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Necessary Condition Analysis (NCA) Does Exactly What It Should Do When Applied Properly: A Reply to a Comment on NCA*

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Abstract

There are two problems with the comment of Thiem about necessary condition analysis (NCA): First, it is based on wrong assumptions about what NCA aims to do. Second, it applies NCA incorrectly. These are critical errors such that the comment's conclusions about NCA are flawed. Contrary to what the comment states, NCA *is* a valid method for identifying necessary conditions.

Keywords

necessary condition analysis (NCA), reply to a comment, goals of NCA, correct application of NCA, necessary conditions

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Necessary Condition Analysis (NCA) is a data analysis approach based on necessity logic (Dul 2016a, 2016b; Dul, Hak, Goertz, and Voss, 2010; Dul, Van der Laan, and Kuik in press; Goertz, Hak, and Dul 2013; Goertz and Starr 2003; Vis and Dul 2016). Necessity logic means that a certain level of *X* (the condition) is necessary for a certain level of *Y* (the outcome). For example, a certain level of intelligence is necessary for a certain level of creativity (Karwowski et al. 2016); a certain level of trust is necessary for a certain level of collaborative performance (Van der Valk et al. 2016). NCA is still in its infancy and many questions exist that need to be discussed and addressed. In general, we therefore welcome critiques and discussion of NCA, since this inspires the never-ending process of methodological reflection and advancement. However, the comment that was recently published in this journal—Thiem (2018)—does not serve these goals.

There are two problems with Thiem's (2018) comment: (1) it is based on wrong assumptions about what NCA aims to do and (2) it applies NCA incorrectly. These critical errors render the comment's conclusion about NCA that—"there is a mismatch between the method's purported search target and its actual output" (p. 1)—simply *wrong*.

In this reply, we start by briefly explaining what NCA is and what it sets out to do. Then we demonstrate that when NCA is applied properly, it produces exactly the results it should produce using Thiem's own data set.

What Is NCA and What Does It Set Out to Do?

The necessity logic on which NCA is based means that NCA is interested only in necessary conditions[1] that are *required* for the outcome rather than *produce* it,[2] which means that NCA is interested only in *part* of the data generation process (DGP). NCA sets out to identify *single* enablers that are necessary but not sufficient for a certain outcome. Because the necessary condition operates in isolation from the rest of the causal structure, NCA analyses one *X* at a time (bivariately). With several potential necessary conditions (several *X*s), the researcher performs multiple bivariate analyses. Necessity theories can be very simple with one or a few potential necessary conditions for the outcome. NCA is attractive for applications in research and practice because it can test such theories without having to give attention to the full causal structure. NCA can be applied with linear algebra (as in regression) or with Boolean algebra (as in qualitative comparative analysis [QCA]). Although most current applications of NCA use linear models ("level of *X* is necessary for level of *Y*"), the comment on NCA only focuses on applying NCA with a Boolean model ("presence of *X* is necessary for presence of *Y*").

NCA Is About Relationships of Necessity, Not About Sufficient Configurations

From the above, it should be clear that NCA's sole purpose is to identify relationships of necessity. It is therefore highly surprising that a large part of the comment on NCA focuses of relationships of *sufficiency*. This is irrelevant for a critique on NCA because NCA cannot—and does not aim to—identify such relationships. Thiem (2018:4) introduces the character John Doe "to discover the determinants of admission success at U . . . " but is not fully clear about what he means by this. If John Doe wants to assess whether the possible exogenous factors (or actually, which *levels* of these factors) are necessary for admission success at U, he has done well by choosing NCA, since that is precisely what NCA sets out to do. However, if John Doe wants to identify the configurations of conditions that are sufficient for admission success at U, the choice for NCA would be wrong, since NCA cannot—and does not aim to—reveal those. By highlighting the >11,000 possible paths to admission success at U (p. 4), it seems that the comment's author has the second objective in mind. NCA is not suited for this purpose and should thus not be used for it. What is more, the comment's author states that m_1 is the DGP "to be ideally recovered" (p. 5). Yes, if a researcher is interested in relationships of sufficiency, this is true. But when he or she is interested in relationships of necessity, and thus can apply NCA, the researcher needs only part of the DGP, namely, m_2.

NCA Is About Relationships of Necessity, Not About INUS Conditions

Different from what the comment claims, it is *not* the goal of NCA to identify INUS conditions. In Boolean logic, an INUS condition is an Insufficient but Necessary factor of an Unnecessary but Sufficient configuration. Hence, in such logic, it functions as a "local" necessary factor of a sufficient configuration enabling the configuration to produce the outcome. Different configurations usually have different INUS conditions, but a factor can also be an INUS condition in more than one sufficient configuration. If a factor is an INUS condition of *all* sufficient configurations, it is "globally" necessary for the outcome. Only when an INUS condition is part of all sufficient configurations, that INUS condition is also a necessary condition. Necessary conditions are separate from other factors (in a configuration). Mackie (1965:253), the founder of INUS logic, highlights the difference between an INUS condition and a necessary condition: "…some causal statements pick out something that is not only an INUS condition, but also a necessary condition."

In the comment, Thiem (2018:3) acknowledges that "none of NCA's main publications… mentions the concept of INUS conditionality." He based his conclusion that NCA is interested in INUS conditions on the NCA development team's website page that discusses differences between NCA and QCA (www.erim.nl/nca). However, Thiem (2018:3) incompletely quotes the website text as follows:

> the NCA development team (2017) has recently clarified that "NCA is a method for identifying necessary conditions (hence its name). …These necessary conditions must be part of all sufficient configurations (and therefore become also INUS conditions for the configurations: insufficient but necessary parts of all unnecessary sufficient configurations).

But the part "…" that is left out from the quote is *essential* and reads:

> NCA is not designed for identifying sufficient configurations, nor for identifying INUS conditions of sufficient configurations. NCA only identifies necessary conditions **for the outcome**. (emphasis in original)

So we reiterate that it makes no sense to evaluate NCA's performance in terms of its ability to identify INUS conditions of sufficient configurations, since that is not what NCA purports to do.

NCA Finds Necessary Conditions If It Is Applied Correctly

In this section, we show that NCA does exactly what it is supposed to do: when properly applied, it identifies necessary conditions. The comment's author did not arrive at this result—and on that basis drew wrong conclusions about NCA's ability to perform inference—because of several critical errors in his analysis. Before we turn to that analysis, we briefly describe the invented example to which the comment's author applied NCA (and QCA). The invented example—generated in the QCApro package in R developed by the comment's author—is about the relationship between a graduate record examination (GRE) test score (condition *X*) and a range of other exogenous factors, and admission success to a university program U (outcome *Y*). The data set is constructed such that a high GRE score is necessary for admission success and

Table 1. Contingency table for testing the necessity of a high GRE score for Admission.

Admission	0	0	264
No admission	768	768	432
	Low GRE score	Medium GRE score	High GRE score

Note: Cell entries are the number of cases.

contains information on 2,232 fictive applicants. The data file with the generated GRE and admission scores is available in our *R* replication script that can be found in the Online Supplemental Appendix 1.

NCA has two approaches for conducting an analysis of necessity. The recommended one depends on the type of variable. (1) The *contingency table approach* (see Dul 2016a, table 4, p. 39) is recommended when *X* and *Y* are dichotomous variables or discrete variables with a small number of variable levels (e.g., <5). (2) The *scatter plot approach* (see Dul 2016a, table 3, p. 38) is recommended when *X* and *Y* are continuous variables or discrete variables with a large number of levels (e.g., >5). The contingency table approach analyses allow a manual/visual data analysis, without the use of software. The scatter plot approach uses an XY scatter plot and NCA software. In the comment's GRE example, the *X* variable "GRE" has three discrete levels (low, medium, and high) and the *Y* variable "Admission" has two discrete levels (no admission and admission), so the contingency table approach is recommended. NCA recommends performing six steps to identify a necessary condition (Dul 2016a):

Step 1: Make the contingency table;
Step 2: Identify the empty space;
Step 3: Draw the ceiling line;
Step 4: Quantify the NCA parameters;
Step 5: Evaluate the effect size and the accuracy;
Step 6: Formulate the necessary condition.

Details of each step are presented in Online Supplemental Appendix 2. Table 1 shows the result of step 1: the contingency table. A quick visual inspection

```
> library ("NCA")
> nca(example, x = "GRE", y = "AD", ceilings = "ce_fdh")

------------------------------------------------------------------------
Effect size(s):
    ce_fdh
GRE 1.000
------------------------------------------------------------------------
```

Figure 1. Basic necessary condition analysis (NCA) of the GRE example with the NCA package in R showing that GRE is necessary for Admission.

of Table 1 already reveals that admission is only possible when the GRE score is high.

In step 2, the researcher observes two empty cells in the upper left corner. In step 3, he or she draws the ceiling line that separates the empty space from the full space (thick step line in Table 1). In step 4, he or she quantifies the two main NCA parameters—necessity effect size and accuracy. The *effect size* is the empty space in comparison to the total space. With a contingency table, the effect size can be quantified by counting cells and using the equation specified in Dul (2016a).[3] Here, the necessity effect size is 1 (which is maximum). Because the empty cells are really empty (without exceptions), the accuracy is 100 percent. In step 5, the researcher indicates how large are the effect size and accuracy, which here is "very large"—even maximum. When the effect is nonzero in step 6, the researcher formulates the necessary condition in degree: "A high GRE score is necessary for Admission."

Applying NCA's contingency table approach to the comment's example demonstrates that NCA can identify the necessary condition with just this approach. Using NCA's scatter plot approach and the NCA software leads to the same result. NCA's recommendations (Dul 2016a:37) state that in "situations with dichotomous variables or discrete variables with a small number of levels (e.g., <5 [as in Thiem's (2018) example]) . . . the CE-FDH ceiling line technique must be used." The scatter plot approach with the NCA software follows similar steps. The differences with the contingency table approach are that in the scatter plot approach, the data in step 1 are visualized using a scatter plot; in step 3, the ceiling line is the ceiling envelopment - free disposal hull (CE-FDH) line drawn with the software; and in step 4, the NCA parameters are calculated by the software. After installing the NCA software in *R*,[4] a basic NCA can be done with the "nca" command as shown in Figure 1 (see the *R* replication script in the Online Supplemental Appendix 1). With an effect size of 1, a high GRE score is necessary for Admission.

```
> library("NCA")
> modelexample<-nca_analysis(example, x = "GRE", y = "AD", ceilings =
"ce_fdh")
> nca_output(modelexample)

--------------------------------------------------------------------------
NCA Parameters : GRE - AD
--------------------------------------------------------------------------

Number of observations 2232
Scope                     2
Xmin                      0
Xmax                      2
Ymin                      0
Ymax                      1

                  ce_fdh
Ceiling zone       2.000
Effect size        1.000
# above            0
c-accuracy       100%
```

Figure 2. Advanced necessary condition analysis (NCA) of the GRE example with the NCA package in R showing that GRE is necessary for Admission (only a selection of output is shown).

A more advanced NCA can be done with the "nca_analysis" command as shown in Figure 2.

Also, the results in Figure 2 show that the effect size is 1 and that the accuracy is 100 percent. When applied correctly, the two variants of NCA—contingency table approach and the scatter-plot approach—thus both show that NCA can identify that a high GRE score is a necessary condition for Admission. So what went wrong in the comment when NCA was applied to this example? We discuss three flaws.

Flaw 1: Incorrectly Replacing High GRE by Low GRE

Flaw 1 in the comment is that High GRE is actually operationalized by a *low* GRE score. Specifically, the qualitative labels of GRE scores as "low," "medium," or "high" are quantified as, respectively, 2, 1, and 0, meaning that a *high* number (2) is allocated to a *low* GRE score and vice versa. This is unconventional (Dul 2016a; Goertz and Mahoney 2012; Vaisey 2009) and counterintuitive. Although the reason of this choice is unclear, it would not have been a problem when it is recognized in the NCA that the relationship that is tested is "high GRE score is necessary for Admission" (rather than a "high coding number is necessary for Admission"). However, if NCA is mechanically conducted with the coding numbers—as is the case in the comment—the result will be incorrect. What Table 1 in the comment reports (Thiem, 2018:5) is that a *high coding number for GRE* is not necessary for Admission: The correct interpretation of his analysis is that a *low GRE score* is not necessary for Admission. This is correct but ignores the relationship of interest, namely, that a high GRE score is necessary for Admission.[5]

Flaw 2: The Comment Uses Unsuitable Ceiling Techniques

NCA recommends that the CE-FDH ceiling technique must be used for the software analysis of dichotomous and discrete data with low number of levels, as in the GRE example. In the comment, Thiem (2018:7) seems to be aware of this, since he mentions that CE-FDH is the "preferred ceiling technique (Dul 2016b:27)." Therefore, it is confusing—at best—that he states earlier that "As NCA does not offer any formal criteria for preferring one particular ceiling technique over another other than the default settings of the eponymous software package, the results for all ceiling options are listed" (Thiem 2018:5–6). However, all techniques other than CE-FDH are *unsuitable* for the kind of data in this example because they produce straight ceiling lines and not the step function to fit the data correctly.

Flaw 3: The Comment Did Not Use the Contingency Table Approach

The recommended contingency table approach was not used. With a contingency table (Table 1), it would have been immediately clear—with or without reverse GRE-coding—that Admission can only be achieved with High GRE, since all 264 admitted cases in Table 1 had High GRE.

Conclusion

In this reply, we have shown that when applied properly and with the correct goals in mind, *NCA does exactly what it sets out to do*. The comment's conclusion that "I have shown that Qualitative Comparative Analysis (QCA) achieves what NCA has only been intended to achieve" (Thiem 2018: 9) is flawed in two crucial respects. First, it is based on a supposed intention that NCA wants to identify sufficient configurations and INUS conditions—it does not. NCA's goal is to identify relationships of necessity.[6] Second, it is based on an NCA that is flawed in several respects, most importantly by replacing *High* GRE (the necessity condition) by *low* GRE score.

We have shown that when applied properly NCA does exactly what it is supposed to do. This means that researchers—contrary to what the comment suggests (p. 9)—*can* still entrust NCA with the analysis of their empirical data in the search for necessary but insufficient causality, both in contexts of linear models (e.g., regression) and in contexts of Boolean models (e.g., QCA). An advantage of NCA that the comment ignores is NCA's ability to make statements *in degree* about necessity ("a specific level of *X* is necessary or not for a specific level of *Y*") instead of only statements about necessity *in kind* ("*X* is necessary or not for *Y*"), as, for example, discussed in this journal (Goertz et al. 2013; Vis and Dul 2016).

This response briefly highlights the target of NCA and its methods. The interested reader is encouraged to visit the NCA website (www.erim.nl/nca) for more details, an extensive bibliography of applications in published research, and the NCA software.

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Supplemental Material

Supplemental material for this article is available online.

Notes

1. Like other data analysis approaches, necessary condition analysis (NCA) alone cannot conclusively establish causality—nor does it claims to. Causal inference from observational data also needs for instance theory, causal mechanism analysis, or process tracing. For NCA's views on causal research strategies (experiments), the role of theory, the distinction between necessary causes ("enablers") and sufficient causes ("producers"), and the difference between necessary causes (causal logic based on theory) and necessary conditions (conditional logic), see the NCA website (www.erim.nl/nca).
2. NCA hereby differs from Qualitative Comparative Analysis (QCA), in which relationships of necessity are typically analyzed in addition to relationships of sufficiency (see, e.g., Schneider and Wagemann 2012). NCA also differs from regression-based data analysis approaches that focus on *additive logic* with several factors that can contribute to producing an outcome *on average*. The latter

contributing factors can be interpreted as being sufficient but not necessary for increasing the likelihood or level of the outcome.

3. The number of empty cells, divided by the total number of cells, minus the number of cells of a column, minus the number of cells of a row, plus 1.
4. The analysis was done with version 3.0 of the NCA package. The same results are obtained with NCA version 2.0 that was used by Thiem (2018). In version 2.0, accuracy is called "Accuracy," and in version 3.0, it is called "c-accuracy" to distinguish it from *p*-accuracy, a newly developed measure that refers to the accuracy of the *p* value that can be estimated in version 3.0 software with a statistical significance test for NCA (Dul, Van der Laan, and Kuik in press).
5. When a researcher for whatever reason wants to use a reversed coding (see data file exampleReverse in the R replication script in the Online Supplemental Appendix 1), the NCA software must be informed about this. This can be done with the "flip" command as follows: nca_analysis(example, x = "GRE", y = "AD", ceilings = "ce_fdh", flip.x = TRUE). Also, this analysis gives the correct results and is exactly the same as the above results: A high GRE score is necessary for admission.
6. We invite the reader to read the full text on the NCA website about the differences between NCA and QCA or to read two papers addressing this issue (Dul 2016b; Vis and Dul 2016).

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