synonyms were located proximate to each other, whereas antonyms were located disparately from each other. This atlas approach is reminiscent of the small world problem[209], popularised as ‘six degrees of separation’[210], in which all humans on earth were able to be linked by a chain of no more than six successive friendship connections. Using this approach, degrees of separation was therefore proposed as a novel measure of semantic relatedness. Degrees of separation is quantified by counting the number of synonymic links required to link words together. Words such as ‘hate’ and ‘abhorrence’ are synonyms and thus semantically proximate. Conversely, the antonyms ‘love’ and ‘hate’ require a minimum of five synonymic steps to link each other, as shown in Fig 4. As would be expected for antonyms, ‘love’ and ‘hate’ are semantically distant. Degrees of separation was therefore adopted as the measure

of semantic relatedness, as shown in Fig 4. Small world methodologies have been applied to computer network topologies[211], social networking[212], and neuronal analysis[213].

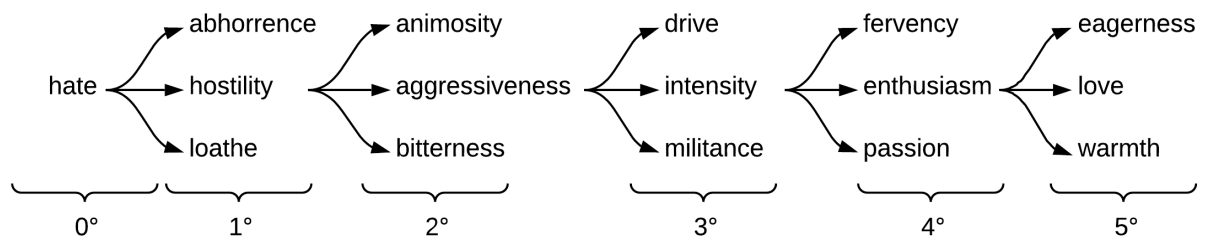


Fig 4. Degrees of separation.

Degrees of separation is a quantitative measure of semantic similarity. Synonyms are semantically proximate, whereas antonyms are semantically distant[104,105,210].

Psychological test questions used in the construction of Five-Factor Model tests are typically presented in sentence form; however, semantic relatedness is limited to operating on collections of words found in thesauri. Therefore, to assess the Five-Factor Model using semantic relatedness, the questions require translation into single words found in thesauri. For example, the questions, “I make friends easily” and “I am the life of the party” are commonly used as measures of extraversion’s positive valence[144,145]. Therefore, it is necessary to translate questions such as these into single-word adjectives, such as “extraversion”, that are amenable to analysis using the measure of semantic relatedness.

Personality measurement generally comprises a battery of questions, where each question is formatted as a sentence[214], for example, “I am the life of the party”. The International Personality Item Pool (IPIP) is a comprehensive and freely-available repository of such questions[206]. The metrological validity of IPIP questions requires each question’s accuracy and precision to be sufficient for an explicitly stated purpose. Each question’s accuracy depends upon whether there is a systematic bias in interpretation between the researcher and respondent. If each question’s interpretation is exactly aligned between the researcher and respondent, then the question would be considered an accurate measurement instrument. The precision of each question depends upon the consistency of interpretation between respondents[215]. If all respondents consistently understand each question, the question would be considered a precise measurement instrument. It is theorised that semantic relatedness can measure both the accuracy and precision of psychological test questions. However, testing accuracy would require each test question’s author to nominate

the adjective they intended to test for. Unfortunately, IPIP does not nominate the relevant adjectival equivalent word for each test question and, therefore, it would not be possible, in practice, to test the accuracy of IPIP questions using semantic relatedness. Nevertheless, testing precision is not dependent upon having a nominated adjectival equivalent for each question; therefore, semantic relatedness would be limited to measuring only IPIP questions' precision.

This article includes four studies. The first study aims to establish a semantic relatedness threshold to differentiate homogeneous from heterogeneous word-groups. The second study aims to use the newly established threshold to measure all IPIP psychological test questions' precision. The third study replicates the second; however, semantic relatedness is replaced by trust-in-self and trust-in-other(s) to measure all IPIP psychological test questions' precision. The fourth study uses trust-in-self and trust-in-other(s) to measure whether the amalgamation of test questions within facets improves test precision.

Study 1

This study aimed to establish a semantic relatedness threshold to differentiate homogeneous from heterogeneous word-groups. Semantic relatedness, and the threshold, may then be used to measure a psychological test questions' accuracy and precision.

Homogeneity implies consistency and sameness, or the absence of variation or contradiction[105]. Being free of variation or contradiction implies that a homogeneous group of words would consist entirely of 1°-synonyms and the absence of antonyms or words synonymic of an antonym. The threshold of homogeneity was, therefore, provisionally selected as the presence of 1°-synonyms only.

Method

Semantic relatedness is a novel measure, and the degrees of separation associated with antonyms was unknown. Semantic relatedness requires only a thesaurus to calculate; however, identifying the minimum number of synonymic links between two words is computationally complex. A Python program was developed to automate identifying the minimum number of synonymic links between two words. The degrees of separation was calculated for 1,593 antonym pairs obtained from the atlas[191]. The upper limit of the threshold was deemed the minimum degrees of separation required to link antonyms.

Results

Seventy (4%) of the antonymic pairs could not be linked synonymically. Of the remaining 1,523 antonymic pairs, the average minimum semantic relatedness was 5.3 (See Fig 5). Antonyms became common at 3° of separation, implying that the upper limit that the threshold of consistency would be 2° of separation. This upper limit of the threshold would require 100% of words in a word collection to be 2°-synonyms to avoid the possibility of antonyms existing within a set of words. However, it was considered possible that 2°-synonyms could be closer in meaning to an antonym. Therefore, the possibility of selecting a 2° threshold was disregarded.

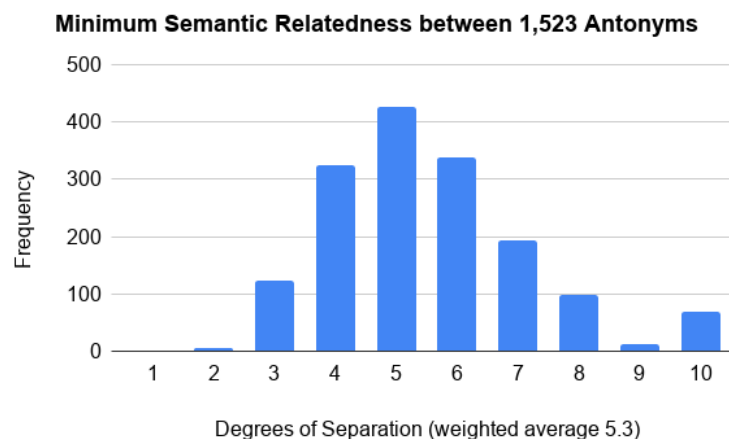


Fig 5. Minimum semantic relatedness between 1,523 antonyms.

1,593 antonymic pairs from the Atlas of personality, emotion, and behaviour were analysed. 70 (4%) antonymic pairs could not be synonymically linked and shown as 10. 1,523 (96%) antonymic pairs could be synonymically linked with a minimum average of 5.3 synonymic links.

Discussion

This study aimed to establish a semantic relatedness threshold to differentiate homogeneous from heterogeneous word-groups, thereby confirming that semantic relatedness could be used to measure psychological test question accuracy and precision. This study confirmed that either 1°- or 2°-synonyms could be used as the threshold to differentiate homogeneous from heterogeneous word-groups. For this article, a word-group was deemed homogeneous provided a minimum of 50% of words were 1°-synonyms. In other situations, the minimum proportion of words required to be 1°-synonyms would require reassessment dependent

upon the purpose of measurement. This study has demonstrated that semantic relatedness can measure psychological test question precision. Semantic relatedness could also be used to measure accuracy, provided the authors of each psychological test question nominated the adjective they intended to test for. In Study 2, a crowdsourcing approach will be used to test the precision of a large number of existing psychological test questions.

Study 2

Study 1 demonstrated that semantic relatedness could measure psychological test question accuracy and precision. This study aimed to use a crowdsourcing approach to measure extant psychological test questions' precision using semantic relatedness. It was hypothesised that readers of psychological test questions would consistently interpret the meaning of the questions. The alternate hypothesis was that readers of psychological test questions would inconsistently interpret the meaning of the questions.

Method

The International Personality Item Pool (IPIP)[206] was selected as a comprehensive repository of freely available personality questions. The IPIP repository consists of 1,506 test questions used in both multi-construct and single-construct personality scales. Amazon's MTurk platform was selected to access crowdsource workers[216]. A crowdsource questionnaire was prepared to ask respondents to nominate the most appropriate adjective to describe an individual's personality exhibiting the characteristics indicated in each IPIP test question. A minimum of 30 and a maximum of 100 crowdsource responses were requested. Once a minimum of 30 responses had been received for each item, additional responses were only required if there was no single majority response. For each IPIP question, the most frequent response (modal response) was selected as the most appropriate adjectival trait descriptor of an individual conforming to the trait description inherent in the question. For responses other than the modal response, the semantic relatedness was calculated, that is, the number of synonymic links required to link the response to the modal response. Given the semantic relatedness measure's novelty, nonparametric tests would be used in preference to parametric[217]. The Macquarie University Human Research Ethics Committee provided written approval for this research on 17/05/2019 (Reference No: 5201953908793, Project ID: 5390).

Results

For the 1,506 IPIP questions, 1,814 respondents provided a total of 56,077 responses of which 50,923 (90.8%) were included in the catalogue. The 9.2% of responses that were not included in the atlas Catalogue[191] generally consisted of spelling mistakes, inflections or slang and were excluded from the analysis. There were 33.8 responses on average per question. For 984 of the IPIP questions with exactly 30 responses, there were 15.5 unique responses on average per question. Five example questions and answers (number of responses in brackets) are:

1. **Sympathize with others' feelings:** empathetic *(15), sympathetic (6), caring (4), compassionate (2), outgoing (1).
2. **Like to begin new things:** adventurous *(8), fresh (3), innovative (2), adventuresome (1), ambitious (1), cool (1), curious (1), fearless (1), hyper (1), initiative (1), optimistic (1), proactive (1), ready (1), risk-taker (1), self-starter (1).
3. **Formulate ideas clearly:** articulate *(5), intelligent (4), analytical (3), clear (3), clear-headed (3), clever (3), concise (3), logical (3), creative (2), eloquent (2), smart (2), astute (1), believable (1), brave (1), calculating (1), communicative (1), cool (1), direct (1), distinct (1), erratic (1), expressive (1), focused (1), imaginative (1), immoral (1), innovator (1), insightful (1), instructor (1), intellectual (1), intuitive (1), levelheaded (1), methodical (1), mindful (1), organized (1), perceptive (1), philosopher (1), planner (1), thoughtful (1), unassuming (1), well-spoken (1).
4. **Feel up to any task:** confident *(6), energetic (4), ready (3), enthusiastic (2), able (1), active (1), adventurous (1), bold (1), capable (1), courageous (1), eager (1), fearless (1), flexible (1), foolish (1), independent (1), love (1), motivated (1), positive (1), responsible (1), sickly (1), steadfast (1), upbeat (1), willing (1).
5. **Don't tolerate critics:** sensitive *(8), intolerant (5), insecure (4), stubborn (3), defensive (2), aggressive (1), argumentative (1), assertive (1), bitter (1), compulsive (1), confident (1), critical (1), efficient (1), egotistical (1), great (1), hypersensitive (1), impulsive (1), insolent (1), irrational (1), narcissistic (1), naturalistic (1), neurotic (1), nice (1), overconfident (1), patient (1), positive (1), proud (1), self-centered (1), selfish (1), skeptical (1), strong (1), thin-skinned (1), tolerant (1), unchanging (1), weak (1), wise (1).

The examples selected match highlighted questions in Study 3. The full list of responses for all IPIP questions is provided in the data repository. The most frequently selected adjective by participants was deemed the most representative for that question and marked with an

asterisk(*). For example, the most frequent response to the question 'Sympathize with others' feelings' was 'empathetic' and, therefore, 'empathetic' was assigned to be the most representative word for that question. For three of the 1,506 IPIP questions, the most frequent response was not included in the atlas Catalogue, and therefore, these three questions were excluded, leaving 1,503 questions and 50,792 total responses.

Of the 50,792 responses, 11,565 (22.8%) were the most frequent, 9,453 (18.6%) were first-degree (1°) synonyms, 13,676 (26.9%) were second-degree (2°) synonyms, 12,551 (24.7%) were third-degree (3°) synonyms, 2,821 (5.6%) were fourth-degree (4°) synonyms, and 726 (1.4%) were unrelated. The proportion of consistent responses was therefore 41.4% (22.8% + 18.6%) leaving 58.6% being the proportion of inconsistent responses. A binomial test confirmed strong evidence to reject the null hypothesis ($p=0.586$, $q=0.414$, $K=751$, $n=1503$, $p\text{-value} < .001$). The alternate hypothesis was therefore accepted, that is, that less than 50% of readers of psychological test questions consistently interpret test questions.

It was further observed that the crowdsourced workers selected identical adjectives for several questions purporting to assess different constructs. For example, 'confident' was selected for 28 (2%) of the 1,503 questions, lazy was selected for 27, and impulsive for 26. Of the 1,503 test questions, there were only 439 unique adjectival responses. The top ten adjectival responses accounted for 237 (16%) of the 1,503 questions. The extent of duplication would raise questions about possible biases that may arise if the duplication was unintended, and the efficiency of existing psychological test batteries if the duplication were intended. Identifying only 439 unique adjectives also raises questions about whether some behavioural traits are omitted from existing psychological test batteries, given that the atlas identifies over 7,000 English language behavioural traits[191]. Therefore only 6% of adjectival trait descriptors are tested by IPIP, resulting in 94% of adjectival trait descriptors being untested.

Discussion

This study aimed to use a crowdsourcing approach to measure extant psychological test question precision using semantic relatedness. Several concerns with existing batteries of psychological test questions were identified. Firstly, the diversity of respondent interpretation of individual test questions suggests that individual psychological test questions may have insufficient precision to be efficacious for some purposes, resulting in invalid testing in those circumstances. Secondly, the concentration of psychological test questions focusing on a limited subset of behavioural traits raises concerns regarding bias and test efficiency. For

example, the discernable focus of questions on confidence, laziness and impulsiveness raises questions such as why these traits have not received the commensurate attention in, for example, Five-Factor Theory. Such biases may result in spurious correlations or the identification of 'dimensions' that arise purely due to inadvertent clustering of data points[218,219]. The converse of concentration on a limited number of adjectival trait descriptors is that 94% of adjectival trait descriptors are omitted from the IPIP test battery. At face value, the proportion of omitted trait descriptors seems very high and inconsistent with the procedures used to establish test batteries[220]. Finally, that extant psychological test batteries appear to test a limited subset of English language trait descriptors suggests that existing psychological tests are at risk of omitting important aspects of personality that may be of interest or relevance. Study 3 aims to repeat this study but replace semantic relatedness with the trust-in-self and trust-in-other(s) to measure precision.

Study 3

Study 2 used a crowdsourcing approach to measure extant psychological test question precision using semantic relatedness. This study aims to repeat Study 2 but replace semantic relatedness with trust-in-self and trust-in-other(s) as the measure of precision. As in Study 2, it was hypothesised that readers of psychological test questions would consistently interpret the questions' meaning. The alternate hypothesis was that readers of psychological test questions would inconsistently interpret the meaning of the questions.

Method

The crowdsource responses to each IPIP question obtained in Study 2 were scored according to the atlas catalogue[191]. Trust-in-self and trust-in-other(s) are measured on a five-point integer scale forming a square matrix with 25 cells. Measuring the precision of existing psychological test questions can be performed by measuring the variance of responses relative to the 25 cell matrix. For each question, the standard deviation of affiliation (trust-in-other(s)) scores and dominance (trust-in-self) scores were independently calculated as the measure of precision. Pythagoras' rule of right-angled triangles was then used to calculate a single, combined, standard deviation. Standard deviation is inversely proportional to precision; that is, a low standard deviation indicates high precision and high standard deviation indicates low precision. High precision indicates that the IPIP question is consistently interpreted by crowdsource respondents, whereas a low precision indicates disparate interpretations by crowdsourcing respondents. Assuming that the crowdsource

respondents' interpretations are normally distributed, a standard deviation of 0.33 indicates that 99.7% of respondent interpretations are expected to fall within a single cell. A standard deviation of 0.5 corresponds with 95% expected to be within a single cell, 1.0 corresponds with 68% and 1.5 corresponds with 50% of questions expected to be within a single cell. It could be argued that 'consistent understanding' implies that all respondents would have an identical understanding of the question, implying a standard deviation of 0. A more practical definition of 'consistent understanding' is that a threshold majority of one standard deviation of respondents have a very similar interpretation and that very few respondents have a widely divergent interpretation.

Results

Questions were ranked by combined standard deviation and questions at the 0th, 12th, 25th, 50th, and 100th percentiles were visualised in Fig 6. For the 0th percentile question 'Sympathize with others' feeling' (Fig 6A), the combined standard deviation was 0.38, and 27 of the 28 scores were within the cell (2,-2). The 12th percentile question 'Like to begin new things' (Fig 6B) is the threshold standard deviation below which responses are considered consistent. Of the 1,503 test questions, 175(12%) had a combined standard deviation of less than 1 and 1,328 (88%) had a combined standard deviation of greater than 1. For the 100th percentile question 'Don't tolerate critics' (Fig 6E), the combined standard deviation was 2.0 and 9 of the 53 scores were within the cell (-1,2). Figs 6A-E visually demonstrates the range of consistency in respondent interpretation of psychological test questions. A binomial test was performed confirming that there was strong evidence to reject the null hypothesis ($p=0.88$, $q=0.12$, $K=750$, $n=1,503$, $p\text{-value} < .001$). It was thus found that crowdsourcing respondents do not consistently interpret psychological test questions.

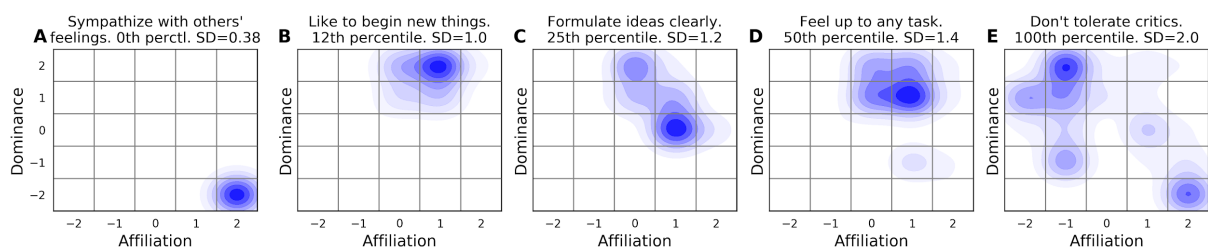


Fig 6. Visualisation of respondent interpretation of IPIP test questions.

Affiliation's latent variable is trust-in-other(s), and Dominance's latent variable is trust-in-self. Inconsistent interpretation of test questions results in imprecise measurement. A unity threshold delineated consistent interpretation of test questions from inconsistent

interpretation. (A, B) 12% of psychological test questions were found to be consistently interpreted by crowdsourcing respondents. (C, D, E) 88% of psychological test questions were found to be inconsistently interpreted by crowdsourcing respondents.

Discussion

This study aimed to use trust-in-self and trust-in-other(s) as the measure of precision. This study's results are consistent with Study 2, finding that crowdsourcing respondents inconsistently interpret psychological test questions. The level of inconsistency in interpretation suggests that the existing psychological test questions were imprecise. Given that studies 2 and 3 use different methods and achieve similar results, confidence in their common findings increases. Taken together, Studies 2 and 3 highlights the need for the reappraisal and revision of existing psychological testing instruments or the need for novel approaches to psychological testing.

Study 4

Studies 2 and 3 considered the precision of individual psychological test questions. However, psychological test questions are rarely asked in isolation and are more commonly grouped hierarchically into facets and domains[144,145,214]. Facets are widely considered homogeneous and narrow descriptors of single traits, whereas domains are clustered groups of closely related facets[221,222]. Facets are typically constructed from a smaller set of personality test questions. This study aimed to assess whether the hierarchical facet/domain structure attenuates the consistency problems identified in studies 2 and 3. The null hypothesis was that the amalgamation of multiple psychological test questions would attenuate individual test questions' imprecision. The alternative hypothesis was that multiple psychological test questions do not attenuate the imprecision of individual test questions.

Method

Two studies dissecting the five domains of the five-factor model into facets were identified[144,145]. The Johnson study[145] was selected for detailed analysis based on it having more citations. The domains and facets were visualised using the atlas, and the methodology of Study 3 was used to calculate the standard deviation for each domain and

facet. Standard deviations below unity were deemed to imply that the grouping of questions attenuated the inconsistent understanding of individual questions. Conversely, standard deviations above unity implied that the grouping of questions did not attenuate the inconsistent understanding of individual questions.

Results

The results of the analysis are summarised in Table 2 and Fig 7. The standard deviation for all five domains exceeded unity indicating that the grouping of multiple personality questions did not attenuate or overcome the inconsistency of understanding psychological test questions. The standard deviation for 46 of the 51 facets identified by Johnson exceeded unity indicating that the personality questions used to measure the domains was not attenuated by the grouping of questions. A binomial test confirmed strong evidence ($p=0.90$, $q=0.10$, $K=26$, $n=51$, $p\text{-value} < .001$) to reject the hypothesis that the aggregation of psychological test questions into domains and facets attenuates the inconsistency in responses measured in Study 2 and 3.

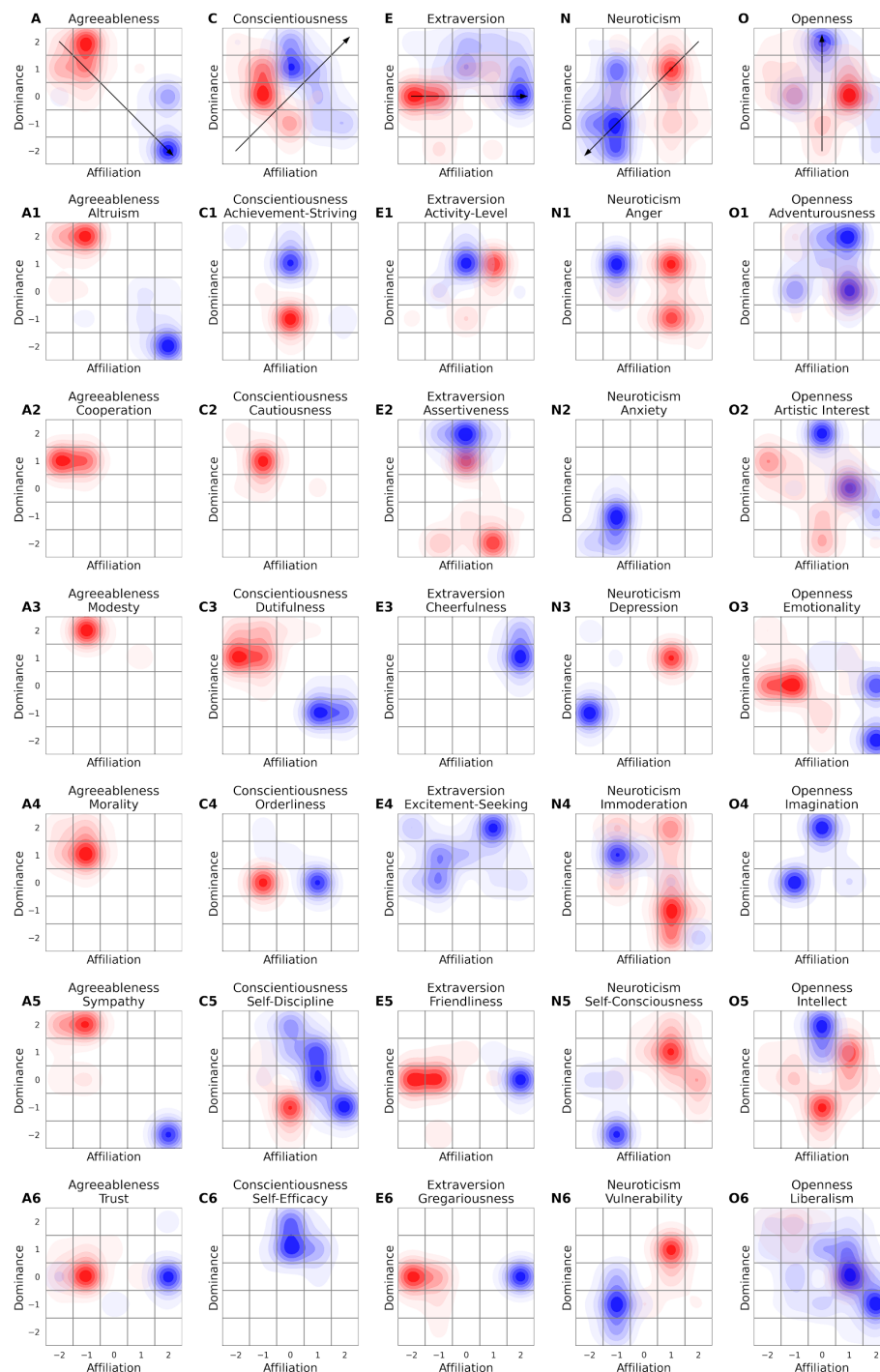


Fig 7. Facets of the Five-Factor Model.

Johnson's facets[145] of the Five-Factor Model were visualised according to the atlas of personality, emotion, and behaviour. Affiliation's latent variable is trust-in-other(s), and Dominance's latent variable is trust-in-self. (E2, E4, N1) Significant bimodality in some facets indicates that facet groups may not contain questions with homogeneous meaning. (A, C, E, N, O) Vectors are visually placed on the major dimensions.

Domain	Facet	Negative valence		Positive valence	
		n	St Dev	n	St Dev
agreeableness	altruism	56	1.33	65	1.58
	cooperation	114	1.12	-	-
	modesty	126	1.23	-	-
	morality	130	1.11	-	-
	sympathy	55	1.50	61	1.11
	trust	35	1.23	87	1.7
	total	516	1.30	213	1.7
conscientiousness	achievement-striving	58	1.31	72	1.58
	cautiousness	113	1.37	-	-
	Dutifulness *	54	1.28	58	* 0.96
	Orderliness *	103	* 0.97	29	1.22
	self-discipline	52	1.17	70	1.46
	self-efficacy	-	-	167	1.16
	total	380	1.43	396	1.48
extraversion	activity-level	26	1.33	108	1.28
	assertiveness	27	1.71	86	1.03
	cheerfulness	-	-	128	1.18
	excitement-seeking	-	-	162	1.66
	Friendliness *	71	1.35	67	* 0.96
	Gregariousness *	59	1.15	56	* 0.88
	total	183	1.51	607	1.6
neuroticism	anger	29	1.26	82	1.1
	anxiety	-	-	109	1.1
	depression	29	1.11	91	1.48
	immoderation	92	1.73	28	1.87
	self-consciousness	35	1.26	83	1.53
	vulnerability	48	1.23	84	1.25
	total	233	1.47	477	1.51
openness	adventurousness	100	1.47	26	1.33
	artistic interest	120	1.68	67	1.56
	emotionality	68	1.57	58	1.61
	imagination	-	-	130	1.31
	Intellect *	107	1.45	29	* 0.66
	liberalism	54	1.58	87	1.73
	total	449	1.60	397	1.66
Grant Total		1,761		2,090	

Table 2. Standard Deviation for each five-factor model domain and facet. Facets have various numbers of questions with n being the number of crowdsourcing responses to all questions for the facet group (where such responses are included in the atlas catalogue). The five facets with standard deviations below unity are identified with an asterisk indicating that these facets are tightly clustered. Standard deviations exceeded unity for 46 or 51 of the facets indicating that these facets were not tightly clustered.

It was further observed that several crowdsourcing modal responses were associated with multiple dimensions. Examples include: 'adventurous' was found to be associated with both positive extraversion (n=22, 4%) and positive openness (7, 2%); 'angry' was associated with negative agreeableness (10, 2%) and positive neuroticism (13, 3%); 'confidence' was associated with negative agreeableness (10, 2%), positive agreeableness (3, 1%), positive conscientiousness (4, 1%), positive extraversion (5, 1%) and negative neuroticism (14, 6%). 'empathetic' was associated with positive agreeableness and positive openness (12, 3%); 'shy' was associated with negative extraversion (10, 5%) and positive neuroticism (31, 6%).

Discussion

This study aimed to assess whether the hierarchical facet/domain structure attenuates the imprecision identified in studies 2 and 3. This study's key finding was that the amalgamation of multiple questions does not ameliorate the imprecision associated with individual test questions observed in Studies 2 and 3.

It was anticipated that the vectors joining the negative and positive valence of each facet within a domain would be similar, or at least not inconsistent with each other. This was not the case for the conscientiousness domain for which the achievement-seeking and orderliness facet were orthogonal, and the dutifulness and self-discipline vectors were orthogonal. This suggests that the hierarchically related facets of conscientiousness, as reported by Johnson, are dissimilar concepts and inappropriately subsumed within the same domain. On the other hand, the dispersion of several facets as measured by the standard deviation were excessive, such as with, for example, liberalism, immoderation and excitement-seeking, indicating that the selection of test questions could be improved for these facets. Similar inconsistencies and excessive dispersion were observed in the dimensions of extraversion, neuroticism, and openness. Agreeableness was the only dimension relatively free of inconsistencies and excessive dispersion. Inconsistencies and

excessive dispersion will likely suppress or obscure correlations. At the extreme, these inconsistencies and excessive dispersions may have resulted in errors such as the false rejection of a true hypothesis or the acceptance of a hypothesis which is in fact, false. These results may explain a portion of the hitherto unexplained existence of interdimensional correlations[7] and relatively low correlations consistently achieved in the social sciences[223].

It was further observed that some regions of the atlas were more represented than others. This conglomeration in some areas and sparsity in other areas of the atlas can be seen with the relative paucity of modal responses in cells (-2,2), (2,2), (-2,-2), and (0,-2), (see Fig 7). The relative sparsity in some cells is matched by relative conglomeration in other cells such as (1,1) as seen in Figs 7N1, 7N3, 7C5, 7N5, and 7O5. It was also observed that negative valence agreeableness was the only dimension predominantly located in the atlas' top-left quadrant. None of the other domains contained a significant number of responses in the top-left quadrant. This suggests that negative agreeableness is a relatively compact measure of personality descriptors in the atlas' top-left quadrant. It was previously observed that the Dark Triad[79] could be mapped exclusively to the top-left quadrant of the atlas[191]. The correlation between negative valence agreeableness and aggressive behaviours concurs with previous observations[224]. Despite this observance of correlations between negative agreeableness and the Dark Triad, no theoretical justification for this association has previously been identified[225]. The latent variables of the atlas, trust-in-self and trust-in-other(s) provide the theoretical justification for the identified correlation between aggressive behaviours and negative valence agreeableness which this study has supported empirically.

This Study identified three major observations. Firstly, several bimodal distributions were identified in some facets (see Figs 7C5, 7E, 7E2, 7N1, 7O3). The bimodalities indicate that respondents interpret the questions grouped to define facets to mean unrelated concepts. Secondly, vectors joining the positive and negative poles of each facet were often pointing in disparate directions (see Figs 7C1, 7C3, and 7C4). The disparate direction of vectors indicates that the facets are being measured in very different ways to render the results for these facets challenging to interpret. The amalgamation of incongruent questions would likely cause unintended spurious correlations between factors, leading to the confounding of disparate concepts and reduced predictive validity.

Thirdly, the vectors joining the positive and negative poles of each dimension indicated that neuroticism and conscientiousness are likely to be better represented as aspects of a

common vector. If so, negative conscientiousness, positive conscientiousness, negative neuroticism, and positive neuroticism are points on a common scale (see Fig 2D). This observation is supported by multiple congruent observations[226–231]. This would indicate that the Five-Factor Model should be a Four-Factor Model. This observation has profound implications for personality testing over the past several decades and demands replication and detailed further analysis. Notwithstanding the need for further confirmatory studies, the Five-Factor Model's revision to having only four factors (subsequently referred to as the Four-Factor Model) appears to unify the Four-Factor Model with several extant theories of personality (see Fig 2D). A further advantage of the Four-Factor Model is that it can be visualised in only two dimensions with the four vectors equidistantly spaced at a 45° angle. This visualisation explains the correlations between the factors that have hitherto withstood theoretical explanation[7,154,155].

General discussion

This article introduces metrology, the science of measurement, to personality psychology[37,38,160]. It has been claimed that metrology enforces consistency of terminology and vocabulary, thus improving the replicability of science[41,42]. Metrology is ubiquitously used in the natural sciences and industry to develop accurate and precise forms of measurement. Sufficient measurement accuracy and precision are vital for measurements to be considered metrologically valid for a particular purpose[35]. The use of metrology may create opportunities for greater integration across the natural and social sciences[37,38,160].

Metrology requires the clear delineation of the phenomenon, the attributes of the phenomenon that may be measured (known as measurands), the measurement instruments, and measurement units. Consciousness and language were identified as two relevant phenomena. Semantic relatedness is a proposed measurand of the language phenomenon, being the lexical distance between word pairs. Semantic relatedness requires only a thesaurus to calculate the number of synonymic links between words.

Identifying the measurand(s) of consciousness first required discovering the latent variables linking personality, emotion, and behaviour. Discovering the latent variables required understanding the algorithmic processes necessary to pay attention to surroundings, evaluate such information, and initiate responsive action. A dynamic model was proposed involving Bayesian inference and game theory that process the latent variables trust-in-self and trust-in-other(s). The proposed latent variables bore a striking resemblance to other two

factor models, such as the interpersonal circumplex, attachment theory, Bakan's agency and communion model, and the atlas of personality, emotion, and behaviour (atlas). The congruence of the proposed latent variables with these extant personality theories engenders confidence, particularly compared to factor derived models that have remained atheoretical since their inception[154,155]. The atlas introduced integer scales of affiliation and dominance, and these scales were adopted to measure the latent variables of trust-in-self and trust-in-other(s). It was demonstrated that both newly developed measurands, trust-in-self, trust-in-other(s), and semantic relatedness, were capable of quantitatively measuring the precision of psychological test questions and the hierarchical nature of psychological constructs. These newly developed measurement instruments strictly conform to metrology's strictures and provide an improved basis for future taxonomic research.

Key findings were that existing psychological test questions are subject to broad interpretation by respondents. The extent of variance in interpretation renders such tests being imprecise measures of personality. The extent of imprecision would likely limit the discriminatory or predictive efficacy of these questions as measurement instruments. Therefore, it is recommended that researchers nominate the adjective they intend each question to measure. By nominating the adjective to be measured, confirmatory studies can be performed and replicated, attesting to each test question's accuracy and precision. This study's results may also indicate that phrasal psychological test questions may introduce a level of abstraction that unavoidably introduces bias or imprecision. If so, an alternative approach is to restructure psychological test questions to use combinations of single-word adjectives. This finding's implications are significant, given the number of psychological tests that currently use sentence-based questions.

Supplementary findings were, firstly, that the widely accepted faceted nature of Five-Factor Theory was not supported. Secondly, the Five-Factor Theory's dimensions of conscientiousness and neuroticism are likely to be better represented as points on a common dimension. This study's results appear to confirm the findings of previous studies that found conscientiousness and neuroticism to have opposite effects in a wide range of circumstances[226–231]. Based on the prior research results, it is perhaps surprising that there had not previously been a proposal to revise the Five-Factor Theory by amalgamating these dimensions. Therefore, this research proposes a revision to Five-Factor Theory and suggests that conscientiousness and neuroticism be recognised as aspects of a common dimension. This revision then allows the remaining four dimensions to be successively arranged at 45 degrees intervals passing through a common origin (see Fig 2d). When

visualised in this manner, the Four-Factor Model aligns with other psychological theories including the interpersonal circumplex[71], attachment theory[196], Bakan's agency and communion model[195], and the recently developed atlas of personality, emotion, and behaviour[191]. The convergence of multiple psychological models having two primary orthogonal dimensions with multiple other vectors of interest provides greater confidence in the convergent model's theoretical basis and realism. This convergent personality model may also form a dimensional model of personality disorders[232]. Utilising these two dimensions, the atlas visually differentiated a wide range of ICD-11[146] and DSM-5[233] personality disorders. This unification of existing psychological models has wide relevance and may facilitate cross-disciplinary collaboration between personality psychology, clinical psychology, medicine, evolutionary science, behavioural biology, anthropology, and sociology.

This article synthesises a range of concepts and makes ambitious claims regarding consciousness, measurement, the unification of several psychological theories, and a revision to the established Five-Factor Theory. Attributed to Carl Sagan is the aphorism "extraordinary claims require extraordinary evidence"[234]. While the proposed consciousness model is made more plausible by using well-established algorithms, no confirmatory testing has been performed. Although the unification of existing theories of personality and the introduction of psychological measures are made more plausible by identifying congruent neurobiological and sociobiological research[191], much more is necessary to demonstrate the model's utility and veracity. Support for the approach taken in this article can be found in the recommendations that researchers separate the process of theory formulation from empirical testing of the theories[25,159].

In conclusion, this research identifies the primary importance of metrology to psychology and introduces two novel metrologically conforming measures. The introduction of metrology to psychology may engender greater collaboration within the scientific community and promote new therapies and translational applications. An author previously introduced the atlas, which posited a novel taxonomy of personality, emotion, and behaviour. The atlas taxonomy was plausible, given the identified associations with prior neurobiological and sociobiological research. In the current article, the theoretical underpinnings of the atlas are proposed. In the future, confirmatory studies are required to confirm the realism and veracity of the theory. If confirmed, the atlas taxonomy and theory will form a complete, theory-realistic model of personality, emotion, and behaviour combined with a metrologically sound basis for measurement.

A system of classifying and measuring personality, emotion, and behaviour

Additional information

Code and data availability

Data and code are available at doi.org/10.6084/m9.figshare.c.4805559 and doi.org/10.6084/m9.figshare.c.4792323. Some Python code requires access to commercially available Oxford and/or Merriam-Webster thesaurus data.

Acknowledgements

Loving appreciation of R.E.A. Mobbs and S.F.W. Mobbs for manuscript editing.

Competing interests

Anthony E.D. Mobbs has submitted Patent Cooperation Treaty PCT/AU2019/051233 titled 'An Improved Psychometric Testing System'. This does not alter our adherence to PLOS ONE policies on sharing data and materials.

Chapter 4: Discussion

This thesis aimed to develop an overarching system of categorising and measuring personality, emotion, and behaviour. In summary, there were five main findings: Firstly, the thesis identified a parsimonious taxonomy of personality, emotion, and behaviour requiring only two orthogonal dimensions, affiliation and dominance, each of which was divided into five ordinal categories. Secondly, the thesis identified the latent variables supporting each dimension, trust-in-self (dominance) and trust-in-other(s) (affiliation). Thirdly, the taxonomy categorised a newly created catalogue of approximately 20,000 words descriptive of personality, emotion, and behaviour. This catalogue is far larger and therefore, more comprehensive than previous catalogues[65,112–114]. Fourthly, metrology was introduced to develop two quantitative measures of personality, emotion, and behaviour. Finally, visualisation techniques developed were capable of visualising a range of psychological and social constructs.

The lexical approach and cataloguing of words relevant to personality have led to significant advances in psychology's ability to develop personality taxonomies[65,112–114]. The newly created, and significantly larger catalogue can potentially extend these taxonomies, or develop new taxonomies, to encompass other sciences and the humanities. This is because the broad-ranging cataloguing process included words relevant to interpersonal relationships, intrapersonal behaviours, law, biology, education, ethics, sociology, psychology, economics, commerce, industry, and diplomacy. Additionally, the catalogue includes words describing the interaction between individuals, individuals and groups, groups and groups, and individuals and groups relating to society. Notwithstanding the catalogue's intended comprehensiveness, further accretions will result from the identification of unintended omissions, rare or technical words for which there are no recognised synonyms, and the evolutionary development of language over time. Such accretions to the catalogue can be included using the included Python library within minutes.

Another potential benefit that the present research offers concerns the visualisation of data. Visualisation of data is ubiquitous in all areas of science as it facilitates rapid communication and shared understanding of concepts that are otherwise difficult to express in prose[235–237]. The proposed classification and measurement system facilitates visualisation in two dimensions of a wide range of psychological and social constructs. More specifically, the assignment of all catalogued words to a specific location on the two-dimensional plane facilitates visualisation of any combination of words describing

personality, emotion, and behaviour. Figure 2.X demonstrates how visualisation affords a comprehensible understanding of how psychological and social constructs relate to each other. For example, a dimensional representation of personality disorders is achieved, a current objective of personality disorder research generally[232,238,239]. A further example is the social concepts of criminality, immorality, and 'bad', and the association of these concepts with other psychological constructs, such as the Dark Triad. Also visualised is how some concepts encompass a broader region of the atlas whereas other concepts are contained within a single cell (see Figs 2.7I and 2.7J). Related to this, and as developed in Chapter two, such a categorisation system can be described as an atlas. This description is apt due to the system's ability to visualise certain psychological concepts as relatively small in scope, whereas other concepts are much larger. This situation is analogous to a map's ability to visualise cities and regions within the context of continents. The system's ability to efficiently visualise the spectrum of psychological and social concepts in two dimensions has not to the author's knowledge been previously possible and represents an advance in the efficient communicability of concepts relevant to the life sciences.

Traditional forms of psychological measurement are typically questionnaire-styled with Likert-type scale responses[240,241]. The metrologically compliant quantitative measurement instruments developed in chapter three provide a basis for measuring these traditionally structured questionnaire-styled psychological tests' accuracy and precision. As the findings there indicate, empirical use of the newly developed measurement instruments identified imprecision within commonly used test questions and imprecision and discrepancies in the Five-Factor Model's hierarchical nature[14,145]. Furthermore, combined with the newly developed visualisation tools, the potential to simplify the Five-Factor Model to be more simply expressed with only four factors was also identified.

There are several limitations previously noted in chapters two and three. These limitations chiefly relate to the absence of further empirical testing, the small size of the expert panel performing the catalogue's initial scoring, the exclusive use of English language in preparation of the catalogue, and the absence of replication studies. Several further studies are required to address these limitations, including, extensive empirical testing to compare the newly developed techniques with established psychological testing approaches, cross-cultural replication of the scoring process by a larger and more diverse cohort of experts, and neuroscience investigation of the latent dimensions trust-in-self and trust-in-other(s). In addition to the future research required to address the identified

limitations, the further analysis and quantification of 'power' are required to complete the proposed dynamic model.

Notwithstanding the limitations and necessity for future research, the proposed taxonomy is made more plausible by the identified biological mechanisms that align with the taxonomy's orthogonal dimensions and the taxonomy's visual similarity with existing taxonomies, primarily the interpersonal circumplex[15], agency/communion[73], and attachment theory[16]. If the model's plausibility is confirmed, the overarching categorisation system and measurement may provide an additional useful tool for researchers exploring personality, emotion, and behaviour.

In conclusion, this research proposes an overarching system of classifying and measuring personality, emotion, and behaviour. The catalogue of English language words used is comprehensive and includes vocabulary potentially relevant to a range of sciences and humanities. The proposed taxonomy is parsimonious, requiring only two orthogonal dimensions, each divided into five ordinal categories. The proposed quantitative measures of personality, emotion, and behaviour are also metrologically compliant, enhancing replicability and integration with other sciences. The combination of the proposed catalogue, taxonomy, visualisation techniques and measurement instruments provides a comprehensive approach to analysing personality, emotion, and behaviour across a range of sciences. In the future, confirmatory studies are required to confirm the realism and veracity of the proposed system. If confirmed, this system will form a complete, theory-realistic model of personality, emotion, and behaviour combined with a metrologically sound basis for measurement.

Appendix 1: Ethics Approval

Human Sciences Subcommittee
Macquarie University, North Ryde
NSW 2109, Australia



17/05/2019

Dear Associate Professor Boag,

Reference No: 5201953908793

Project ID: 5390

Title: Converting adjectival phrases to single word adjectives

Thank you for submitting the above application for ethical review. The Human Sciences Subcommittee has considered your application.

I am pleased to advise that ethical approval has been granted for this project to be conducted by Associate Professor Simon Boag, and other personnel: Mr Anthony Mobbs.

This research meets the requirements set out in the National Statement on Ethical Conduct in Human Research 2007, (updated July 2018).

Standard Conditions of Approval:

1. Continuing compliance with the requirements of the National Statement, available from the following website:
<https://nhmrc.gov.au/about-us/publications/national-statement-ethical-conduct-human-research-2007-updated-2018>.
2. This approval is valid for five (5) years, subject to the submission of annual reports. Please submit your reports on the anniversary of the approval for this protocol. You will be sent an automatic reminder email one week from the due date to remind you of your reporting responsibilities.
3. All adverse events, including unforeseen events, which might affect the continued ethical acceptability of the project, must be reported to the subcommittee within 72 hours.
4. All proposed changes to the project and associated documents must be submitted to the subcommittee for review and approval before implementation. Changes can be made via the [Human Research Ethics Management System](#).

The HREC Terms of Reference and Standard Operating Procedures are available from the Research Services website:
<https://www.mq.edu.au/research/ethics-integrity-and-policies/ethics/human-ethics>.

It is the responsibility of the Chief Investigator to retain a copy of all documentation related to this project and to forward a copy of this approval letter to all personnel listed on the project.

Should you have any queries regarding your project, please contact the [Faculty Ethics Officer](#).

The Human Sciences Subcommittee wishes you every success in your research.

Yours sincerely,

A handwritten signature in black ink, appearing to read "N Sweller".

Dr Naomi Sweller

Chair, Human Sciences Subcommittee

The Faculty Ethics Subcommittees at Macquarie University operate in accordance with the National Statement on Ethical Conduct in Human Research 2007, (updated July 2018), [Section 5.2.22].

Appendix 2: Ethics Application



MACQUARIE
University
SYDNEY AUSTRALIA

HASS PROJECT DESCRIPTION FORM

Information about this form:

1. This document is a mandatory component of the Humanities and Social Science (HASS) human research ethics application form.
2. The purpose of a project description is to provide information that will assist the ethics review body to assess the merit of the research project.
3. Section headings represent a desired structure for the presentation of information about a research project that meets the needs of an ethics review body.
4. The project description must be **a maximum (2) pages**, and approximately **1,000-1,500 words**. Please note that scholarly references are not included in the word count.
5. Please use non-technical language to ensure comprehension by a lay audience.

Research Aims and Rationale

Refer to Section 1.1 of the [National Statement](#) on Research Merit and Integrity.

Please include the following in your response:

- Provide five (5) to seven (7) scholarly references from the current literature.
- Describe how the research will fill any gaps; contribute to knowledge and understanding, improve social welfare and individual wellbeing, etc.
- Outline the research questions, aims, objectives, and/or hypotheses and expected outcomes of the research.

Research Question

There is currently wide support for taxonomies of personality with five or more dimensions [47,62,242]. These taxonomies are typically derived from extensive empirical studies followed by dimensional reduction techniques such as Principal Components Analysis with orthogonal rotations [243]. Empirically derived taxonomies of personality have been criticized for having highly correlated dimensions, indicating that the dimensions are not orthogonal and therefore not supporting claims that these are basic independent dimensions. These approaches have also been criticised for lacking a substantive theoretical basis [7,63,244,245].

An alternative sound method of deriving dimensions is to select theoretically orthogonal dimensions, and then empirically test them to confirm that those dimensions are capable of classifying the relevant observed phenomenon. This approach has been used to propose a range of theoretically orthogonal dimensions [23,73,82,246–249]. If the dimensions are amenable to being divided into non-overlapping categories, then the taxonomy may also be referred to as a topology, of which temperature (1-dimensional), cartographic maps and the periodic table of elements (2-dimensional) are examples. Bailey [30] argues that topologies

that are able to classify all observed phenomenon and have theoretical support for the dimensions are considered to be superior. Therefore, it appears desirable for contemporary personality psychology research to develop a theoretically derived, empirically tested, topology of personality.

There is extensive neurobiological support for the dimensions of affiliation and dominance, [250–252][253–257]. The dimensions are also found in some personality accounts[83]. Therefore, the dimensions of affiliation and dominance were selected for the present study.

The author has grouped the descriptors of each dimension used in the above-mentioned theoretical approaches into two groups and then subdivided into the terms used to describe the positive and negative valence:

1. Group 1
 - a. Positive valence: **affiliation**, friendliness, communion, positivity, social, social competence, warm-agreeable
 - b. Negative valence: unfriendliness, negativity, antisocial
2. Group 2
 - a. Positive valence: **dominance**, agency, dynamism, assertiveness, effortful-control
 - b. Negative valence: submissiveness, unassertiveness

Previous researchers have mapped five and six factor models and two-dimensional models similar to those above [76,83,258].

The author has proposed a topology consisting of the two orthogonal dimensions of affiliation and dominance. Each axis is divided into 5 non-overlapping categories forming a square matrix of 25 cells. A newly developed catalogue of 4,135 adjectives was constructed and scored according to the topology using a delphi process with three clinical psychologists serving as judges.

The author's proposed topology classifies antonyms whereas psychological tests often use multiple word adjectival phrases [240,259–262]. It is therefore necessary to assign a unique adjective to each question used by the open-source tests. For example:

1. If a person usually 'accepts apologies easily', they may have a personality trait described as 'forgiving'.
2. If a person usually 'accepts challenging tasks', they may have a personality trait described as 'fearless'
3. If a person usually 'is out for personal gain', they may have a personality trait described as 'self-interested'

Aim

To test the proposed topology (25 cell square matrix with dimensions affiliation and dominance) using an extensive array of open-source validated psychological tests.

Hypothesis

It is hypothesised that:

1. Existing multi-word questions in psychological tests are able to be effectively represented using single-word adjectives.
2. That the adjectives representative of the psychological tests can be scored according to the proposed topology, and

3. That similar psychological constructs will be closely proximate when scored according to the proposed topology and that dissimilar psychological constructs will be disparate when scored according to the topology.

Project Design

Refer to Section 1.1(b) of the [National Statement](#) on Research Merit and Integrity.

This section is the main body of the project description. Please include the following in your response:

- Explain how the proposed methodology is appropriate for achieving the research aims.
- Describe what are participants being asked to do and the level of participant commitment.
- Describe any consequences of withdrawing from the research project.

Methodology

Explain how the proposed methodology is appropriate for achieving the research aims.

To confirm the efficacy of a newly hypothesised topology of personality, it is appropriate to confirm that existing and empirically validated constructs can be classified using the proposed topology and that these existing constructs can be usefully compared and contrasted.

To perform this comparison, a comprehensive range of open-source validated psychological tests must be identified and compared. It is proposed that the all tests within the International Personality Item Pool (<https://ipip.ori.org/>), Open Source Psychometrics Project (<https://openpsychometrics.org/>) and Delroy L. Paulhus' Psychological Tests (http://www2.psych.ubc.ca/~dpaulhus/Paulhus_measures/) be incorporated within the testing process. All items are regularly use in personality testing without reported incident. The items relating to Hare's Psychopathy test were excluded given that the items are relevant to forensic samples. In aggregate, these tests consist of more than 1,500 adjectivally phrased questions and more than 250 constructs (e.g. dark triad, anger, liveliness and submissiveness). Hare's test of psychopathy describes a range of unpleasant personal attributes which will be excluded from the survey and the author will provide relevant adjectives to these items. The full list of questions is included as an appendix.

Steps

1. All of the questions within the above tests will be compiled into a single list.
2. A customised MTurk questionnaire will be developed allowing between 30 and 100 responses for each of the 1,500 questions (see Survey Design below for an example). Participants will be first shown one of the 1,500 multiple-word adjectival phrases, and then be asked to provide the single word adjective which best encapsulates the personality trait exemplified in that phrase.
3. MTurk
 - a. MTurk workers will self-select whether to participate, self-select when and where to participate and self-select how long they will participate. MTurk workers will be paid \$0.01 per item answered.
 - b. There is no restriction on how many questions and Amazon participant may answer, that is, MTurk workers will self-select whether to answer one, ten or all 1,500 questions.
 - c. Between 30 and 100 individual respondents will be required to answer each of these 1,500 questions implying that a minimum of 45,000 individual


- responses will be obtained. It is expected that 30 responses will be required for the majority of questions.
- d. Participants are allowed 5 minutes to answer each question. Participants who do not answer within 5 minutes will be automatically deemed to have neglected to answer the question, and the test will move to the following question.
 - e. The Amazon Mechanical Turk application prevents any individual from answering the same question twice.
 - f. The MTurk questionnaire will be made available for two weeks.
4. It is expected that for each given question, a variety of answers will be given by the participant pool. However, it is also expected that one or a small number of words will be selected by participants more often than other words.
- a. The word with the highest frequency will be selected as the best single-word adjective that represents the multiple-word phrase.
 - b. If two or three words are equally as frequent, then the quota for additional responses will be increased by 10 until a single word is the most frequent. If this process does not result in a single word being selected the author and two other independent judges (clinical psychologists) will select the most appropriate adjective. The panel of clinical psychologists are Jane Highfield, Dr Anna Miskovic-Wheatley and Dr Jenny Mitchell who are associate practitioners of Sydney Cognitive (<https://www.sydcog.com.au/>).
 - c. If the Amazon Mechanical Turk process does not result in any single word or group of words that are more frequent than other words, the two independent judges will select a word unanimously using a Delphi process.
5. When a single adjective has been assigned to each adjectival question:
- a. The adjectives will be encoded according to the topology.
 - b. Each psychological construct will then be visualised using the topology using kernel density plots.
 - c. For each construct consisting of a dipole (i.e. with a positive and negative valence):
 - i. The author will evaluate whether the visualisation of each pole demonstrates that the construct is tightly clustered on the topology.
 - ii. The author will evaluate whether the visualisation of each pole is visually separated.

Survey Design

The survey implementation has used standard mturk widgets in order to maintain a consistent typography and visiospatial layout to that used by Amazon. The screenshot below is taken from the Amazon Turk Development Environment and is not accessible to the general population. The first screenshot below shows an example question. The second screenshot shows the positioning and layout of the Participant Information and Consent Form.

A system of classifying and measuring personality, emotion, and behaviour

You are using the Mechanical Turk Developer Sandbox. This site is for test and development only. [Learn more](#)

Worker ID: A3JNU5U4O8Q5D8 

amazonmturk
Worker

Personality ([HIT Details](#))

☒ Auto-accept next HIT

Requester [Tony Mobbs](#)

HITs 15

Rewards \$1.00

Participant Information and Consent

If you usually/are usually "*am the last to laugh at a joke*", then your personality may be described as

- Example: If you usually/are usually "*accept apologies easily*", then your personality may be described as '**forgiving**'
- Example: If you usually/are usually "*accept challenging tasks*", then your personality may be described as '**fearless**'
- Example: If you usually/are usually "*out for my own personal gain.*", then your personality may be described as '**self-interested**'

Please enter the one word that best describes the personality.

Submit

← → ↺ 🏠

https://workersandbox.mturk.com/projects/3JG2O8WUZH86HRPUJTKI836B...

☆ 🔄 ⚙️ 📧 📄 📱 👤 ⋮

You are using the Mechanical Turk Developer Sandbox. This site is for test and development only. [Learn more](#)

Worker ID: A3JNU5U4O8Q5D8 📄

Hello, Tony Mobbs | [Sign Out](#)

Return

Personality (HIT Details)

☒ Auto-accept next HIT

Tony Mobbs

HITS 45

Reward \$0.01

Time Elapsed 0:22 of 10 Min

Participant Information and Consent

If you usual

- Example
- Example
- Example

Please enter th

Submit

Participant Information and Consent Form

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Faculty of Human Sciences
MACQUARIE UNIVERSITY NSW 2109 Australia
Phone: +61 2 9850 8024
Fax: +61 2 9850 8082
Email:simon.boag@mq.edu.au

Chief Investigator's / Supervisor's Name & Title: Associate Professor Simon Boag

Name of Project: Antonymic descriptors of personality

You are invited to participate in a study of adjectival descriptors of personality. The purpose of the study is to identify single-word adjectives with equivalent meaning to multiple-word behavioural statements commonly used in psychological testing.

This research is supervised by Associate Professor Simon Boag (Phone: +61 2 9850 8024 simon.boag@mq.edu.au) within the Department of Psychology at Macquarie University. The research is being conducted by Tony Mobbs (Phone +61 416 279 803 anthony.mobbs@hdr.mq.edu.au) in partial fulfilment of a Masters of Research degree.

If you decide to participate, you will be asked to provide a single word that has equivalent meaning to a multiple-word descriptor of behaviour. You will be paid \$0.01 for each answer provided. You can answer as many or as few items as you like. There are no risks anticipated with this research.

No personal or identifying information about you will be collected, therefore no individual will be identified in any publication of the results. Only Tony Mobbs and Simon Boag will have access to the answers you provide. A summary of the answers you give can be provided on request to Tony Mobbs. A summary of the results will be available upon request in December 2019.

Participation in this study is entirely voluntary; you are not obliged to participate and if you decide to participate, you are free to withdraw at any time without having to give a reason and without consequence.

Withdrawing

Describe any consequences of withdrawing from the research project.

The survey design does not rely on having the same respondent answer all questions. It is acknowledged that MTurk users self-select whether to participate and for how long they choose to participate. There is no discernable consequences of a responder withdrawing from the project. MTurk has many thousands of participants and in the event that a responder withdraws, there will be many others able to replace them.

Participants who withdraw will not receive their financial reimbursement for questions that they do not complete. All MTurk respondents are anonymous, ameliorating any potential for negative impact on the participant.

Data Collection and Analysis

Refer to Section 1.1(b) of the [National Statement](#) on Research Merit and Integrity.

Please include the following in your response:

- Describe the research data that will be collected directly from participants and detail how it will be obtained. This includes the discovery and/or disclosure of information from participants or records that are of a personal, private or sensitive nature.
- Detail how your data will be analysed. This includes identifying matching and sampling strategies, accounting for potential bias, confounding factors and missing information, planned or anticipated data linkage/s.

Data will be collected exclusively through the Amazon Mechanical Turk web portal.

Using Python 3 in combination with Amazon's boto3 library (<https://boto3.amazonaws.com/v1/documentation/api/latest/reference/services/mturk.html>), a custom application was developed that populates the questionnaire for all 1,500 questions and then uploads the questions directly to Amazon. A separate Python 3 program has been developed that extracts the responses and retains a local copy for analysis. (Python scripts available upon request). The International Personality Item Pool contains the bulk of questions and a list of these questions can be found at <https://pip.ori.org/AlphabeticalItemList.htm>.

The sampling approach is to collect 30 or more responses for each of the 1,500 survey questions. Amazon prequalifies respondents to ensure that they are English speaking and meet basic eligibility requirements, such as having access to a computer. No personal or demographic information of any kind will be requested, though it is a requirement of Amazon that participants be over 18 years of age.

30 Sample Questions

Note: Items that may give rise to ethical concerns are struck out and will not be included in the MTurk survey process.

1. Accept apologies easily.
2. Accept challenging tasks.
3. Accept people as they are.
4. Accomplish a lot of work.
5. Accomplish my work on time.
6. Acknowledge others' accomplishments.
7. Act according to my conscience.
8. Act at the expense of others.
9. Act before thinking through the consequences.
10. Act comfortably with others.
11. Act impulsively when something is bothering me.
12. Act like different people in different situations.
13. Act quickly without thinking.
14. Act wild and crazy.
15. Act without consulting others.
16. Act without planning.
17. Act without thinking.
18. Adapt easily to new situations.
19. Adjust easily.
20. Admire a really clever scam.
21. Admit when I am wrong.
22. Allow others to make a fresh start.
23. Always admit it when I make a mistake.
24. Always know what I am doing.
25. Always know why I do things.
26. Am a bad loser.
27. Am a brave person.
28. Am a creature of habit.
29. Am a firm believer in thinking things through.
30. Am a goal-oriented person.

The full list of IPIP items is available at doi.org/10.6084/m9.figshare.c.4805559

Appendix 3: Authorship Contributions



MACQUARIE UNIVERSITY

AUTHORSHIP CONTRIBUTION STATEMENT


In accordance with the [Macquarie University Code for the Responsible Conduct of Research](#) and the [Authorship Standard](#), researchers have a responsibility to their colleagues and the wider community to treat others fairly and with respect, to give credit where appropriate to those who have contributed to research.

Note for HDR students: Where research papers are being included in a thesis, this template must be used to document the contribution of authors to each of the proposed or published research papers. The contribution of the candidate must be sufficient to justify inclusion of the paper in the thesis.

1. DETAILS OF PUBLICATION & CORRESPONDING AUTHOR

Title of Publication (can be a holding title)		Publication Status Choose an item.
Metrology applied to personality, emotion, and behaviour		<input type="checkbox"/> In Progress or Unpublished work for thesis submission <input checked="" type="checkbox"/> Submitted for Publication <input type="checkbox"/> Accepted for Publication <input type="checkbox"/> Published
Name of corresponding author	Department/Faculty	Publication details: Indicate the name of the journal/ conference/ publisher/other outlet
Anthony E. D. Mobbs	Department of Psychology, Faculty of Medicine, Health and Human Sciences	PLOS ONE

2. STUDENTS DECLARATION (if applicable)

Name of HDR thesis author (If the same as corresponding author - write "as above")	Department/Faculty	Thesis title
Anthony E. D. Mobbs	Department of Psychology, Faculty of Medicine, Health and Human Sciences	A system of classifying and measuring personality, emotion and behaviour
Description of HDR thesis author's contribution to planning, execution, and preparation of the work if there are multiple authors (for example, how much as a percent did you contribute to the conception of the project, the design of methodology or experimental protocol, data collection, analysis, drafting the manuscript, revising it critically for important intellectual content, etc.)		
Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing		
I declare that the above is an accurate description of my contribution to this publication, and the contributions of other authors are as described below.		Student signature  Date 01/15/2021

4. Author Declarations

I agree to be named as one of the authors of this work, and confirm:

- i. that I have met the authorship criteria set out in the Authorship Standard, accompanying the Macquarie University Research Code,*
- ii. that there are no other authors according to these criteria,*
- iii. that the description in Section 3 or 4 of my contribution(s) to this publication is accurate*
- iv. that I have agreed to the planned authorship order following the Authorship Standard*

Name of author	Authorised * By Signature or refer to other written record of approval (eg. pdf of a signed agreement or an email record)	Date
A/Prof Simon Boag	Email dated 29 December 2020	12/29/2020
	Provide other written record of approval for additional authors (eg. pdf of a signed agreement or an email record)	

5. Data storage

The original data for this project are stored in the following location, in accordance with the *Research Data Management Standard* accompanying the *Macquarie University Research Code*.

If the data have been or will be deposited in an online repository, provide the details here with any corresponding DOI.

Data description/format	Storage Location or DOI	Name of custodian if other than the corresponding author
Python, JSON, CSV, XLS	doi.org/10.6084/m9.figshare.c.4805559	

A copy of this form must be retained by the corresponding author and must accompany the thesis submitted for examination.



3. Description of all other author contributions

Use an Asterisk * to denote if the author is also a current student or HDR candidate.

The HDR candidate or corresponding author must, for each paper, list all authors and provide details of their role in the publication. Where possible, also provide a percentage estimate of the contribution made by each author.

Name and affiliation of author	Intellectual contribution(s) (for example to the: conception of the project, design of methodology/experimental protocol, data collection, analysis, drafting the manuscript, revising it critically for important intellectual content etc.)
A/Prof Simon Boag	Supervision, Writing – review & editing, Revising the paper critically for important intellectual content
	Provide summary for any additional Authors in this cell.

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