



RESEARCH ARTICLE

Development of an Intervention Population Ontology for specifying the characteristics of intervention participants

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Abstract

Background

The uptake, effectiveness and generalisability of interventions are influenced by the features of the populations targeted. However, populations exposed to interventions are not consistently specified in published reports.

Purpose

To create an Intervention Population Ontology providing a clear, usable and reliable classification system to specify characteristics of populations exposed to interventions.

Methods

The Intervention Population Ontology was developed in seven main stages 1) Defining the ontology's scope, (2) identifying key entities by reviewing existing classification systems (top-down) and 100 intervention reports (bottom-up), 3) Refining the preliminary ontology by annotating ~150 intervention reports, 4) Stakeholder review by 29 behavioural science and public health experts, 5) Assessing inter-rater

reliability of using the ontology by two coders familiar with the ontology and two coders unfamiliar with it, 6) Specifying ontological relationships between entities in the ontology and 7) making the Intervention Population Ontology machine-readable using Web Ontology Language (OWL) and publishing online.

Results

The Intervention Population Ontology features 218 entities representing attributes of human individuals across 12 key groupings: personal attributes, geographic location, person, quality, mental capability, role, expertise, objects possessed, behaviour, personal vulnerability and personal history. It has a further 666 classes relating to how individual-level attributes are aggregated to describe groups of people. Inter-rater reliability was $\alpha=0.79$ for coders familiar with the ontology and 0.85 for coders unfamiliar with the ontology.

Conclusions

The Intervention Population Ontology can be applied to specify precisely information from diverse sources, annotate population characteristics in existing intervention evaluation reports and guide future reporting.

Plain language summary

Intervening to change behaviour is key to addressing many of the most serious challenges facing the world today. However, the effectiveness of interventions varies according to the characteristics of the people taking part. We need to build our knowledge of what types of interventions work best for people with particular characteristics. This study developed a unifying framework, called an “ontology”, for describing the characteristics of intervention participants.

We developed the Intervention Population Ontology using a standardised method. This included the following steps: identifying key entities to include by reviewing intervention reports and existing classification systems; coding examples of population characteristics in studies; and asking behavioural science and public health experts for feedback on the ontology. The resulting Intervention Population Ontology has 206 entries representing different human characteristics and a further 638 classes representing how these characteristics can be aggregated to describe groups of people (e.g. mean age, percent female).

The importance of the Intervention Population Ontology lies in its ability to support users in precisely describing, comparing and integrating evidence about the human participants in different studies. Going forward, users of the ontology will be able to contribute to it by providing feedback and suggestions for improvement

Keywords

Ontology, human populations, intervention, behavioural science, reproducibility of results



This article is included in the [Human Behaviour-Change Project \(including the APRICOT project\)](#) gateway.

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Background

Efforts to enhance population health, wellbeing and environmental sustainability all require changing human behaviour. There is a sizable, and rapidly increasing, literature concerning the effectiveness of behaviour change interventions, defined as “interventions that have the aim of influencing human behaviour” (Michie *et al.*, 2020). Behaviour change interventions can involve the use of products, services, activities, rules or environmental objects. Evidence syntheses of such interventions (e.g. Flodgren *et al.*, 2017; Nieuwlaat *et al.*, 2014) demonstrate considerable variation in their effectiveness across different studies, according to the content of the intervention, its context in terms of the target population and setting, and how and by whom the intervention is delivered. One important moderator of effectiveness is the population exposed to the intervention. Reviews have demonstrated that the same intervention content can be differentially effective, for instance depending on the age of the sample (Ashford *et al.*, 2010; French *et al.*, 2014) or the proportions of male and female participants in the sample (Epton *et al.*, 2017).

Policymakers and practitioners may want to identify interventions that are effective for a specific population group, for example those experiencing inequities. The World Health Organization defines health inequities as “differences in health status or in the distribution of health resources between different population groups, arising from the social conditions in which people are born, grow, live, work and age” (<https://www.who.int/news-room/facts-in-pictures/detail/health-inequities-and-their-causes>). In England, for example, COVID-19 mortality rates for people younger than 65 were higher in areas with lower employment rates and more people living in overcrowded housing (Williams *et al.*, 2022). Such inequalities in health status are due to numerous factors, including the conditions in which people are born, live, work and age, and how these influence their thoughts, feelings and behaviours. Identifying interventions that are potentially useful for reducing health inequalities requires good description of the intervention participants in published reports, so readers can judge the extent to which findings will generalise to the population of interest.

Taking this example further, it is important to examine whether there is variation in intervention effectiveness or uptake for different population groups and, if so, whether there is a risk of an intervention increasing inequalities. It has been argued that behaviour change interventions that require a high degree of individual agency will be less successful for people with lower socioeconomic status, thereby deepening inequalities (Adams *et al.*, 2016). For example, a systematic review of healthy eating interventions found that interventions involving individual-based information, education or dietary counselling appeared to be more effective for those with higher socioeconomic position, potentially increasing health inequalities, while interventions that altered the price of food products seemed to change behaviour most for people with lower socioeconomic position and so could serve to reduce health inequalities (McGill *et al.*, 2015). Similarly, a

study examining inequalities in uptake of different home energy efficiency interventions (Curley *et al.*, 2020) found that a programme offering rebates against the purchase of new energy efficient appliances was used more by predominantly White households with high levels of education. In contrast, a home energy consumption audit programme that provided householders with some low-cost/free actions to help decrease home energy loss had better uptake among more ethnically diverse households, and so was more likely to address inequalities in sustainability-related outcomes.

Accurately specifying the characteristics of participants in intervention evaluations is essential for identifying gaps in the evidence, where there is little known about the nature of interventions that might be most effective for people from a particular social group. In a systematic review, careful coding of the characteristics of the participants in the included studies can reveal that certain groups of people are under-represented in the evidence. This could guide research funders and researchers to consider why these groups are under-represented and focus on generating evidence about effective interventions for these groups.

Understanding how intervention effectiveness varies according to target population, examining the impact of interventions on inequalities and identifying evidence gaps all require a method to consistently specify the characteristics of the population involved in a given intervention in sufficient detail. One appropriate approach to specifying and classifying information is to use an **ontology**: a data structure that facilitates precise specification of knowledge in a given field or domain (Arp *et al.*, 2015) (See Table 1 for a glossary of terms in bold italics). Ontologies provide a set of: i) unique, unambiguous identifiers that represent types of **entity** (objects, attributes and/or processes), ii) labels and definitions corresponding to these identifiers, and iii) specifications of the relationships between the entities (Arp *et al.*, 2015; Larsen *et al.*, 2017). These labels, definitions and relationships create formal specification for the given domain, providing a ‘controlled vocabulary’. Ontologies are dynamic representations that are maintained over time and updated in response to new evidence in the given field (Arp *et al.*, 2015; Michie & Johnston, 2017). Ontologies are also machine-readable, hence suitable for **annotation**, evidence synthesis and other computational applications (Hastings, 2017).

No ontology has been identified to describe the full detail of intervention populations (Norris *et al.*, 2019). A comprehensive Behaviour Change Intervention Ontology (BCIO) is being developed as part of the Human Behaviour-Change Project (Michie *et al.*, 2020; Michie *et al.*, 2021b). The BCIO consists of an upper level with 42 entities, one of which is behaviour change intervention population, defined as “An aggregate of people who are exposed to a behaviour change intervention” (Michie *et al.*, 2020). While there are many classification systems and ontologies describing aspects of human populations, these are often not relevant across the range of global contexts, lack a well-organised structure

Table 1. Glossary of terms.

Term	Definition	Source
Annotation	Process of coding, or tagging, selected parts of documents or other resources to identify the presence of ontology entities.	Michie et al. (2017)
Annotation guidance manual	Written guidance on how to identify and tag pieces of text from intervention evaluation reports with specific codes relating to classes in the ontology, using for example EPPI-Reviewer software.	Michie et al. (2017)
Basic Formal Ontology (BFO)	An upper-level ontology specifying foundational distinctions between different types of entity, such as between continuants and occurrents, developed to support integration, especially of data obtained through scientific research.	Arp et al. (2015)
Class	A category of entities as represented in an ontology.	Arp et al. (2015)
Entity	Anything that exists or can be imagined, including objects, processes, and their attributes. It includes mental process, i.e., the process and content of cognitive representations, and emotions. Classes can be represented hierarchically by parent and child classes (see definition of parent class).	Arp et al. (2015)
EPPI-Reviewer	A web-based software program for managing and analysing data in all types of systematic review (meta-analysis, framework synthesis, thematic synthesis etc. It manages references, stores PDF files and facilitates qualitative and quantitative analyses. It also has a facilitate to annotate published papers.	Thomas et al. (2010) EPPI-Reviewer 4: http://eppi.ioe.ac.uk/eppireviewer4/ EPPI-Reviewer Web Version: https://eppi.ioe.ac.uk/eppireviewer-web/
GitHub	A web-based platform used as a repository for sharing code, allowing version control.	https://github.com/
Inter-rater reliability	Statistical assessment of similarity and dissimilarity of coding between two or more coders. If inter-rater reliability is high this suggests that ontology class definitions and labels are being interpreted similarly by the coders.	Gwet (2014)
Interoperability	Two systems are interoperable to the extent that the data in each system can be used by the other system. Note: An ontology is interoperable with another ontology if it can be used together with the other ontology.	http://www.obofoundry.org/principles/fp-010-collaboration.html
Issue tracker	An online log for problems identified by users accessing and using an ontology.	BCIO Issue Tracker: https://github.com/HumanBehaviourChangeProject/ontologies/issues

Term	Definition	Source
Open Biological and Biomedical Ontology (OBO) Foundry	A collective of ontology developers that are committed to collaboration and adherence to shared principles. The mission of the OBO Foundry is to develop a family of interoperable ontologies that are both logically well-formed and scientifically accurate.	Smith et al. (2007) www.obofoundry.org/
Ontology	A standardised representational framework providing a set of entities for the consistent description (or “annotation” or “tagging”) of data and information across disciplinary and research community boundaries.	Arp et al. (2015)
Parent class	A class within an ontology that is hierarchically related to one or more child classes (subclasses) such that all members of the child class are also members of the parent class, and all properties of the parent class are also properties of the child class.	Arp et al. (2015)
Relationship	The manner in which two entities are connected or linked.	Arp et al. (2015)
ROBOT	An automated command line tool for ontology workflows.	Jackson et al. (2019) http://robot.obolibrary.org
Uniform Resource Identifiers (URI)	A string of characters that unambiguously identifies an ontology or an individual entity within an ontology. Having URI identifiers is one of the OBO Foundry principles.	http://www.obofoundry.org/principles/fp-003-uris.html
Versioning	Ontologies that have been released are expected to change over time as they are developed and refined, leading to a series of different files. Consumers of ontologies must be able to specify exactly which ontology files they used to encode their data or build their applications and be able to retrieve unaltered copies of those files in perpetuity. Versioning is one of the OBO Foundry principles.	http://www.obofoundry.org/principles/fp-004-versioning.html
Web Ontology Language (OWL)	A formal language for describing ontologies. It provides methods to model classes of “things”, how they relate to each other and the properties they have. OWL is designed to be interpreted by computer programs and is extensively used in the Semantic Web where rich knowledge about web documents and the relationships between them are represented using OWL syntax.	https://www.w3.org/TR/owl2-quick-reference/

or have incomplete coverage of population characteristics relevant to behaviour change.

Aim

The current study aimed to develop an Intervention Population Ontology, for specifying and classifying characteristics of populations who are exposed to interventions.

Methods

The Intervention Population Ontology was developed in an iterative process of seven steps.

Step 1: defining the scope of the ontology

The initial scope for the ontology was developed by reviewing multiple sources to identify entities relevant to an

intervention target population. A definition of “behaviour change intervention population” was created by consulting the Cochrane Handbook for Systematic Reviews of Interventions (Higgins *et al.*, 2019) and the CONSORT statement (Schulz *et al.*, 2010).

Step 2: identifying key entities and preliminary definitions

An initial prototype version of the ontology was developed using both bottom-up and top-down approaches. In the top-down approach, existing classification systems for intervention populations were identified by consulting i) the Patient Intervention Comparison Ontology (‘PICO’) developed by the Cochrane Collaboration (<https://linkeddata.cochrane.org/pico-ontology>) ii) published ontologies containing terms relevant to behaviour change interventions identified by searching the Ontology Lookup Service (<https://www.ebi.ac.uk/ols/index>) and Biportal (<https://biportal.bioontology.org/>) and iii) relevant controlled vocabularies such as MeSH and iv) reviewing other relevant sources including 1) APA Style guidelines on describing research participants (American Psychological Association, 2019), 2) Ethnic groups used in the UK Census (<https://www.ethnicity-facts-figures.service.gov.uk/style-guide/ethnic-groups>), 3) the International Standard Classification of Education (UNESCO Institute for Statistics, 2012), 4) Health Survey for England (Bridges *et al.*, 2015), 5) Behavioural Risk Factor Surveillance System survey items (Centers for Disease Control and Prevention, 2015) 6) National Health Interview Survey items (National Center for Health Statistics, 2015), 8) World Health Organisation mhGAP intervention guide (World Health Organization, 2016) and 9) International Tobacco Control Surveys (<https://itcproject.org/surveys/>). In the bottom-up approach, 100 behaviour change intervention reports were reviewed to develop a preliminary list of terms relevant to behaviour change intervention populations. The reports were randomly selected from an existing dataset of behaviour change intervention reports coded for behaviour change techniques, mechanisms of action and modes of delivery, covering a variety of health behaviours (Carey *et al.*, 2018; Michie *et al.*, 2021a).

The clarity and coverage of the prototype ontology was piloted with published reports of smoking cessation and physical activity interventions (Michie *et al.*, 2017). The reports were annotated independently by two researchers in groups of ten, with each entity annotated as present or absent. Inter-rater agreement was examined by calculating the i) percentage of agreement between the coders and ii) Cohen’s kappa.

Step 3: refinement of the ontology through further literature annotation, discussion and revision

The prototype version of the Intervention Population Ontology was next refined through its application to annotating intervention reports that formed part of the corpus of smoking cessation intervention reports being used to develop the Human Behaviour-Change Project “knowledge system” (Michie *et al.*, 2020). Using *EPPI-Reviewer 4* software (Thomas *et al.*, 2010), pairs of researchers independently annotated a total

of 75 smoking cessation intervention and 40 physical activity intervention reports using the Intervention Population Ontology. An open alternative to this software used for annotation is PDFAnno (Shindo *et al.*, 2018). An *annotation guidance manual* was created to provide information on how and when to annotate each population class, helping to standardise the procedure. Discrepancies between coders were discussed and the ontology’s structure, definitions and annotation guidance revised accordingly. To ensure the Intervention Population Ontology was relevant not only to smoking cessation studies, twenty physical activity intervention reports were annotated following the same procedure. All annotated reports were randomised controlled trials from either Cochrane Smoking Cessation Systematic Reviews or papers annotated for behaviour change techniques in a previous project (Carey *et al.*, 2018; Michie *et al.*, 2021a) (see <https://osf.io/6xcwy> for the list of papers used across each step of the development of the Intervention Population Ontology).

Step 4: expert stakeholder review

99 expert stakeholders were invited to provide feedback on the Intervention Population Ontology resulting from step 3. The experts came from an existing list of behavioural science and public health experts who had provided feedback on previous projects at the UCL Centre for Behaviour Change and stakeholders who expressed interest in being involved in Human Behaviour-Change Project stakeholder initiatives in response to invitations on Twitter and the Project newsletter. To enhance the geographical diversity of the expert stakeholder group, we also contacted experts from less-represented countries who were authors of papers in the Behaviour Change Technique Taxonomy v1 (BCTTv1) database (<http://www.bct-taxonomy.com/interventions>). Ethical approval was granted by the Research Ethics Committee of University College London, in October 2016 (reference CEHP/2016/555)

Invitations to take part were sent via email, with feedback collected via an online survey using Qualtrics software (<https://osf.io/64mx9>). The task had two parts and the experts were asked to select a specific behavioural domain relevant to their work and to consider this domain when answering the questions. First, to ensure that the Intervention Population Ontology covered all population characteristics the experts felt were important, an open-ended question asked experts to identify the characteristics of the intervention populations they felt were of most interest in understanding variation in the effectiveness of behaviour change interventions. Secondly, the experts were provided with a copy of the Intervention Population Ontology (<https://osf.io/m6udx>) and asked to if there were 1) any population characteristics they deemed missing from the ontology, 2) any classes that should be added to the ontology and 3) any changes that should be made to labels or definitions of entities in the ontology. They were also asked to reflect upon the structure of the IPO and whether they felt any of the entities would fit better in a different part of the ontology. All feedback was discussed by the research team and led to revising class labels or definitions, removing or adding classes, rearranging

the structure of the ontology or providing explanations for not revising.

Of the 99 experts contacted, 81 (81.8%) were from ‘well-represented’ countries and 18 (18.2%) from ‘less-represented’ countries. 29 experts (29.3%) completed the survey and provided feedback. Of these, 22/29 (75.9%) were from ‘well-represented’ countries and 7/29 (24.1%) from ‘less well-represented’ countries

Step 5: inter-rater reliability of annotations using the intervention population ontology

First, we assessed the *inter-rater reliability* of annotations by the two researchers leading the ontology development using 70 reports from Cochrane reviews of interventions (50 smoking cessation reports and 20 physical activity reports). We then assessed inter-rater reliability for annotations by two behaviour change experts unfamiliar with the ontology, but with experience in annotating behaviour change intervention reports, for a further batch of 50 reports. These reports were a random sample of randomised controlled trials from a database of papers which had been previously coded for Behaviour Change Techniques (Carey *et al.*, 2018; Michie *et al.*, 2021a) featuring interventions that targeted a variety of behaviours. Inter-rater reliability was assessed using Krippendorff’s Alpha (Hayes & Krippendorff, 2007) calculated using version 1.0.0 of the Automation Inter-Rater Reliability script developed by the Human Behaviour-Change Project team (Finnerty & Moore, 2020), incorporating the python script Krippendorff 0.3.2. The research team made additional changes to the ontology based on the issues arising from inter-rater reliability testing.

Step 6: specifying the relationships between intervention population ontology entities and ensuring alignment with other parts of the BCIO and relevant ontologies

The research team discussed and specified relationships between *entities* in the ontology. Relationships were specified in line with *Basic Formal Ontology* principles described in Arp *et al.* (2015) and the Relation Ontology (Smith *et al.*, 2005). The entities in the Intervention Population Ontology were reviewed for consistency with other parts of the BCIO and related ontologies that were structured using Basic Formal Ontology: particularly the Addiction Ontology (Hastings *et al.*, 2020), and the Mental Functioning Ontology (Hastings *et al.*, 2012). This review was led by the HBCP’s ontology expert (JH), who flagged inconsistencies between these ontologies. These inconsistencies were discussed with the wider research team and the Intervention Population Ontology updated as appropriate.

The Intervention Population Ontology comprises entities that reflect characteristics of individuals. However, it also needs to represent how these entities are aggregated to describe intervention populations. For example, age is a characteristic of an individual, but intervention populations are aggregates of individuals and so the population’s age can be reported

as a mean, a median or a range, with or without minimum and maximum values. For categorical characteristics (e.g. relationship status), intervention reports tend to report the percentage of the intervention population in a given category (e.g. 24% married). Therefore, for each *entity* in the ontology, we also specified how they can be aggregated to describe intervention populations.

Step 7: making the intervention population ontology machine-readable and available online

The IPO was developed as a table of entities, with separate rows for each entity and its label, definition, synonyms, examples, relationships with other entities, elaborations and how it is aggregated to describe an intervention population. Following step 6, the IPO was converted into the computable *Web Ontology Language (OWL)* format (Antoniou & van Harmelen, 2004). This is a standard representation format for ontologies widely used across domains. It’s possible to search, visualise and query the OWL representation of the ontology using standard ontology tools and software. The conversion was done using the *ROBOT* ontology toolkit library (Jackson *et al.*, 2019). An additional custom script was created to append aggregate versions of the entities according to the specification of allowed aggregation operations for individual population attributes. Aggregate entities are classified as data items and are linked to the individual attributes with an ‘aggregate_of’ relation.

The OWL version of the IPO is stored in the Human Behaviour-Change Project’s *GitHub* repository. GitHub is an online platform for sharing and *versioning* resources and has an *issue tracker*, allowing feedback and queries to be submitted by members of the GitHub community. Feedback and queries can then be responded to in a transparent fashion and, if necessary, addressed in subsequent ontology releases. The IPO is part of the Behaviour Change Intervention Ontology which is available online in the Behavioural and Social Sciences Ontology Foundry, a repository for ontologies in the behavioural and social science domains.

Results

Step 1. Defining the scope of the intervention population ontology

The initial definition of behaviour change intervention population was “An aggregate of people who are exposed to a behaviour change intervention”.

Step 2. Identifying key entities and developing the intervention population ontology

The initial prototype version of the Population Ontology (v0.1) had a four-level hierarchical structure, containing 246 entities (<https://osf.io/jhymg>). For the pilot annotations of 55 intervention reports, inter-rater agreement for identifying the presence of an intervention population entity was low at 45.5%. Kappa statistics varied considerably, from ‘perfect’ and ‘outstanding’ for entities such as language proficiency’ (kappa=1) and ‘age’ (kappa=0.927) ‘to ‘moderate’ agreement (κ=0.449) for entities such as ‘activity level’.

Step 3. Refinement of the intervention population ontology through literature annotation

Annotating intervention reports led to numerous changes to the Intervention Population Ontology. 38 entities were added, 54 were retained (23 with revised labels) and 192 entities were removed, resulting in a refined version of the Population Ontology (<https://osf.io/m6udx>) with 92 classes. Added classes related to income and material resources, occupations, religious group membership, completed education and psychological status. Changes to labels often served to make classes more internationally applicable.

Of the removed classes, 70 were “unclear/insufficient information” and “other” in relation to various population characteristics. These classes did not meet the ontological requirement that classes are unique, discrete entities with corresponding definitions (Arp *et al.*, 2015). 31 health status classes were removed because it became clear that reusing classes from an existing ontology of health conditions (the [Disease Ontology](#) (Schriml *et al.*, 2019)) would be more appropriate than developing such classes as part of the Intervention Population Ontology. We selected the Disease Ontology for reuse because it is freely available, uses Basic Formal Ontology as a top-level, and provide cross-references to other medical classification systems such as MeSH, the International Classification of Diseases (ICD) and SNOMED. 37 classes relating to behaviours were removed to avoid duplication of effort with work to develop the Human Behaviour Ontology (Schenk *et al.*, 2024a).

Step 4. Expert stakeholder review

The 29 experts provided 139 comments on the ontology via the online survey. Expert responses and how they were addressed can be found on OSF [here](#). Expert feedback led to 40 classes being added to the ontology and 2 classes removed. 51 classes were retained unchanged, while nine classes had revised labels, 24 had revised definitions and six had both a revised label and a revised definition. Notable additions to the ontology included a wider range of sexual orientations, classes relating to immigration, additional types of employment status, more family relationships and having a caregiving role. Where experts’ suggestions for were not acted upon, this was often because the change suggested was only relevant to a single country, while the ontology is intended to have international applicability. Several experts suggested adding classes that reflected labels for different ethnic groups used in a particular country. However, we defined ethnic group membership as a self-identity (i.e. an identity that a person has about themselves) and so there are a vast number of classes that could fall under this umbrella. We also noted that some of the terms used to refer to different ethnic groups were used differently in different countries (e.g. the ethnic groups labelled as “Asian” differ between the UK and USA), creating a further level of complexity if we tried to add more ethnicity classes. We also did not add classes that reflected methods to measure population characteristics, rather than the population characteristics themselves. At the end of the expert stakeholder feedback review,

the revised version of the Intervention Population Ontology (v0.3) had 132 classes (<https://osf.io/8uw52>).

Step 5. Inter-rater reliability of annotations using the population ontology

Inter-rater reliability for the 70 papers annotated by researchers familiar with the ontology was found to be ‘good’ ($\alpha = .79$) (Hayes & Krippendorff, 2007). Inter-rater reliability for the papers that were annotated by the researchers unfamiliar with the ontology was also ‘good’ ($\alpha = .85$) (Hayes & Krippendorff, 2007).

Step 6: Specifying the relationships between intervention population ontology entities and ensuring alignment with other parts of the BCIO and relevant ontologies

One key relationship used in the ontology is the ‘is_a’ relation, which captures hierarchical organisation. This relationship is specified for every entity in the ontology, that is, every entity is assigned a single parent class within the ontology. In addition, the aggregates of individual population attributes are connected to the individual attributes using the ‘aggregate_of’ relation, for example, ‘mean human age’ aggregate_of ‘human age’. Following the review of the alignment between the Intervention Population Ontology and other parts of the BCIO, as well as with relevant external ontologies, particularly the Addiction Ontology (Hastings *et al.*, 2020) and the Mental Functioning Ontology, (Hastings *et al.*, 2012), 86 classes were added. These additions included classes to represent various aspects of an individual’s personal history and a greater range of family members than previously included. To reflect the scope of the ontology being broader than just behaviour change intervention populations, we introduced the class “Intervention population,” defined as “A human population who are exposed to an intervention,” as the parent of “behaviour change intervention population”.

Step 7 making the population ontology machine readable and available online

The final version of the Intervention Population Ontology consists of 218 entities reflecting individual characteristics of human beings, across key areas such as personal attributes, geographic location, person, quality, mental capability, role, expertise, objects possessed, behaviour, personal vulnerability and personal history. These individual level entities are linked to 666 entities reflecting how the characteristics can be aggregated to describe intervention populations. [Table 2](#) shows the individual-level classes, with their *Uniform Resource Identifiers (URIs)*, labels and definitions, together with how they are aggregated. An annotation manual that provides guidance on how to annotate for these entities in intervention reports is available online (<https://osf.io/u9wb4>). A downloadable version of the Intervention Population Ontology is available from the [HBCP GitHub repository](#) and it can be browsed in the dedicated [BCIO Search tool](#) and the [Ontology Lookup Service](#)

Table 2. IDs, labels, definitions, parent classes and how aggregated for all Intervention Population Ontology entities.

ID	Label	Definition	Parent	Aggregated
BCIO:041000	human population	An object aggregate that consists of two or more people.	object aggregate	
BCIO:015095	intervention population	A human population who are exposed to an intervention.	human population	
BCIO:015000	behaviour change intervention population	An intervention population who are exposed to a behaviour change intervention.	intervention population	
BCIO:050892	social grouping	A human population who share some common attribute that involves some form of social interaction.	human population	
BCIO:050891	social group	A social grouping that identifies as such and sometimes acts collectively.	social grouping	
BCIO:050888	out-group	A social group that is part of a person's social environmental system and with which the person does not identify.	social group	
MF:0000016	person	An extended organism that is a member of the species Homo sapiens.	extended organism	
BCIO:015094	intervention participant	A person who is exposed to an intervention.	person	
BCIO:015001	behaviour change intervention participant	An intervention participant who is exposed to a behaviour change intervention.	intervention participant	
ADDICTO:0000352	adult	A person who has reached maturity.	person	percentage; proportion
BCIO:015096	child	A person who has not yet reached maturity.	person	percentage; proportion
ADDICTO:0001050	teenager	A person between 13 and 19 years of age.	person	percentage; proportion
BCIO:050889	person in a social environmental system	A person who is part of a social environmental system.	person	percentage; proportion
BCIO:015012	immigrant	A person who has previously been a resident of a country and is now resident in another country.	person	percentage; proportion
BCIO:015013	second generation immigrant	A person who has at least one parent who is an immigrant.	person	percentage; proportion
BCIO:010095	family member	A person who is a member of a group of persons united by blood, or by marriage or other legal arrangement, or by self-identity as belonging to the same family.	person	percentage; proportion
BCIO:015110	parent	A family member who is a key caretaker or immediate progenitor of a child.	family member	percentage; proportion
BCIO:050476	father	A parent who is male gender.	parent	percentage; proportion
BCIO:050480	mother	A parent who is female gender.	parent	percentage; proportion
BCIO:015136	sibling	A family member with whom the subject shares a parent.	family member	percentage; proportion
BCIO:015149	twin	One of two siblings who resulted from the same pregnancy.	sibling	percentage; proportion

ID	Label	Definition	Parent	Aggregated
BCIO:015123	child relation	A family member who is a person's first generation offspring.	family member	percentage; proportion
BCIO:015114	adoptive parent	A parent in a parent-child relationship established by a legal adoption process.	parent	percentage; proportion
BCIO:015116	adoptive father	An adoptive parent who is male gender.	adoptive parent	percentage; proportion
BCIO:015115	adoptive mother	An adoptive parent who is female gender.	adoptive parent	percentage; proportion
BCIO:015127	adoptive child	A child relation in a parent-child relationship established by a legal adoption process.	child relation	percentage; proportion
BCIO:015129	adoptive son	An adoptive child who is male gender.	adoptive child	percentage; proportion
BCIO:015128	adoptive daughter	An adoptive child who is female gender.	adoptive child	percentage; proportion
BCIO:015140	adoptive sibling	A sibling with whom the subject shares a parent through a parent-child relationship established by a legal adoption process.	sibling	percentage; proportion
BCIO:015142	adoptive brother	An adoptive sibling who is male gender.	adoptive sibling	percentage; proportion
BCIO:015141	adoptive sister	An adoptive sibling who is female gender.	adoptive sibling	percentage; proportion
BCIO:015111	biological parent	A parent who provided one of the gametes that resulted in one's conception.	parent	percentage; proportion
BCIO:015113	biological father	A biological parent who provided the sperm.	biological parent	percentage; proportion
BCIO:015112	biological mother	A biological parent who provided an egg.	biological parent	percentage; proportion
BCIO:015124	biological child	A child relation who is genetically related to their parent.	child relation	percentage; proportion
BCIO:015125	biological daughter	A biological child who is female gender.	biological child	percentage; proportion
BCIO:015126	biological son	A biological child who is male gender.	biological child	percentage; proportion
BCIO:015137	biological sibling	A sibling with whom the subject shares a biological parent.	sibling	percentage; proportion
BCIO:015138	biological sister	A biological sibling who is female gender.	biological sibling	percentage; proportion
BCIO:015139	biological brother	A biological sibling who is male gender.	biological sibling	percentage; proportion
BCIO:015120	foster parent	A parent who cares for a child who has been placed with them in a foster care arrangement.	parent	percentage; proportion
BCIO:015122	foster father	A foster parent who is male gender.	foster parent	percentage; proportion
BCIO:015121	foster mother	A foster parent who is female gender.	foster parent	percentage; proportion
BCIO:015133	foster child	A child relation in a parent-child relationship created by a foster care arrangement.	child relation	percentage; proportion
BCIO:015134	foster daughter	A foster child who is female gender.	foster child	percentage; proportion

ID	Label	Definition	Parent	Aggregated
BCIO:015135	foster son	A foster child who is male gender.	foster child	percentage; proportion
BCIO:015146	foster sibling	A sibling who shares a parent through a parent-child relationship created by a foster care agreement.	sibling	percentage; proportion
BCIO:015148	foster brother	A foster sibling who is male gender.	foster sibling	percentage; proportion
BCIO:015147	foster sister	A foster sibling who is female gender.	foster sibling	percentage; proportion
BCIO:015117	step-parent	A parent in a parent-child relationship established by the parent's subsequent marriage to one of the child's original biological or legal parents.	parent	percentage; proportion
BCIO:015119	stepfather	A step-parent who is male gender.	step-parent	percentage; proportion
BCIO:015118	stepmother	A step-parent who is female gender.	step-parent	percentage; proportion
BCIO:015130	stepchild	A child relation in a parent-child relationship established by the parent's subsequent marriage to one of the child's original biological or legal parents.	child relation	percentage; proportion
BCIO:015131	stepdaughter	A stepchild who is female gender.	stepchild	percentage; proportion
BCIO:015132	stepson	A stepchild who is male gender.	stepchild	percentage; proportion
BCIO:015143	step-sibling	A sibling who is the child of one's step-parent.	sibling	percentage; proportion
BCIO:015145	stepbrother	A step-sibling who is male gender.	step-sibling	percentage; proportion
BCIO:015144	stepsister	A step-sibling who is female gender.	step-sibling	percentage; proportion
BCIO:015150	grandparent	A family member who is the parent of one's parent.	family member	percentage; proportion
BCIO:015152	grandfather	A grandparent who is male gender.	grandparent	percentage; proportion
BCIO:015151	grandmother	A grandparent who is female gender.	grandparent	percentage; proportion
BCIO:015153	aunt	A family member who is the sister of one's parent.	family member	percentage; proportion
BCIO:015154	uncle	A family member who is the brother of one's parent.	family member	percentage; proportion
BCIO:015155	cousin	A family member who is a child relation of one's aunt or uncle.	family member	percentage; proportion
BCIO:015157	nephew	A family member who is a child relation of one's sibling and is male gender.	family member	percentage; proportion
BCIO:015156	niece	A family member who is a child relation of one's sibling and is female gender.	family member	percentage; proportion

ID	Label	Definition	Parent	Aggregated
BCIO:015036	homeless person	A person who does not own a residential facility and does not have an agreement with a residential facility owner that would enable them to live in a residential facility.	person	percentage; proportion
BCIO:015035	occupier of employer-provided housing	A person who lives in a residential facility they do not own with the agreement of the residential facility owner, by virtue of the occupier bearing a role realised in an employment process.	person	percentage; proportion
SDGIO:00010028	owner	A person or organization that participates in an ownership process wherein they realize their role as owner by exercising their right to use, sell, rent, or gift an object.	material entity	percentage; proportion
BCIO:015028	residential facility owner	An owner of a residential facility.	owner	percentage; proportion
BCIO:015029	owner-occupier	A person who lives in a residential facility of which they are the residential facility owner	person	percentage; proportion
BCIO:015032	rent-free occupier	A person who lives in a residential facility they do not own without paying an agreed sum of money to the residential facility owner.	person	percentage; proportion
BCIO:015033	agreed rent-free occupier	A rent-free occupier who lives in the residential facility with the agreement of the residential facility owner.	rent-free occupier	percentage; proportion
BCIO:015034	rent-free occupier without owner's permission	A rent-free occupier who lives in the residential facility without the agreement of the residential facility owner.	rent-free occupier	percentage; proportion
BCIO:015030	renter	A person who lives in a residential facility they do not own in return for paying an agreed sum of money to the residential facility owner	person	percentage; proportion
BCIO:015031	renter of housing from a social provider	A renter who lives in a residential facility where the residential facility owner decides who can live in the residential facility based on their perceived social or economic needs.	renter	percentage; proportion
BCIO:015021	member of a multi-person household	A person living in a household with at least one other person.	person	percentage; proportion
BCIO:015023	member of a multi-person household all related	A member of a multi-person household where all of the household members are related.	member of a multi-person household	percentage; proportion
BCIO:015025	member of a multi-person household not related	A member of a multi-person household where none of the household members are related.	member of a multi-person household	percentage; proportion
BCIO:015024	member of a multi-person household some related	A member of a multi-person household where some household members are related.	member of a multi-person household	percentage; proportion
BCIO:015022	member of a multi-person multi-generational household	A member of a multi-person household where some household members belong to different generations.	member of a multi-person household	percentage; proportion
BCIO:015020	member of a one person household	A person living alone in a household.	person	percentage; proportion
OMRSE:00000076	household	A human or collection of humans that occupies a housing unit by storing their possessions there and habitually sleeping there thereby participating in the realization of its residence function.	material entity	

ID	Label	Definition	Parent	Aggregated
BCIO:050300	personal attribute	A specifically dependent continuant that inheres in a person.	specifically dependent continuant	
BCIO:015091	caste membership	A personal attribute as belonging to a group within a stratified system of categorisation based on a status conferred at birth based on descent, in which individuals have limited or no mobility due to custom or law.	personal attribute	percentage; proportion
BCIO:050474	disabled	A personal attribute in which the person has impaired physical or mental functioning that has a notable effect on their ability to do typical daily activities.	personal attribute	percentage; proportion
BCIO:050479	long-term disabled	Disabled for at least 12 months.	disabled	percentage; proportion
BCIO:015092	health status attribute	A personal attribute that is the state of an individual's mental or physical condition.	personal attribute	percentage; proportion
BCIO:015093	medication use status	A health status attribute that is having been prescribed the use of one or more drugs to improve, maintain or protect one's health.	health status attribute	percentage; proportion
BCIO:015002	human age	A personal attribute that is a time quality inhering in a person by virtue of how long since the person was born.	personal attribute	Mean; Minimum; Maximum; Median
BCIO:015026	individual income	A personal attribute reflecting a benefit the person receives derived from their capital or labour, usually measured in money.	personal attribute	Mean; Minimum; Maximum; Median; percentage; proportion
BCIO:015037	income-related welfare benefit	Individual income that an individual otherwise of low-income receives as a payment made by the state or an insurance scheme in the form of housing vouchers, credit or benefits.	individual income	percentage; proportion
BCIO:015065	homemaker status	A personal attribute inhering in a person who does not bear a role realised in an employment process and who manages their home as their main daily activity.	personal attribute	percentage; proportion
BCIO:015066	independently wealthy status	A personal attribute inhering in a person who does not bear a role realised in an employment process due to possessing enough wealth to not need financial support from another person or require income from employment.	personal attribute	percentage; proportion
BCIO:015061	not seeking employment	A personal attribute inhering in a person by virtue of that person not having a paid job and not currently seeking to begin participating in an employment process.	personal attribute	percentage; proportion
BCIO:015062	not working for health reasons	A personal attribute inhering in a person by virtue of that person not bearing a role realised in an employment process, due to being unable to work due to illness or disability.	personal attribute	percentage; proportion
BCIO:015067	retired status	A personal attribute inhering in a person who previously bore a role realised in an employment process but has withdrawn from that employment process, having concluded their working or professional career.	personal attribute	percentage; proportion

ID	Label	Definition	Parent	Aggregated
BCIO:015063	stay at home parent or guardian status	A personal attribute inhering in a person by virtue of that person not bearing a role realised in an employment process, due to being a homemaker whose work includes caring for children.	personal attribute	percentage; proportion
SDGIO:00010026	unemployed status	A personal attribute inhering in a person by virtue of that person not bearing a role realised in an employment process, but being eligible for and currently seeking paid work.	personal attribute	percentage; proportion
BCIO:015064	unpaid carer for an adult status	A personal attribute inhering in a person by virtue of that person not bearing a role realised in an employment process, due to their primary occupation being caring, without receiving a wage for it, for an adult friend or family member who, due to illness or disability, requires support in their daily life activities.	personal attribute	percentage; proportion
BCIO:015060	voluntary worker status	A personal attribute inhering in a person by virtue of that person working or assisting at a workplace without receiving remuneration.	personal attribute	percentage; proportion
OPMI:0000121	socioeconomic status	A personal attribute reflecting a person's economic and social position in relation to others, based on their income, education, or occupation.	personal attribute	
BCIO:015068	socioeconomic status category	A data item about a category assigned to a person based on an assessment of a score calculated from various measures of their income, education, occupation, family size or household.	data item	percentage; proportion
BCIO:015069	socioeconomic status score	A data item about a score on a measure of a person's socioeconomic status, calculated by combining information about the number of years of education completed, their individual or household income, their current occupation or the industry in which they work or family size or household.	data item	Mean; Minimum; Maximum; Median
BCIO:015014	religious group membership	A personal attribute that is belonging to a group that is characterised by the practice of a common religion by the group members.	personal attribute	percentage; proportion
BCIO:015043	highest level of formal educational qualification achieved	A personal attribute related to the highest level of education achieved.	personal attribute	percentage; proportion
BCIO:015051	achieved doctoral or equivalent level education	A highest level of formal educational qualification achieved after participating in an education process devoted to advanced study and original research that led to the award of a PhD or equivalent level qualification.	highest level of formal educational qualification achieved	percentage; proportion
BCIO:015050	achieved master's or equivalent level	A highest level of formal educational qualification achieved after participating in an education process which has as a prerequisite an undergraduate degree and which is intended to result in the acquisition and development of advanced academic or professional skills and knowledge in a specialised discipline, that culminated in the award of a Master's or equivalent degree.	highest level of formal educational qualification achieved	percentage; proportion
BCIO:015049	achieved bachelor's degree or equivalent level	A highest level of formal education qualification achieved after participating in an education process intended to result in the acquisition and development of skills and knowledge in a specialised discipline that culminated in the award of an undergraduate degree.	highest level of formal educational qualification achieved	percentage; proportion

ID	Label	Definition	Parent	Aggregated
BCIO:015048	achieved upper secondary education	A highest level of formal educational qualification achieved after participating in an education process intended to result in the acquisition and development of skills and knowledge that prepare participants for tertiary education or employment.	highest level of formal educational qualification achieved	percentage; proportion
BCIO:015047	achieved lower secondary education	A highest level of formal educational qualification achieved after participating in an education process intended to result in the acquisition and development of skills and knowledge in subject areas more specialised than basic reading, writing and mathematics, with the overall goal of laying the foundation for lifelong learning and human development on which education systems may systematically expand further educational opportunities.	highest level of formal educational qualification achieved	percentage; proportion
BCIO:015046	achieved primary education	A highest level of formal educational qualification achieved after participating in an education process intended to result in the acquisition of fundamental skills in reading, writing and mathematics.	highest level of formal educational qualification achieved	percentage; proportion
BCIO:015045	achieved early childhood education	A highest level of formal educational qualification achieved after participating in an education process intended to introduce very young children to a school-type environment.	highest level of formal educational qualification achieved	percentage; proportion
BCIO:015071	relationship status	A personal attribute that is whether an individual is connected or associated with another through romantic attraction or marriage.	personal attribute	percentage; proportion
BCIO:015075	divorced or separated	A relationship status where the individual was previously in a legally formalised relationship and this relationship has now ended or dissolved.	relationship status	percentage; proportion
BCIO:015074	in a legal marriage or union	A relationship status where the individual is in a legally formalised marriage or civil partnership.	relationship status	percentage; proportion
BCIO:015073	in a stable or common law relationship	A relationship status where the individual has had the same partner for a significant length of time but is not in a legal union.	relationship status	percentage; proportion
BCIO:015072	single	A relationship status where the individual is not in a relationship with another person.	relationship status	percentage; proportion
BCIO:015076	widowed	A relationship status where the individual is no longer in a legally formalised marriage or civil partnership due to the death of their spouse or partner.	relationship status	percentage; proportion
BCIO:050491	situational personal attribute	A personal attribute that holds within a given situation.	personal attribute	
BCIO:050492	unawareness of a behaviour	A situational personal attribute in which a person has not thought about enacting a behaviour.	situational personal attribute	percentage; proportion
BCIO:050493	undecidedness about enacting a behaviour	A situational personal attribute in which the person has thought about a behaviour but not formed an intention regarding whether to enact it.	situational personal attribute	percentage; proportion
BCIO:050886	extent of past behavioural achievement	A personal attribute that is the extent to which the person's past behaviour has reached or exceeded a standard.	personal attribute	Mean; Minimum; Maximum; Median; percentage; proportion

ID	Label	Definition	Parent	Aggregated
BCIO:015159	personal psychological attribute	A personal attribute reflecting a person's mental dispositions, mental processes or capabilities.	personal attribute	Mean; Minimum; Maximum; Median; percentage; proportion
BCIO:050893	socio-demographic characteristic	A personal attribute that, together with other attributes, characterises a person's position in society.	personal attribute	Mean; Minimum; Maximum; Median; percentage; proportion
BCIO:015003	sexual orientation	A personal attribute that is the pattern of a person's emotional, romantic and/or sexual attractions.	personal attribute	percentage; proportion
BCIO:015004	asexual	A sexual orientation of an individual who does not experience sexual attraction.	sexual orientation	percentage; proportion
BCIO:015005	bisexual	A sexual orientation of an individual who experiences sexual attraction to members of more than one sex.	sexual orientation	percentage; proportion
BCIO:015006	heterosexual	A sexual orientation of an individual who experiences sexual attraction exclusively or primarily to members of a different sex.	sexual orientation	percentage; proportion
BCIO:015007	homosexual	A sexual orientation of an individual who experiences sexual attraction exclusively or primarily to members of the same sex.	sexual orientation	percentage; proportion
BCIO:015010	other sexual orientation	A sexual orientation of an individual who is sure of their sexual orientation and reports it as other than asexual, bisexual, heterosexual, homosexual, queer or questioning.	sexual orientation	percentage; proportion
BCIO:015009	queer	A sexual orientation that is not exclusively homosexual or heterosexual, or of a person who does not identify with heterosexual, homosexual or bisexual labels.	sexual orientation	percentage; proportion
ADDICTO:0000381	identity	A cognitive representation of themselves by a person or group.	cognitive representation	
ADDICTO:0000399	self-identity	An identity a person has about themselves.	identity	
BCIO:015098	gender identity	A self-identity as having a particular gender, which may or may not correspond with sex assigned at birth.	self-identity	percentage; proportion
BCIO:015104	cisgender	A gender identity that matches the person's assigned sex at birth.	gender identity	percentage; proportion
BCIO:010111	female gender	A gender identity as being female.	gender identity	percentage; proportion
BCIO:010112	male gender	A gender identity as being male.	gender identity	percentage; proportion
BCIO:015101	nonbinary gender	A gender identity as having a gender that is not well-described by the binary categories of male or female.	gender identity	percentage; proportion
BCIO:015103	transgender	A gender identity that differs from the person's assigned sex at birth.	gender identity	percentage; proportion
BCIO:015102	non-gendered identity	A self-identity as not having a particular gender.	self-identity	percentage; proportion

ID	Label	Definition	Parent	Aggregated
BCIO:015008	questioning sexual orientation	A self-identity as being in the process of exploring one's sexual orientation.	self-identity	percentage; proportion
BCIO:015097	ethnic group membership	A self-identity as belonging to a social group or groups whose members have a common cultural or ancestral heritage.	self-identity	percentage; proportion
BFO:0000019	quality	A specifically dependent continuant that, in contrast to roles and dispositions, does not require any further process in order to be realized.	specifically dependent continuant	
SDGIO:00010029	employment status	A quality inhering in a person by virtue of that person bearing a role realised in an employment process.	quality	percentage; proportion
BCIO:015052	employed	An employment status realised by an individual being engaged in an activity or service for wages or salary.	employment status	percentage; proportion
BCIO:015053	employed full time	An employment status realised by an individual working a standard number of hours defined as full-time by their employer.	employment status	percentage; proportion
BCIO:015059	employed in shift work	An employment status realised by an individual working for recurring periods in which different groups of workers do the same jobs in relay.	employment status	percentage; proportion
BCIO:015054	employed part time	An employment status realised by an individual whose working hours involving less than the standard or customary working time.	employment status	percentage; proportion
BCIO:015055	in permanent employment	An employment status realised by an individual working for a company or other organisation without a pre-determined end date, with security of employment and known working conditions.	employment status	percentage; proportion
BCIO:015056	in short term or temporary employment with known conditions	An employment status realised by an individual working for a company or other organisation in a position that is of a known, fixed duration with security of employment for that duration and certain working conditions.	employment status	percentage; proportion
BCIO:015057	in uncertain employment	An employment status realised by an individual working for a company or other organisation in a position with uncertain duration or hours with unknown or low security of working conditions or pay.	employment status	percentage; proportion
BCIO:015058	self employed status	An employment status realised by a person earning income directly from customers, clients, or other organisations rather than as a specified salary or wages from an employer.	employment status	percentage; proportion
MF:0000074	bodily quality	A quality that inheres in some extended organism.	quality	
BCIO:015105	biological sex	A bodily quality based on reproductive function or organs.	bodily quality	percentage; proportion
BCIO:015106	female biological sex	A biological sex associated with the ability to produce female gametes.	biological sex	percentage; proportion
BCIO:015107	male biological sex	A biological sex associated with the ability to produce male gametes.	biological sex	percentage; proportion
MF:0000048	mental capability	A personal capability that includes mental processes in its realisation.	personal capability	Mean; Minimum; Maximum; Median; percentage; proportion

ID	Label	Definition	Parent	Aggregated
MF:0000050	linguistic capability	A mental capability that is realised in processes of communication involving language or in expressions of language.	mental capability	Mean; Minimum; Maximum; Median; percentage; proportion
BCIO:015019	ability to comprehend spoken intervention language	A linguistic capability that is realised by following and understanding speech in the intervention language.	linguistic capability	percentage; proportion
BCIO:015016	ability to read in intervention language	A linguistic capability that is realised by reading and understanding text in the intervention language.	linguistic capability	percentage; proportion
BCIO:015018	ability to speak in intervention language	A linguistic capability that is realised by producing speech in the intervention language.	linguistic capability	percentage; proportion
BCIO:015017	ability to write in intervention language	A linguistic capability that is realised by generating written text in the intervention language.	linguistic capability	percentage; proportion
BCIO:015015	language proficiency	A linguistic capability that is realised by using a language accurately and appropriately in more than one setting.	linguistic capability	Mean; Minimum; Maximum; Median; percentage; proportion
BCIO:015011	country of birth	A geographic location that is the country in which a person was born.	geographic location	percentage; proportion
BCIO:050490	place of residence	A geographic location in which a person resides.	geographic location	percentage; proportion
BFO:0000023	role	b is a role means: b is a realizable entity & b exists because there is some single bearer that is in some special physical, social, or institutional set of circumstances in which this bearer does not have to be & b is not such that, if it ceases to exist, then the physical make-up of the bearer is thereby changed.	realizable entity	
BCIO:015077	caregiving role	A role which inheres in a person and is realised by the person assuming responsibility for the physical and emotional needs of another who has difficulties with self care.	role	percentage; proportion
BCIO:015158	insured party role	A role that inheres in an organism that is able to receive benefits from an insurance policy.	role	percentage; proportion
OMRSE:00000094	policy holder role	An insured party role that inheres in a person who participates in the creation of the insurance contract and is eligible to receive benefits as specified by the insurance contract.	insured party role	percentage; proportion
BCIO:015038	health insurance policy holder role	A policy holder role that inheres in a person who participates in the creation of an insurance contract designed to cover some or all of the cost of treating the insured person's illnesses or injuries as well as possibly providing preventive health care.	policy holder role	percentage; proportion
BCIO:050478	influencer role	A social role that involves influencing other people to adopt new ideas or behaviours.	social role	percentage; proportion
BCIO:050887	leadership role	A social role in which the holder is given or creates authority to exert influence on other members of a social group.	social role	percentage; proportion

ID	Label	Definition	Parent	Aggregated
BCIO:015070	interpersonal role	A role relating to personal relationships or association between an individual and other individuals, including kinship relations, romantic, business, and social interactions.	role	percentage; proportion
BCIO:015081	occupational role	A role that is realised by a person doing a specified type of work or working in a specified way.	role	percentage; proportion
BCIO:015078	organisational role	A role which inheres in a person and is realised by performing the activities deemed appropriate for that particular role as specified in the organisation rules.	role	percentage; proportion
BCIO:015108	parental role	An interpersonal role that is realised through a process of promoting and supporting the physical, emotional, social, and intellectual development of a child from infancy to adulthood.	interpersonal role	percentage; proportion
OBI:0000093	patient role	A role which inheres in a person and is realized by being under the care of a physician or health care provider.	role	percentage; proportion
BCIO:015079	inpatient role	A patient role which inheres in a person and is realized by being under the care of a physician or health care provider and being admitted to a hospital or equivalent facility.	patient role	percentage; proportion
BCIO:015080	outpatient role	A patient role which inheres in a person and is realized by coming to a healthcare facility for diagnosis or treatment but not being admitted for an overnight stay.	patient role	percentage; proportion
BCIO:010084	student or trainee role	A role which inheres in a person and is realised by being enrolled in an educational institution or a formal programme of professional training.	role	percentage; proportion
BCIO:015087	higher education student role	A student or trainee role realised by currently learning on an advanced educational programme in a university, college or professional school. For example, completing a university bachelor's or master's course of study, medical school or other professional school.	student or trainee role	percentage; proportion
BCIO:050475	doctoral student role	A higher education student role realised by currently studying for a doctoral degree.	higher education student role	percentage; proportion
BCIO:015090	masters student role	A higher education student role realised by currently studying for a masters degree.	higher education student role	percentage; proportion
BCIO:015089	graduate student role	A higher education student role realised by currently studying for a more advanced degree after completing an undergraduate degree.	higher education student role	percentage; proportion
BCIO:015088	undergraduate student role	A higher education student role realised by currently studying for an undergraduate degree.	higher education student role	percentage; proportion
BCIO:015086	vocational training student or trainee role	A student or trainee role realised by currently learning the curriculum material of vocational programme, normally in preparation for employment in a trade, job or profession.	student or trainee role	percentage; proportion
BCIO:015085	school student role	A student or trainee role realised by currently learning at a primary or secondary education level in an institutional, organised setting.	student or trainee role	percentage; proportion
BCIO:015084	preschool student role	A student or trainee role realised by currently learning at an initial level of organised instruction, primarily to familiarise the bearer to the school-type environment.	student or trainee role	percentage; proportion

ID	Label	Definition	Parent	Aggregated
BCIO:015083	informal education student role	A student or trainee role realised by currently learning in a non-institutional setting.	student or trainee role	percentage; proportion
BCIO:010123	expertise discipline	An attribute that is a field of knowledge or practice.	specifically dependent continuant	percentage; proportion
BCIO:010093	discipline of current programme of study or training	An expertise discipline of the programme of study currently undertaken by the bearer of a student or trainee role.	expertise discipline	percentage; proportion
BCIO:015044	discipline of highest level of formal educational qualification achieved	An expertise discipline of the highest level of formal educational qualification a person has achieved.	expertise discipline	percentage; proportion
SDGIO:00010001	education process	A planned process wherein knowledge and skill is imparted.	planned process	
BCIO:015042	number of years in education completed	The number of years a person spent engaged in an education process.	data item	Mean; Minimum; Maximum; Median
BCIO:015027	household income	An aggregate of the individual incomes received by all the members of a household.	object aggregate	Mean; Minimum; Maximum; Median; percentage; proportion
BCIO:015039	valuable material resource owned	An object aggregate under the control of some person or organisation which confers an economic benefit to that person or organisation in an economic system.	object aggregate	
BCIO:015040	quantity of valuable material resource owned	A data item about the number of units of a valuable material resource possessed by a person.	data item	Mean; Minimum; Maximum; Median
BCIO:015041	value of valuable material resource owned	A data item about the monetary value of a valuable material resource possessed by a person.	data item	Mean; Minimum; Maximum; Median
BCIO:036000	individual human behaviour	Individual human activity that involves co-ordinated contraction of striated muscles controlled by the brain.	individual human activity	Mean; Minimum; Maximum; Median; percentage; proportion
BFO:0000182	history	A process that is the sum of the totality of processes taking place in the spatiotemporal region occupied by a material entity or site, including processes on the surface of the entity or within the cavities to which it serves as host.	process	
BCIO:015161	personal history	A history that is of a person.	history	
BCIO:050487	personal history part	A process that is part of a personal history.	process	
BCIO:050477	having enacted a behaviour	A personal history part that includes previously performing a behaviour.	personal history part	percentage; proportion
BCIO:015163	history of exposure to an occupational hazard	A personal history part that includes exposure to a potentially harmful agent as a result of one's occupation.	personal history part	percentage; proportion
BCIO:015162	history of exposure to childhood maltreatment	A personal history part that includes experience of physical, sexual, or psychological maltreatment during the first 18 years of life.	personal history part	percentage; proportion

ID	Label	Definition	Parent	Aggregated
BCIO:050481	past behaviour	A personal history part that includes a behaviour.	personal history part	Mean; Minimum; Maximum; Median; percentage; proportion
BCIO:050482	personal history of behavioural lapse	A personal history part that includes a change from a less desired behaviour pattern to a more desired behaviour pattern followed by a temporary reversion to the previous behaviour pattern.	personal history part	Mean; Minimum; Maximum; Median; percentage; proportion
BCIO:050483	personal history of events that influence behaviour	A personal history part that includes experience of events that influence behaviour.	personal history part	Mean; Minimum; Maximum; Median; percentage; proportion
BCIO:050484	personal history of intervention exposure for the same outcome	A personal history part of exposure to an intervention targeting the same outcome as the current intervention.	personal history part	Mean; Minimum; Maximum; Median; percentage; proportion
BCIO:050485	personal history of intervention exposure for the same outcome behaviour	A personal history part that includes exposure to a prior intervention targeting the same outcome behaviour as the current intervention.	personal history part	Mean; Minimum; Maximum; Median; percentage; proportion
BCIO:050486	personal history of same intervention exposure	A personal history part that includes exposure to the same intervention as the current intervention.	personal history part	Mean; Minimum; Maximum; Median; percentage; proportion
BCIO:050488	personal history part of intervention exposure	A personal history part that includes exposure to one or more interventions.	personal history part	Mean; Minimum; Maximum; Median; percentage; proportion
MF:000032	bodily disposition	A bodily disposition is a disposition that inheres in some extended organism.	disposition	
MF:0000202	personality	A bodily disposition that is an aggregate of complex dispositions, endures over a period of years and is realised as emotion, belief, mood, motivational processes or behaviour.	bodily disposition	Mean; Minimum; Maximum; Median; percentage; proportion
BCIO:015160	personal vulnerability	A disposition to undergo undesirable change in response to exposure to another entity.	disposition	Mean; Minimum; Maximum; Median; percentage; proportion

ID	Label	Definition	Parent	Aggregated
BCIO:050489	personal vulnerability to harmful behaviour	A personal vulnerability towards performing a behaviour that causes net harm.	personal vulnerability	Mean; Minimum; Maximum; Median; percentage; proportion
BCIO:050890	protective factor for harmful behaviour	A disposition that decreases the likelihood of engaging with harmful behaviour.	disposition	Mean; Minimum; Maximum; Median; percentage; proportion

Discussion

This study developed the Intervention Population Ontology for describing the characteristics of people exposed to interventions. Although initially developed to specify the attributes of populations exposed to behaviour change interventions, the characteristics apply to populations exposed to other types of interventions and to human populations more broadly. The ontology consists of 186 entities relating to different human characteristics. To allow the ontology to reflect the populations of participants exposed to interventions, further classes relate to the ways that data about each of those human characteristics can be aggregated and reported. Inter-rater agreement was found to be 0.79 – 0.85 (good) as assessed with Krippendorff's alpha. This suggests that the ontology entities' labels and definitions could be consistently interpreted and applied to the literature by researchers.

The Intervention Population Ontology is part of the Behaviour Change Intervention Ontology (BCIO), currently comprising eleven ontologies: intervention delivery mode (Marques *et al.*, 2021), source (Norris *et al.*, 2021), schedule and dose (in preparation), style (Wright *et al.*, 2023), human behaviour (Schenk *et al.*, 2024a), mechanisms of action (Schenk *et al.*, 2024b), engagement (in preparation), fidelity (in preparation), and setting (Norris *et al.*, 2020). In the BCIO, population, together with setting and time, forms the context in which an intervention is applied. Population characteristics can moderate the relationships between intervention content and mechanisms of action, or between the intervention's mechanisms of action and behaviour. Population characteristics can also influence the reach of the intervention and participants' engagement with it. By using the Intervention Population Ontology to classify the nature of participants in different intervention evaluations, we have a more consistent foundation for answering the “big question” of behaviour change intervention research: “What works, compared with what, for what behaviours, how well, for how long, *with whom*, in what setting, and why?” (Michie *et al.*, 2017).

Strengths and limitations

The Intervention Population Ontology compares well against several ontology evaluation criteria (Vrandečić, 2009). The ontology's *completeness*, or how well it covers the domain of

interest, was enhanced by scoping terms from relevant classification systems and from relevant literature, together with annotations of further papers describing a variety of interventions. In the stakeholder review, experts were asked if they thought any terms should be added to the ontology. The ontology's *accuracy*, in terms of how closely it accorded with experts' knowledge was targeted by having the ontology reviewed by expert stakeholders. The *clarity* of the ontology, in terms of whether it communicated the intended meaning of the defined terms was explored through literature annotation, where differences between annotators were viewed as indicating problems with the communicated meaning and need for revisions. *Clarity* was additionally examined through inter-rater reliability testing, which tested whether the communicated meaning of terms was sufficiently clear that coders could agree on what constitutes an example of an entity.

A strength of the Intervention Population Ontology is the use of international expert stakeholder feedback in appraising and revising the ontology. However, only 30% of invited experts provided feedback on the ontology. Gaining feedback from a broader group of experts might have led to a larger range of suggested changes to the ontology. A further limitation of this work is that most intervention evaluation reports were from high income countries, potentially limiting the applicability of the ontology to low- and middle-income countries. Therefore, it is possible that we have missed some entities that are relevant to populations in low- and middle-income countries or populations targeted by other types of complex intervention (for example in education, social care, rehabilitation or psychotherapy). Future work could include collaborating with experts in such fields to add further entities relevant to these areas.

Future work on the Intervention Population Ontology could involve adding further, more detailed subclasses to some of the classes in the current version of the ontology. For example, *occupational role* does not have subclasses reflecting all possible occupations. To date, we have developed ontology classes for occupational roles that are typically those of the person who might deliver an intervention, for the Source Ontology (see Norris *et al.*, 2021). We have based these classes on the International Standard Classification of

Occupations (ISCO-08, [International Standard Classification of Occupations \(ISCO\) - ILOSTAT](#)), as it is designed to be a globally applicable categorisation system. However, ISCO-08 contains over 600 occupations, so developing ontology classes to reflect all of them was deemed beyond the capacity of the current project but could be the goal of future work. Describing people's behaviour, its patterning and history is complex ontologically, but is being tackled through work to develop the Human Behaviour Ontology (forthcoming) as part of the Human Behaviour-Change Project. Once this work is complete, it will be possible to add further detail relating to the *individual human behaviour* class in the Intervention Population Ontology. Similarly, representing the pattern and diverse nature of events that can comprise the details of an individual's *personal history* is complex and has been left for future work. Subclasses for *personal psychological attribute* were not developed as part of the Intervention Population Ontology but were the topic of the Mechanisms of Action Ontology ([Schenk et al., 2024b](#)). We therefore recommend that these psychological attributes are drawn from the Mechanism of Action Ontology ([Schenk et al., 2024b](#)) or, if not present in the Mechanism of Action Ontology, from the Mental Functioning and Emotion Ontologies ([Hastings et al., 2011](#); [Hastings et al., 2012](#)).

Future work

Ontologies should be maintained and updated according to new evidence about entities and relationships ([Arp et al., 2015](#); [He et al., 2018](#)). To support ontology *interoperability* and limit duplication of work, ontology developers must collaborate with others where possible ([He et al., 2018](#)). Just as for the other ontologies produced as part of the Human Behaviour-Change Project ([Michie et al., 2020](#)), the Intervention Population Ontology will be refined through application and as a result of feedback received from users via GitHub (<https://github.com/HumanBehaviourChangeProject/ontologies/issues>). We will release any updated versions of the Intervention Population Ontology via GitHub. All updates will also be available in the [BCIO Search](#) and [OLS](#) tools as well as via the Behavioural and Social Sciences Ontology Foundry repository ([Hastings et al., 2024](#)). We recommend prospective users of the Intervention Population Ontology check these resources to ensure they have the latest version of the ontology.

The Intervention Population Ontology has multiple possible uses. In addition to its role in the larger Behaviour Change Intervention Ontology, it provides a stand-alone system for describing and reporting population characteristics. This system can be applied to evidence synthesis, identifying research gaps and writing study protocols and papers. Because the Intervention Population Ontology is available in a computer-readable format, it can also be used to facilitate database integration and automated approaches to evidence synthesis.

Conclusion

The Intervention Population Ontology provides a classification that can be reliably used to specify the characteristics

of intervention participants. Its use by researchers and other stakeholders will contribute to improved consistency in reporting, simplifying evidence synthesis and enabling the identification of evidence gaps. Application of the ontology will increase understanding of how the characteristics of intervention participants can affect the impact of intervention content on intervention outcomes. The ontology can be further refined through user feedback, becoming an increasingly useful resource for identifying what interventions work for whom.

Ethics and consent

Ethical approval was granted by the Research Ethics Committee of University College London, London, England, UK in October 2016 (reference CEHP/2016/555). We obtained online, written informed consent from the participants in the expert stakeholder review.

Data availability statement

Underlying data

Open Science Framework: Human Behaviour-Change Project. <https://doi.org/10.17605/OSF.IO/QRGC4> ([West et al., 2020](#)).

The BCIO is available from: <https://github.com/HumanBehaviourChangeProject/ontologies>

Archived version of the Intervention Population Ontology as at time of publication: <https://github.com/HumanBehaviourChangeProject/ontologies/tree/master/Population>

Zenodo: HumanBehaviourChangeProject/ontologies: <https://doi.org/10.5281/zenodo.14882463> ([Schenk et al., 2025](#))

Data are available under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).

Extended data

Open Science Framework: Human Behaviour-Change Project. <https://doi.org/10.17605/OSF.IO/QRGC4> ([West et al., 2020](#)).

This project contains the following extended data:

- Papers used across steps of development of the Intervention Population Ontology (<https://osf.io/6xcwy>)
- Version 0.1 Preliminary prototype version of Intervention Population Ontology (<https://osf.io/jhymg>)
- Version 0.2 Version of the Intervention Population Ontology after initial annotations (<https://osf.io/m6udx>)
- Expert feedback survey; Full survey provided to behavioural science and public health experts in review of the Intervention Population Ontology (<https://osf.io/64mx9>)
- Expert feedback on Intervention Population Ontology: Feedback received from behavioural science and public health experts together with the ontology development team's responses (<https://osf.io/6quv2>)

- Version 0.3 Version of the Intervention Population Ontology after expert stakeholder feedback (<https://osf.io/8uw52>)
- Inter-rater reliability testing results – annotations by researchers from the ontology development team (<https://osf.io/ywpgt>)
- Inter-rater reliability testing results – two behaviour change experts unfamiliar with the ontology (<https://osf.io/9p5zc>)
- Annotation guidance manual for using the Intervention Population Ontology (<https://osf.io/u9wb4>)

Data are available under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).

Software availability

Source code used to calculate alpha for inter-rater reliability available from:

<https://github.com/HumanBehaviourChangeProject/Automation-InterRater-Reliability>

Archived code at time of publication: <https://doi.org/10.5281/zenodo.3833816> (Finnerty & Moore, 2020)

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