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RESEARCH ARTICLE

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Using qualitative comparative analysis as a mixed methods synthesis in systematic mixed studies reviews: Guidance and a worked example

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Abstract

Qualitative comparative analysis (QCA) is a hybrid method designed to bridge the gap between qualitative and quantitative research in a case-sensitive approach that considers each case holistically as a complex configuration of conditions and outcomes. QCA allows for multiple conjunctural causation, implying that it is often a combination of conditions that produces an outcome, that multiple pathways may lead to the same outcome, and that in different contexts, the same condition may have a different impact on the outcome. This approach to complexity allows QCA to provide a practical understanding for complex, real-world situations, and the context of implementing interventions. There are guides for conducting QCA in primary research and quantitative systematic reviews yet, to our knowledge, no guidance for conducting QCA in systematic mixed studies reviews (SMSRs). Thus, the specific objectives of this paper are to (1) describe a step-by-step approach for novice researchers for using QCA to integrate qualitative and quantitative evidence, including guidance on how to use software; (2) highlight specific challenges; (3) propose potential solutions from a worked example; and (4) provide recommendations for reporting.

KEYWORDS
guidance, qualitative comparative analysis, systematic mixed studies reviews, worked example

Highlights

What is already known

- Qualitative comparative analysis (QCA), an innovative research synthesis method that allows researchers to look beyond qualitative/quantitative divide, can be used to meaningfully analyze smaller data sets, and can identify critical features of highly complex interventions and multiple pathways to success.
- There are several guides on conducting QCA in primary research and in systematic reviews of RCTs.

What is new

- We believe QCA is an innovative and practical method of synthesizing heterogenous results from qualitative and quantitative studies, specifically for reviews interested in exploring the influence of contexts on outcomes.
- To our knowledge, this is the first step-by-step guidance to conducting QCA in systematic mixed studies reviews (SMSRs), using a worked example to identify and solve challenges in this application.

Potential impact for readers Research Synthesis Methods

- This guidance will be useful to researchers learning to conduct QCA in SMSRs in any field.

1 | INTRODUCTION

Mixed studies reviews or mixed methods reviews include qualitative, quantitative, and mixed methods studies. They constitute an increasingly popular type of systematic review in all health disciplines because they can address complex research questions such as why, how or in what context an intervention works.[1,2] Significant methodological advancements of systematic mixed studies reviews (SMSR) have been witnessed in the past decade with respect to the selection, for example, the selection assisted by machine learning,[3] the appraisal, for example, the validation of the mixed methods appraisal tool,[4] and the synthesis of included studies.[5] Specifically, types of designs and numerous methods have been developed to synthesize and integrate qualitative and quantitative evidence.[2,5–8] The two main types of synthesis designs are convergent and sequential synthesis designs. The convergent synthesis design is the most commonly used design where "the quantitative and qualitative evidence is collected and analyzed during the same phase of the research process in a parallel or a complementary manner."[5] The most common convergent synthesis design subtype is the data-based design, where all included studies are analyzed using the same synthesis method, either by converting quantitative data into qualitative data or vice versa. In this type of design, synthesis methods can then be quantitative (such as meta-summary) or qualitative (such as thematic synthesis). However, among the challenges that still exist in the data-based convergent synthesis design is the difficulty of quantifying qualitative evidence to combine it with quantitative evidence, and thus providing it with a level of "predictability."[9] One synthesis method that could address this issue is qualitative comparative analysis.

Qualitative comparative analysis (QCA), falls under the umbrella of configurational comparative methods (CCM),[10] that is, a set of methods that compare configurations across cases. Developed in 1987 by Charles Ragin for smaller- or intermediate-N designs (which are difficult to address via traditional statistics), for example, between 15 and 150 cases, CCM have since been widely applied in diverse social scientific fields including political science, sociology, management, organizational and health care research.[11] It is grounded in the mathematical branch of set-theory (i.e., a mathematical logic branch that studies sets of elements) and compares cases using Boolean algebra to produce solutions that demonstrate whether the presence or absence of one condition or a set of conditions is linked to the absence or presence of an outcome.[10] CCM is a hybrid method[12] designed to "bridge the qualitative (case-oriented) and quantitative (variable-oriented) research gap."[13] It can be used for qualitative or quantitative data, but is a case-sensitive approach that considers each "case" holistically as a complex "configuration" of conditions and outcomes.[14] Its goal of identifying combinations of conditions linked to an outcome is useful in theory or model development and testing.[13] The term QCA is more frequently used in the literature and will be used in this paper.

QCA allows for multiple conjunctural causation, implying that it is often a combination of conditions that produces an outcome, that multiple pathways may lead to the same outcome, and that in different contexts, the same condition may have a different impact on the outcome.[15,16] This approach to complexity allows QCA to provide a practical understanding for complex, real-world situations, and the context of implementing interventions. QCA can be useful for identifying intervention components or contextual characteristics that differ between successful and nonsuccessful interventions.

QCA has traditionally been used in empirical primary research, but within the last decade has also been applied as a synthesis method in systematic reviews.[17–19] In December 2021, we conducted a quick review of reviews indexed in Scopus in health-related fields using the search terms "QCA" OR "CCM" AND "systematic reviews" and uncovered 30 relevant articles describing applications of

QCA in literature reviews. Out of 24 articles describing systematic reviews, five described SMSRs, including two protocols, indicating that this method is still underutilized in SMSRs. A recent systematic review on the use of QCA in research on public health interventions reported that in 9 included systematic reviews, the authors used QCA to compare interventions "to identify successful (and non-successful) configurations of conditions across contexts."[19] As an indication of the rise of the use of QCA in health research: a methodological review included 31 studies from 1987 to August 2015, and another 30 studies from September 2015 to 2019.[20]

We believe QCA is an innovative and practical method of synthesizing heterogenous results from qualitative and quantitative studies, specifically for reviews interested in exploring the influence of contexts on outcomes.[18] This synthesis method provides a unique perspective that is different from effectiveness reviews that usually include only randomized controlled trials (RCT) for performing meta-analysis. There are several guides on conducting QCA in primary research, including mixed methods research, and in systematic reviews of RCTs.[10,13,18,21] To our knowledge, there is however no guidance yet for conducting QCA in SMSRs, whereas there are specific issues related to integrating qualitative and quantitative evidence. In this paper, we will provide step-by-step guidance on how to conduct a QCA analysis and discuss specific challenges for using QCA to integrate qualitative and quantitative evidence by proposing solutions from a worked example. The approach of QCA and the language it uses is distinct, and so the terms will be defined throughout this paper and included in a glossary in the Appendix S1.

2 | GUIDANCE AND WORKED EXAMPLE: OUTCOMES OF ONLINE CONSUMER HEALTH INFORMATION

2.1 | Background

As of 2018, more than 80% of households have access to high-speed internet in OECD countries.[22] In these countries, the proportion of adults seeking online health information (OHI) has more than doubled between 2008 and 2017.[23] The Internet is one of the most frequently accessed platforms for finding consumer health information, in addition to traditional health information sources such as health care professionals or members of one's social circle, and other offline sources such as books and television.[24,25] The use of trustworthy OHI can improve quality of life and is generally associated with increased empowerment of consumers and their families, and improved health outcomes.[26–28] Several studies focus on specific types of OHI (e.g., specific health information

TABLE 1 Summary of steps followed in the review (Pluye et al., 2019[31]).

Step	Summary of details
Eligibility criteria	The following inclusion criteria were used: studies pertaining to the use of OHI, or health outcomes of OHI, or both; empirical studies on primary care; and studies focusing on general information about health and medical topics.
Information sources	Nine bibliographic databases were searched. The gray literature was also searched using Google Scholar.
Search strategy	The bibliographic database search strategies were developed by four specialized librarians. The search strategy was developed for Medline (Ovid) and adapted for other bibliographic databases. The gray literature search was conducted by a specialized librarian with OHI expertise
Selection of relevant studies	Records were imported into EndNote X7, and duplicates removed. Records were then imported into specialized online software for coding (DistillerSR).
Quality appraisal of included studies	The methodological quality was assessed using the Mixed Methods Appraisal Tool (MMAT; Pluye et al., 2009). The MMAT is a validated tool and has been tested for reliability.[47,48] Two reviewers independently assessed the included studies using the 2011 version of the MMAT. Any discrepancy between reviewers' appraisal was usually resolved by discussion. No studies were excluded based on the appraisal.
Data extraction and framework synthesis of included studies	Results of included studies were extracted and analyzed using a "best fit" framework synthesis method, the objective of which is to revise an existing framework (Carroll et al., 2013).[32] We followed the following four phases. Phase 1. Coding data and creating new themes. Phase 2. Harmonizing themes pertaining to OHI outcomes: This led to further refining and clarifying results of the Phase 1 thematic analysis. Phase 3. Grouping themes pertaining to factors associated with OHI outcomes. Phase 4. Producing a revised framework.

websites as part of an intervention) or specific outcomes of OHI (e.g., change in the patient-clinician relationship) or specific populations (e.g., pregnant women). Few studies, however, explored the outcomes of general OHI from a consumer perspective in a primary care context. We, therefore, conducted an SMSR with the goal of developing a framework on these outcomes, and exploring the influencing factors linked to these outcomes.

2.2 | Methods

We conducted a SMSR following the steps outlined by the PRISMA statement for quantitative systematic literature reviews,[29] and the ENTREQ statement for enhancing transparency in reporting a qualitative review.[30] The full details of the review are published elsewhere[31] but a summary is presented in Table 1. We conducted a thematic synthesis of the included studies and described themes related to the use and outcomes of OHI, as well as the influencing factors related to use and outcomes. These themes were harmonized and used to revise an existing framework on OHI outcomes using the framework synthesis method detailed by Carroll et al., (2013).[32]

2.3 | Exploratory synthesis using QCA

The team decided to conduct a QCA synthesis to explore the relationship between key themes and the outcomes of OHI use. There are several QCA techniques (including fuzzy-set QCA and multi-value QCA). The original QCA technique is the crisp-set QCA (csQCA) that involve the dichotomization of conditions and outcomes as 1 and 0 s.[33] In this synthesis, QCA was used to identify the relationship between specific influencing factors and positive or negative outcomes of OHI in the included studies. In this analysis, we used csQCA for three main reasons:

1. Three of the four conditions we explored were dichotomous (present or not).
2. The fourth condition (health literacy) was reported heterogeneously across studies, so we could dichotomize it as 1 – reported or 0 – not reported.
3. csQCA is simpler to perform and interpret[33] which is ideal to highlight avenues for future research.

3 | STEPS FOR CONDUCTING QCA IN SMSRS

We followed the steps outlined by Rihoux and de Meur and summarized by Cragun et al. on conducting csQCA, which are listed in Figure 1 and described in detail below.[13,33] As the authors noted, these steps are not linear, and in fact follow a more iterative process, which we describe in more detail. We recommend using the FSQCA software, which was developed by Charles Ragin and is freely available for download online at http://www.fsqca.com along with a user manual.

3.1 | Step 1: Defining the outcome

One of the challenges of conducting csQCA in general is that all the variables, including the outcome, need to be dichotomized into 1 and 0. However, this is not truly a limitation in the application of QCA in SMSRs where variables are extracted in a homogenous manner, and it is possible to determine if a condition is present or absent. The first step, therefore, is to define the outcome and operationalize it as a binary code (0 or 1). The 1/0 can represent the presence/absence of the outcome, or the presence of a positive/negative outcome. If the research question includes multiple outcomes, a separate QCA should be conducted for each outcome.

In our example, the outcome of interest is consumer health outcomes of OHI-use, which could be positive (=1) or negative (=0). We used the outcomes and their definitions that were uncovered in the framework synthesis of the review. Positive outcomes include increased involvement in health care, health improvement, and better communication with health care providers. Main negative outcomes include deterioration of the patient-clinician relationship, increased worrying, and overuse or misuse of health services.

3.2 | Step 2: Selecting cases

In primary research, cases should be similar enough to be comparable yet diverse enough to produce empirical diversity.[10] Researchers take into account theoretical, practical and empirical considerations when selecting their cases.[21] In SMSRs, these considerations have likely influenced eligibility criteria and the cases are selected from the included studies. Depending on the study population, a study can include one or more cases, or no cases if the outcome is not reported.

Our review included 78 relevant studies (published between 1990 and 2018) that explored how consumers use OHI.[31] For the QCA analysis we only included the 32 studies that reported at least one outcome of OHI use. and we did not include studies that only explored OHI use without reporting an outcome. We defined each case as the relationship between an outcome and one or more

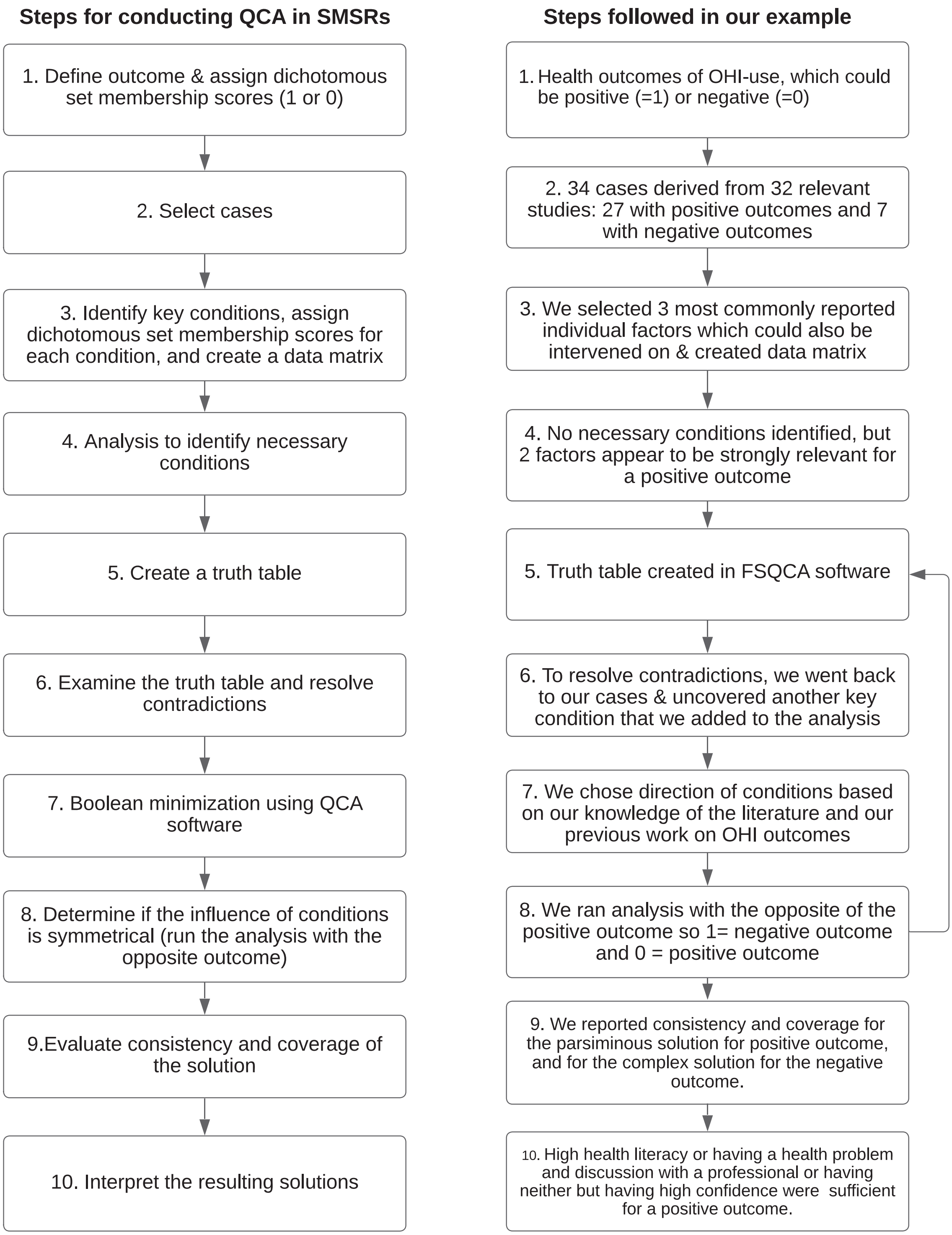

FIGURE 1 Summary steps used to perform csQCA.

conditions of interest in a study on OHI use. We produced 34 cases for QCA analysis: 27 with positive outcomes and seven with negative outcomes. There were 2 studies that produced 2 cases: Study 60 that included 2 combinations of conditions that produced a positive outcome, and Study 72 that included a case with a positive outcome and a case with a negative outcome.

3.3 | Step 3: Defining conditions and creating a data matrix

3.3.1 | Step 3a: Defining conditions

Conditions refer to the "variables" or "factors" related to the outcome that we are interested in exploring. In QCA, only a relatively small number of conditions should be used.[34] The number of logically possible configurations is 2^k where k is the number of included conditions, thus the higher the number of conditions, the higher the number of configurations. Having a larger number of configurations compared to the number of cases may lead to a problem of limited empirical diversity, where a high proportion of the logically possible configurations do not have cases representing them.[10,34] Identifying the conditions of interest is, therefore, an important step that should be conducted with the larger research team using theoretical, empirical and practical considerations.[21] The researchers should develop and pilot-test a codebook with all the conditions of interest using definitions and examples developed during the initial analysis of the included studies in the review (e.g., qualitative thematic or content analysis). The conditions should also be operationalized as a binary code (0 or 1).

One of the most time-consuming steps is deciding what the "zero" means for each condition. This challenge has been discussed in detail previously by de Block & Vis (2018) who examine the use of CCM in qualitative research where a concept may be missing from interview transcripts, and suggest including the conditions in the interview guide.[35] This issue of defining the zero is also a challenge in systematic reviews where analysis is conducted on secondary data: is the condition truly absent, or is it not mentioned/reported in the study? One solution to determine the likelihood of either possibility is to go back to the cases. We suggest triangulating the data using established literature on each condition to find other factors that could be used to infer the presence or absence of the given condition. An example from the worked example below is the condition health literacy: not all studies explicitly describe the health literacy level of their participants. However, research shows that higher education is usually associated with higher levels of health literacy.[36] We can therefore use higher level of education as a proxy for higher health literacy to code our condition. If there was no clear evidence of either health literacy levels or education levels, the condition was coded as "0."

We selected three of the most commonly reported individual factors which could also be intervened on: presence of a health problem (PROB), health information literacy (LIT), and confidence in OHI (CONF). We also included one of the most commonly reported OHI uses: discussion with a healthcare professional (DISC). This condition emerged as a part of the iterative QCA process (it was not specified a priori). We developed, pilot-tested and revised a codebook with all the conditions using definitions developed during the harmonization process in the framework synthesis of the review (Table 1). The codebook is presented in Appendix 1.

3.3.2 | Step 3b: Creating a data matrix

A data matrix is a table where each line represents a case, and the columns include the conditions and outcomes. It should be created by two coders who review all the studies included in the review, code the conditions and outcomes as 0 and 1 s, and extract data excerpts to justify each code in additional columns. Their coding is then compared, and any disagreement can be resolved by discussion or through a third independent coder. A recommendation to increase the study's replicability by increasing transparency is to publish the raw data matrix, as demonstrated in Appendix 2.[37] After removing all the columns with text, the data matrix is then imported into the FSQCA software for analysis as a .csv file.

3.4 | Step 4: Analysis to identify necessary conditions

A necessary condition is one that, based on the data provided, is present in all cases where the outcome is present; simply put, that the presence of this condition is necessary for the outcome to occur. On the other hand, a condition is considered sufficient if every time it is present the outcome is present; it guarantees the occurrence of an outcome. The goal of QCA is mainly to identify sufficient conditions, since necessary conditions are usually hard to prove due to the complex nature of causality in most cases. This is especially true in literature reviews where the data may not accurately reflect the complexity of the phenomenon being reported because it was not collected for the purpose of the review question. However, it is recommended to test for and identify potentially necessary conditions before proceeding with sufficiency analysis in order to prevent their potential elimination during minimization.[37] This is specifically true if there is a theoretical or empirical basis for hypothesizing that a specific condition may be necessary and/or sufficient, for example in our analysis, we hypothesized that higher health literacy may be necessary for a positive outcome. This step can be done in FSQCA by selecting "Analyze" and "Necessary Conditions," and then selecting each condition and its negation separately for analysis. This step is then repeated with the negation of the outcome as QCA does not assume symmetry of conditions. Results of our analysis are shown in Figure 2.

Consistency measures how often the condition is associated with the outcome. The closer the consistency is to 1, the more likely it is that the condition is almost always associated with the outcome and that it is necessary. Some experts recommend a consistency threshold of 0.9 to establish necessity.[38] Coverage in this context

Outcome variable: OUTCOME

	Consistency	Coverage
PROB	0.592593	761905
~PROB	0.407407	0.846154
LIT	0.777778	1.000000
~LIT	0.222222	0.461538
CONF	0.518519	0.875000
~CONF	0.481481	0.722222
DISC	0.814815	0.956522
~DISC	0.185185	0.454545

Outcome variable: ~ OUTCOME

	Consistency	Coverage
PROB	0.714286	0.238095
~PROB	0.285714	0.153846
LIT	0.000000	0.000000
~LIT	1.000000	0.538462
CONF	0.285714	0.125000
~CONF	0.714286	0.277778
DISC	0.142857	0.043478
~DISC	0.857143	0.545455

FIGURE 2 Analysis of necessity – output as shown in FSQCA. ~: not (i.e., where the outcome of interest is =0). CONF, confidence in OHI; DISC, discussion with a health professional; LIT, high health information literacy; PROB, presence of a health problem. [Colour figure can be viewed at wileyonlinelibrary.com]

indicates the empirical relevance of a necessary condition; values closer to one indicate that a necessary condition is highly empirically relevant. If the consistency is high but the coverage is low then the condition is trivial, for example, the condition is always present in every single case.[39]

While our analysis does not reveal any necessary conditions, it shows that high health literacy appears to be strongly relevant for a positive outcome: all cases with high health literacy report a positive outcome (consistency = 0.78, coverage = 1). Moreover, discussion with a health care professional also appears to be strongly relevant for a positive outcome: only one case with discussion is linked to a negative outcome (consistency = 0.81, coverage = 0.96). Therefore, while we do not consider these two conditions as being "necessary," we do expect that they will play some role in the sufficiency analysis that will follow.

3.5 | Step 5: Create a truth table

A truth table summarizes the distribution of configurations (data observations) where each row includes a combination of conditions and the outcome, as well as frequency of that configuration observed in the data. This frequency is not relevant to the QCA analysis and does not influence the solution produced, but it serves as a reminder that each row is a summary of all cases with the same configuration. After uploading the data matrix, select "Analyze" and "Truth Table algorithm." A window will open listing all the variables in the matrix. Select the outcome variable and the preliminary list of causal conditions and select "show solution cases in output." The truth table has a row for every possible combination of conditions (configurations), represented as 2^k (k is the number of conditions). The column "number" refers to how many cases contain the configuration of conditions displayed. The column labeled OUTCOME is blank and needs to be filled in by the researcher, by going back to the individual cases. This allows the researchers to reflect on the row configuration and identify rows with contradictions where some cases have an outcome of 1 and others have an outcome of 0. These contradictions are resolved in Step 6. The column "raw consistency" refers to the proportion of cases in each row that display the outcome; in this instant the outcome is equal to 1, that is, positive outcomes, indicating that the rows with raw consistency = 0 have an outcome of 0. In csQCA any value other than 1 or 0 indicates there are one or more contradictory cases. The PRI and SYM are values equal to the raw consistency in csQCA (in fuzzy set QCA they are alternative measures of consistency). The rows with blank raw consistency values represent configurations with no cases covering them and can be deleted by clicking on the "Edit" tab.

3.6 | Step 6: Resolve contradictions

The iterative nature of QCA becomes apparent in the following steps, as the researcher needs to re-review the primary data and further explore the theoretical underpinnings related to the conditions and outcomes being explored. The truth table allows the researcher to observe all the cases that share the same configuration (i.e., the same combination of condition values), and that ideally share the same outcome value; contradictions arise when they do not. Contradictions are not meant to be ignored or to provide justification to drop cases, but to allow researchers to go back to their cases to gain additional understanding.[10] Potential solutions to resolve these contradictions involve going back to steps 1 to 3: changing case selection, adding other conditions, or re-defining the outcome.[37] In the FSQCA software, the researcher can identify configurations with contradictions by clicking on the "cases" for each row. They then manually enter the outcome values for all configurations after resolving any contradictions.

The researcher then decides which rows are irrelevant based on frequency. In this application of QCA in SMSRs, it is recommended to include all rows with at least one case as the number of cases is less likely to be too high. In other QCA applications, typically with a larger *N*, a frequency threshold may be used. Input from the research team on what assumptions to make for the outcome for configurations without cases (remainders, in red below) can be added. These assumptions can be made using theoretical knowledge of the conditions from the literature. Otherwise, they can be deleted using the "Edit" and "Delete current row" option.

In our analysis, the initial truth table with only three conditions revealed several contradictory rows. To resolve these contradictions, we went back to our cases and uncovered another key condition that was missing from the initial model (discussion with a healthcare professional). Adding this condition produced the final truth table (above) with no contradictory rows.

3.7 | Step 7: Boolean minimization using QCA software

Boolean minimization refers to the use of QCA software that utilizes an algorithm that will reduce the configurations from the truth table to the most logically simple expression of a Boolean formula (one that uses "AND," "OR," or "NOT" to combine terms). Stated otherwise, if two configurations producing the same outcome differ in only one condition, that condition is then removed to produce the simplest formula. The software will only recognize the truth table configurations and thus, the number of cases in each configuration is not relevant to the minimization. The cases will be displayed with the corresponding final formula (called a "solution") in the output.[33]

Minimization produces the following three solutions:

1. The complex solution which only minimizes configurations with existing cases, and thus may produce a solution that is too complex to be useful.
2. The parsimonious and intermediate solutions require input from the researcher on what assumptions to make for the outcome for remainders (configurations without cases). The software uses these remainders to simplify the solution. If the researcher enables the software to exploit all logically useful remainders (useful from the perspective of obtaining shorter solutions), the software produces the shortest, parsimonious solution. If the researcher decides instead to restrict to exploiting only the more "plausible" remainders (typically: those in line with the theory and some directional expectations), the software produces an intermediate solution, usually shorter than the complex one but longer than the parsimonious one.

Once the truth table is fully constructed in FSQCA, select "standard analyses" which prompts the user to decide how each causal condition should theoretically contribute to the outcome. This will allow the algorithm to simplify the solution. If the condition could contribute to the outcome when it is present or absent, select "Present or Absent." If all conditions are coded "Present or Absent," then the intermediate solution will be identical to the complex solution.

In our analysis, we specified that high health literacy and discussion with a professional should contribute to a positive outcome. This is based on our knowledge of the literature and our previous work (including field knowledge) on OHI outcomes.[40] Three solutions were produced by the software as shown in Figure 3: complex, intermediate, and parsimonious. Each row represents a term of the solution where the conditions are combined with an * (AND), and the terms are combined with an OR to represent the full solution.

If the algorithm cannot fully reduce the truth table using only the previous input, the user is prompted to consider "prime implicants." Simply put, prime implicants are configurations that produce the same outcome but have only one condition different between them, in an attempt to minimize the solution. The user must use theoretical

```
--- COMPLEX SOLUTION ---
frequency cutoff: 1
consistency cutoff: 1
                              raw       unique
                           coverage    coverage    consistency
                          ----------  ----------  ----------
PROB*DISC                  0.592593    0.148148    1
LIT*DISC                   0.666667    0.148148    1
~PROB*LIT*~CONF            0.185185    0.111111    1
~PROB*~LIT*CONF*~DISC      0.0740741   0.0740741   1
solution coverage: 1
solution consistency: 1

--- INTERMEDIATE SOLUTION ---
frequency cutoff: 1
consistency cutoff: 1
Assumptions:
LIT (present)
DISC (present)
                          raw       unique
                       coverage    coverage    consistency
                      ----------  ----------  ----------
~PROB*LIT              0.333333    0.333333    1
PROB*DISC              0.592593    0.592593    1
~PROB*CONF*~DISC       0.0740741   0.0740741   1
solution coverage: 1
solution consistency: 1

--- PARSIMONIOUS SOLUTION ---
frequency cutoff: 1
consistency cutoff: 1
                          raw       unique
                       coverage    coverage    consistency
                      ----------  ----------  ----------
LIT                    0.777778    0.333333    1
PROB*DISC              0.592593    0.148148    1
~PROB*CONF*~DISC       0.0740741   0.0740741   1
solution coverage: 1
solution consistency: 1
```

FIGURE 3 Solutions produced for a positive outcome – output in FSQCA. ~: not (i.e., where the condition of interest is =0), * = and. CONF, confidence in OHI; DISC, discussion with a health professional; LIT, high health information literacy; PROB, presence of a health problem.

knowledge to select the prime implicants to be used; to determine which simplifying assumptions were tenable.[10] If you have not used any theoretical knowledge to choose prime implicants or to choose the direction of conditions, then you cannot trust that the minimization of the parsimonious solution is viable, so you should opt for the complex or intermediate solutions.

3.8 | Step 8: Determine if the influence of conditions is symmetrical

As previously mentioned, QCA is not based on correlations and thus does not assume symmetrical influence. In other words, the presence of a condition that leads to the presence of an outcome does not imply that the absence of that condition will lead to the absence of the outcome. It is therefore important to run the same analysis as in Step 6 but with the outcome "negated" (absent/negative outcome) to also identify sufficient conditions in connection with that negated outcome. When completing the truth table, the rows with the negated outcome are coded with "1" and those with the outcome originally as 1 are coded 0. When we ran standard analysis and Figure 5 appeared again, we specified that low health literacy should contribute to a negative outcome but did not chose a direction for the other three conditions as the literature is mixed on those factors.[31] Solutions produced are presented in Figure 4.

3.9 | Step 9: Evaluate coverage and consistency of the solutions

Coverage and consistency were defined earlier in Step 4 as related to individual conditions, here they will be evaluated for solutions (combinations of conditions). Coverage is a metric provided by the software that demonstrates to what extent the solution produced is the only path to the outcome. A solution coverage of 1 indicates that "all cases with the outcome of interest are represented by at least one of the combinations of conditions in the solution."[13] If there are multiple solution "terms" (i.e., combinations of conditions within a solution), raw and unique coverage can be used to determine the importance of each combination of conditions (the higher, the more important). Raw coverage calculates the proportion of cases (with a given outcome value) that are covered by a given combination of conditions (a given "term"), while unique coverage shows how much of that outcome (in terms of proportion of cases) is exclusively explained a given combination of conditions.

Consistency is another metric that measures when the combination of conditions in the solution is associated with the outcome. The closer the consistency is to 1, the more likely it is that the solution is associated with the outcome. For the positive outcome, we present the parsimonious solution in Table 2. For the negative outcome analysis, as we cannot rely on substantive knowledge to support the intermediate and parsimonious solutions, we chose to focus on the complex solutions as presented in Table 3. The first two terms in each table demonstrate relatively high raw coverage, that is, higher coverage in terms of proportion of cases with a given outcome.

3.10 | Step 10: Interpret the resulting solutions

A condition or combination of conditions may be consistently associated with an outcome, yet this does not mean that there is a causal relationship with the outcome. Researchers can, however, explore the solutions in conjunction with "theory, conceptual frameworks, and detailed knowledge about the cases to develop causal models that help unpack potential mechanisms leading to the outcome."[13] This entails returning to the cases[12,41] to explain the resulting solutions leading to the presence of the outcome and those leading to the absence of the outcome.

Table 2 represents the solution terms for a positive outcome. High health literacy alone is sufficient for a positive outcome of OHI use. Having a health problem and discussion with a professional or having neither but having high confidence were also sufficient for a positive outcome. This provides justification for focusing on interventions that overcome lower health, increase individual confidence in OHI and encourage discussion with professionals. For the negative outcome, the low number of cases ($n = 7$) with low empirical diversity (representing only four configurations) produced a solution that was too complex to be useful as shown in Table 3. However, the solution terms for these negated outcome cases could be explored further in future empirical research.

4 | DISCUSSION

QCA is an innovative research synthesis method that allows researchers to look beyond the qualitative and quantitative divides and is therefore ideal for integrating data in SMSRs. QCA has several advantages in SMSRs. First, it can be used to analyze data from a smaller number of studies (compared to traditional statistical methods) and for data from studies that use

```
--- COMPLEX SOLUTION ---
frequency cutoff: 1
consistency cutoff: 1
                              raw         unique
                            coverage     coverage     consistency
                           ----------   ----------   ----------
~LIT*~CONF*~DISC            0.714286     0.142857     1
PROB*~LIT*~DISC             0.714286     0.142857     1
~PROB*~LIT*CONF*DISC        0.142857     0.142857     1
solution coverage: 1
solution consistency: 1


--- INTERMEDIATE SOLUTION ---
frequency cutoff: 1
consistency cutoff: 1
Assumptions:
~LIT (absent)
                              raw         unique
                            coverage     coverage     consistency
                           ----------   ----------   ----------
~LIT*~CONF*~DISC            0.714286     0.142857     1
PROB*~LIT*~DISC             0.714286     0.142857     1
~PROB*~LIT*CONF*DISC        0.142857     0.142857     1
solution coverage: 1
solution consistency: 1


--- PARSIMONIOUS SOLUTION ---
frequency cutoff: 1
consistency cutoff: 1
                              raw         unique
                            coverage     coverage     consistency
                           ----------   ----------   ----------
PROB*~DISC                  0.714286     0.142857     1
~PROB*~LIT*DISC             0.142857     0.142857     1
~LIT*~CONF*~DISC            0.714286     0            1
~PROB*~LIT*~CONF            0.142857     0            1
solution coverage: 1
solution consistency: 1
```

FIGURE 4 Solutions produced for a negative outcome – output in FSQCA. ∼: not (i.e., where the condition of interest is =0), * = and. CONF, confidence in OHI; DISC, discussion with a health professional; LIT, high health information literacy; PROB, presence of a health problem.

1) The paper title and abstract should state "Qualitative Comparative Analysis";
2) The rationale for selection of cases from the included studies in the review is justified (e.g.: each study is a case, or each intervention is a case);
3) There are sufficient cases to provide credible coverage across the number of conditions included in the model, and the rationale for the number of conditions included is stated;
4) There is a clear justification for how choices of relevant conditions have been made;
5) There is sufficient transparency for replicability: raw data matrices should be available where possible; truth tables should be reported in publications, and reports of coverage and consistency provided.

*Adapted from Hanckel B, Petticrew M, Thomas J, Green J. The use of Qualitative Comparative Analysis (QCA) to address causality in complex systems: a systematic review of research on public health interventions. BMC Public Health. 2021;21(1):1-22.

FIGURE 5 Reporting criteria for QCA in SMSRs*.

TABLE 2 Solution for outcome = 1.

Solution terms	Outcome	Raw coverage	Unique coverage	Consistency
High health literacy	Positive	0.78	0.33	1
Health problem * Discussion with a professional	Positive	0.59	0.15	1
No health problem * Confidence in OHI * No discussion with a professional	Positive	0.07	0.07	1

Note: The shaded cells relate to the 2 variables where the coverage was 1 or very close to 1. * = and, ~ = not.

TABLE 3 Solution for outcome = 0.

Solution terms	Outcome	Raw coverage	Unique coverage	Consistency
Low health literacy * Low confidence in OHI * No discussion with a professional	Negative	0.71	0.14	1
Health problem * Low health literacy * No discussion with a professional	Negative	0.71	0.14	1
No health problem * Low health literacy * High confidence in OHI * Discussion with a healthcare professional	Negative	0.14	0.14	1

Note: The shaded cells relate to the 2 variables where the coverage was 1 or very close to 1. * = and, ~ = not.

diverse methods, which is common in SMSRs that include qualitative, quantitative, and mixed methods research studies. Second, it can enable the identification of critical features of highly complex interventions and multiple pathways to success. QCA can also be used to identify the features of intervention failures and highlight avenues for future research using conventional evaluation methods. It may enable exploration of data in new ways by uncovering evidence that may have otherwise remained hidden. QCA is thus increasing in popularity in health services research.

This exploitation of QCA for the purpose of SMSR is, in many ways, just an extension of the use of QCA in primary research, that is, when each case is simply a distinct empirical entity (an empirically distinct unit of analysis bounded by time and space). When exploiting QCA for both purposes, one may rely on some level of case-based or field knowledge (substantive, 'grounded' knowledge) and on some theoretical knowledge as well—which enables one to construct an appropriate model and some relevant hypotheses (or propositions) linking the respective conditions to the outcome. In both uses of QCA, one may also exploit raw data that takes many initial forms, numerical or not—and in the latter situation, some robust protocols are now available to transform the "qualitative" (read: initially non-numerical) data into meaningful numerical codes. And in both exploitations of QCA, one potentially gains a lot of useful knowledge via the core QCA operation of minimization that produces some level of parsimony, that is, some level of complexity reduction—while still giving justice to empirical complexity via QCA's "multiple conjunctural causation" approach. Nonetheless, the exploitation of QCA for a meta-analysis of SMSR does display some specificities: the cases in SMSRs are most often individual studies which are an aggregation of individual cases. Thus, the identification of cases within a SMSR that meet the eligibility criteria for the QCA analysis is an additional unique step.

As mentioned in the title, QCA consists of a genuine mixed methods synthesis in SMSRs. QCA integrates qualitative and quantitative evidence. What is more, this integration combines quantitative and qualitative methods. First, QCA is a method based on algebra, which is part of mathematics; for example, it uses binary digits (e.g., false = 0 and true = 1) and three Boolean operators (AND, OR, NOT). Second, for each case QCA is based on qualitative interpretations that transform case-based data (statistics and qualitative data in SMSR) into numbers (values assigned to conditions and outcomes), for example, to resolve contradictions (going back and forth from data to assigned values). This type of data transformation is called "quantitizing" in the literature on strategies for integrating data in mixed methods.[42] Stated otherwise, QCA can be seen as a "genuinely integrated" mixed method among case study methodologies,[43] and it can also be seen as an "integrative approach," as it is

TABLE 4 Reporting of QCA in SMSRs.

Reporting criteria	Khannassov et al 2014[49]	Hudon et al 2019[50]	Lee 2022[51]
1. The paper title and abstract should state the QCA design.	X	X	√
2. The rationale for selection of cases from the included studies in the review is justified.	X Conditions were derived from the qualitative analysis of all studies and QCA was conducted for cases comprising of randomized controlled trials only.	√ "One was excluded from the CCM analysis, owing to lack of information about the conditions (characteristics) of CM intervention in the documents. Thus, 20 studies (18 CM interventions) were included in the synthesis."	√ "Each intervention arm (i.e., case) identified from systematic review of randomized trials was coded for either the presence (=1) or absence (=0) of the characteristic."
3. There are sufficient cases to provide credible coverage across the number of conditions included in the model, and the rationale for the number of conditions included is stated.	X	√ "The number of conditions was limited so that the ratio between the number of possible logical combinations of conditions and the number of cases was kept sufficiently low."	√ "In total, 34 studies met the inclusion criteria and were included for the CsQCA. Two studies were included twice in the CsQCA because they each contributed to two intervention arms."
4. There is a clear justification for how choices of relevant conditions have been made.	√ "We identified the conditions with the most important influence on outcomes"	√ "We identified 4 initial conditions that were most commonly reported in the included studies (informed by the team's experience with CM and prior research on CM for frequent users)"	√ "Our systematic review of qualitative studies which identified characteristics (i.e., conceptual categories) from the literature. These characteristics formed the conditions that were examined in the CsQCA."
5. There is sufficient transparency for replicability: raw data matrices should be available where possible; truth tables should be reported in publications, and reports of coverage and consistency provided.	X	√	√

"about case-based evidence but also about mathematical formalization in the research process."[12]

As any method, QCA displays some limitations. Its state-of-the-art use requires some specific conceptual and technical competences in which only few researchers have been trained thus far. It also requires an iterative, team-based approach with frequent discussions to address the epistemological gulf between researchers with different paradigms. Some of the technical operations (e.g., threshold-setting in csQCA or "calibration" in fsQCA[35]) may also be particularly challenging. Another challenge is that it is sometimes difficult to identify the conditions of interest for conducting QCA. In this article, we have attempted to address these barriers by providing a step-by-step guidance for conducting QCA in SMSRs and provided a worked example to provide solutions to potential challenges. Another limitation is the qualitative interpretation that drives the transformation of case-based data (quantitative and qualitative) into values assigned to conditions and outcomes. The rigor of this interpretation can be strengthened in at least two manners. First, in line with qualitative (read: case-informed) research methods, the interpretation can be based on a consensus between two independent researchers (and a third-party decision when there is no consensus). Second, the centennial quantitative content analysis methods can be used, including the development of a validated and reliability-tested codebook, which is applied by independent researchers/coders; then, the inter-coder reliability is calculated using appropriate measure such as Cohen's alpha or intra-class correlations.[44,45]

We recommend the use of the FSQCA software in this synthesis for SMSR as we describe the process of a csQCA analysis, and the software is simple and easy to use for the novice researcher. However, we acknowledge that analysis using R software is currently more commonly used among QCA researchers as it may allow for more calibration and visualization of the data. A recent systematic review of randomized studies on school-based self-management interventions for asthma in children and adolescents describes the use of R to conduct QCA.[46] In that review, the authors conduct QCA as the primary synthesis method to address their first objective, followed by a meta-analysis to address their second objective. In another systematic review, the authors conduct the meta-analysis first and then conduct QCA on a subset of the included studies that were conceptually coherent.[18]

Finally, there are no consolidated reporting guidelines for QCA yet, but in a recent review Hanckel et al (2021) propose a list of criteria which may increase the uptake of QCA and increase the credibility of QCA findings.[19] The authors conducted a systematic review of research on public health interventions using QCA and discovered that few papers met all these criteria. We have adapted these criteria to the application of QCA in SMSRs in Figure 5. Since the unit of analysis in SMSRs is research articles, non-relevant reporting criteria about case selection were removed. In the review we conducted in December 2021 mentioned earlier, we uncovered five articles that described SMSRs, including two protocols. We reviewed three SMSRs (protocols were excluded) using the reporting criteria (Table 4) and also report that none met all the reporting criteria.

AUTHOR CONTRIBUTIONS

Reem El Sherif: Conceptualization; data curation; formal analysis; investigation; methodology; writing – original draft; writing – review and editing. **Pierre Pluye:** Conceptualization; data curation; formal analysis; funding acquisition; methodology; supervision; writing – original draft; writing – review and editing. **Quan Nha Hong:** Methodology; validation; writing – original draft; writing – review and editing. **Benoit Rihoux:** Conceptualization; formal analysis; methodology; supervision; writing – original draft.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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SUPPORTING INFORMATION

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