Necessary Personality Conditions for Innovative Behavior at Work: NCA-based replicated studies[1]

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Résumé :

Cette étude s'intéresse aux traits de personnalité nécessaires à un comportement innovant au travail, en utilisant la méthodologie de l'analyse des conditions nécessaires (NCA) et des réplications exactes et proches. Quatre études ont été menées, avec un total de 1157 auto-évaluations fondées sur l'inventaire des Big Five et les échelles de comportement innovant au travail. Nos résultats mettent en évidence l'ouverture et l'extraversion comme des traits de personnalité unanimement nécessaires pour un comportement innovant. La consciencieusité est apparue comme une condition nécessaire dans trois études. Sur la base des réplications, des seuils de nécessité sont proposés pour ces traits, offrant une compréhension nuancée de leur rôle dans les comportements innovants. Cette étude fait progresser la théorie en mettant l'accent non plus sur la corrélation mais sur la nécessité. Elle a des implications pratiques pour les RH et les psychologues du travail dans l'évaluation des futurs innovateurs. Elle apporte également une contribution méthodologique en démontrant la reproductibilité des études NCA, ouvrant ainsi la voie à une exploration plus approfondie de la personnalité et d'autres dynamiques d'innovation.

Mots-clés : traits de personnalité, comportement innovant au travail, analyse des conditions nécessaires, réplications

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INTRODUCTION

In increasingly competitive and evolving environments, innovation remains a major aspect of the survival of an organization, and employees are the primary driving force. It is therefore essential to understand the factors that enable employees to contribute effectively to innovation. Among these, personality traits stand out as a key determinant of innovative behavior, influencing individuals' ability to generate, promote, and implement new ideas (Yao and Li, 2021). Literature in management and psychology offers a wealth of studies showing this influence (Dyer, Gregersen, and Christensen, 2009). Based primarily on the Big Five personality model, a widely accepted model in literature (Chen et al., 2021), numerous studies focusing on innovators, entrepreneurs, and intrapreneurs consistently identify that Openness to new experiences, extraversion, conscientiousness, agreeableness, and neuroticism can influence an individual's capacity to engage in innovative behavior. However, no study identifies which traits are necessary to adopt an innovative behavior at work and to what extent. Indeed, existing research mainly focuses on statistical comparisons, correlations, or linear regressions. Yet, they overlook the necessary conditions that must be met for these behaviors to emerge.

This research fills this gap by using the Necessary Conditions Analysis (NCA) method. Based on four studies that allow us to perform exact and close replications, it enables us to identify which personality traits are necessary for innovative behavior in various professional contexts. Thus, Openness to experience proves to be a universally necessary condition, with significant effect sizes in all studies, followed by *Extraversion*, which also shows a very significant level

of necessity, with medium to large effect sizes across various contexts. Next, *Conscientiousness* appears to be significantly necessary in two out of the four studies where the work environment is less structured. The comparative analyses of the bottleneck tables further validate these results by establishing generic thresholds for the personality traits necessary for significant innovative behavior at work, as well as for belonging to the most innovative segment of their reference population.

In doing so, this research offers theoretical and practical advancements regarding the necessary links between personality traits and innovative behavior, as well as a first approach to replication for NCA. We provide nuances to the works in psychology and management that establish these links by focusing on the necessary in-kind and in-degree for innovative behavior, primarily Openness and Extraversion. We propose a new approach for analyzing replication study results on necessary conditions. Finally, we offer practitioners, especially HR managers, a new perspective on selection and evaluation of future innovators, revising the thresholds they should refer to.

LITERATURE BACKGROUND AND HYPOTHESIS

1.1. THE PSYCHOLOGY OF PERSONALITY: DEFINITION AND ISSUES

In psychology, personality is a widely studied concept with origins dating back to the 1930s (Allport and Odbert, 1936 ; McAdams, 1997), with the foundational work of Allport (1937). His differential approach to psychology sought to identify the characteristics unique to each individual, distancing itself from a deterministic perspective (McAdams, 1997). Personality is defined as "*the characteristic patterns of individuals' thoughts, emotions, and behaviors, as well as the underlying psychological mechanisms*" (Funder, 2001, p. 198). Recognized as a multidimensional concept, it has given rise to numerous models aiming to describe its

components (Eysenck, 1978; Cattell and Mead, 2008). However, one model has achieved consensus: the Big Five model (Chen et al., 2021), which defines personality based on five major dimensions: Openness to new experience, Extraversion, Conscientiousness, Agreeableness, and Neuroticism (Abdullah et al., 2016; Conley, 1985; Goldberg, 1990a; McCrae & Costa, 1987; Wortman et al., 2012).

This model is based on five factors that make up and define personality (Goldberg, 1990). These factors, or personality traits, are bipolar, based on a *continuum* between two extremes, and the measurement scales seek to measure the dominant personality type for each individual (Hansenne, 2019), which are detailed below:

- **Openness (*vs*. Closure),** is marked by intellectual curiosity, imagination, acceptance of non-traditional ideas, and aesthetic sensitivity (Farrukh et al., 2016; Hansenne, 2019, p.43; Kwang & Rodrigues, 2002, p.257; Zell and Lesick, 2022).This trait involves the pursuit of novel and varied experiences in life.

- **Conscientiousness (*vs*. Spontaneity**) is characterized by diligence, reliability, and seriousness in task performance, with individuals being honest, meticulous, and thorough (Farrukh et al., 2016; Hansenne, 2019, p.43; Kwang & Rodrigues, 2002, p.257)

- **Extraversion (*vs*. Introversion**), characterized by assertiveness and dominance in social contexts, describes a person who is sociable, active, dominant, and warm (Hansenne, 2019, p.43; Kwang & Rodrigues, 2002, p. 257).

- **Agreeableness (*vs*. Distance)**, defined by trust, cooperation, and courtesy, it reflects individual differences in warmth and kindness in interpersonal relationships (Farrukh et

al., 2016, p. 600; Kwang & Rodrigues, 2002, p.257). This trait manifests in sympathy, altruism, and attentiveness to others (Hansenne, 2019, p. 43).

- **Neuroticism (*vs*. Emotional Stability)** is characterized by a tendency toward anxiety, depression, and stress vulnerability, whereas emotional stability reflects calmness and self-confidence (Farrukh et al., 2016; Hansenne, 2019, p.43; Kwang & Rodrigues, 2002, p.257).

These various personality traits translate into character traits based on one's score. For instance, someone with a high score in Extraversion would be described as sociable and enthusiastic. The table below converts the five major personality traits into character traits according to the level of the score (high vs low). This table offers a more qualitative description of the personality traits outlined by the Big Five model.

Table 1 - Characters traits according to (1) personality traits and (2) degree of score.

Personality traits	High score	Low score
Openness	Curious, creative, imaginative	Routine, conservative, predictable
Conscientiousness	Controlled, efficient, methodical, precise	Spontaneous, adaptable
Extraversion	Sociable, enthusiastic, adventurous	Shy, reserved, attentive
Agreeableness	Pleasant, cooperative, benevolent	Cold, distant, distrustful
Neuroticism	Stressed, nervous, impulsive	Calm, serene, stable

From this model, several psychometric tools have been developed, including the instrument by Plaisant et al. (2010), used in this research as it is specifically adapted to a French population.

1.2. Personality of Innovators and Innovative Behavior

The question of the intrinsic characteristics of innovators has sparked interest among management researchers for many years, particularly through comparisons between two types of innovators: intrapreneurs (*e.g.* Bager et al., 2010; Farrukh et al., 2016) and entrepreneurs (*e.g.* Kennard, 2021). The study of innovators' personality traits holds significant organizational and strategic stakes for organizations (Antoncic et al., 2015; Georget, 2020; Salmony & Kanbach, 2022), which must generate new ideas to address, in particular, socio-environmental challenges and Grand Challenges (Barlatier et al., 2024) and implement them.

These studies have shown that *Openness* is a key determinant of innovators' personalities (Antoncic et al., 2015; Bager et al., 2010; Farrukh et al., 2016; Nguyen & Nga, 2024; Zheng et al., 2022), as it encourages risk-taking (Bager et al., 2010) and a preference for novel tasks over familiar ones (Bager et al., 2010). To a lesser extent, *Extraversion* also positively correlates with innovators' personalities (Farrukh et al., 2016; Salmony & Kanbach, 2022; Zheng et al., 2022). This trait facilitates collaboration with others (Zheng et al., 2022) and enables the mobilization of extensive networks, which is essential for promoting and developing innovation (Nguyen & Nga, 2024). Conversely, the trait of *Conscientiousness* produces divergent results. Some studies report a positive correlation with innovators' personalities (Bager et al., 2010; Nguyen & Nga, 2024; Salmony & Kanbach, 2022), while others observe no significant relationship (Antoncic et al., 2015) or even identify a negative correlation (Farrukh et al., 2016). These contradictions may be explained by differences between innovator categories (Salmony & Kanbach, 2022). For instance, Bager et al. (2010) point out that intrapreneurs adopt a more

structured approach to launching innovation projects compared to entrepreneurs. Intrapreneurs are more likely to follow advice on creating a startup plan or organizing their process (Bager et al., 2010). Moreover, they dedicate more time to planning than their entrepreneurial counterparts (Bager et al., 2010). Finally, the traits of *Neuroticism* and *Agreeableness* generally do not appear to significantly correlate with innovators' personalities (Antoncic et al., 2015; Nguyen & Nga, 2024). However, some studies nuance these findings by revealing a negative correlation with agreeableness (Farrukh et al., 2016) or neuroticism (Salmony et al., 2022).

These studies help identify the personality dimensions associated with innovators (Antoncic et al., 2015; Farrukh et al., 2016; Nguyen & Nga, 2024) and distinguish different personality profiles depending on the category of innovators (Bager et al., 2010; Salmony & Kanbach, 2022). However, the results remain sometimes contradictory (Salmony & Kanbach, 2022), which can partly be attributed to a fragmented approach to studying innovators' personalities, focusing on specific subcategories (Ferreira et al., 2019; Salmony & Kanbach, 2022), or to the absence of causal links between personality and innovators (Salmony & Kanbach, 2022). However, these findings do not allow for the identification of the personality traits necessary for innovation (Salmony et al., 2022), nor do they determine their level of necessity.

Indeed, such studies select their samples based on the empirical status of individuals (innovators or not). Whether they adopt a comparative approach or not, these studies identify personality dimensions specific to innovators: individuals who are holding or hold an innovation project. However, joining an innovation program or being recognized as an innovator does not necessarily guarantee that the surveyed individual is truly innovative (Salmony & Kanbach, 2022). For instance, an intrapreneur who joins an intrapreneurial device may fail to complete their project or may see it terminated before even reaching the commercialization phase. Thus, none of the aforementioned studies statistically evaluate the innovative behavior of the

surveyed individuals. In other words, the selection of the "innovator" population relies on empirical criteria (Salmony & Kanbach, 2022), a methodology that is questionable given the diversity of realities encompassed by the term "innovator" (Salmony & Kanbach, 2022).

Therefore, before discussing innovators' personality traits, it seems essential to examine the notion of innovative behavior. It is defined as: *"a multiple-stage process in which an individual recognizes a problem for which she or he generates new (novel or adopted) ideas and solutions, works to promote and build support for them, and produces an applicable prototype or model for the use and benefit of the organization or parts within it"* (Carmeli et al., 2006, p. 78). There are two main types of scales for measuring innovative behavior at work: (1) unidimensional scales and (2) multidimensional scales (Al-Omari et al., 2019). Multidimensional scales assess the different phases of innovative behavior: the generation, experimentation, and implementation of ideas (Dorenbosch et al., 2005; Krause, 2004). Unidimensional scales, on the other hand, consider innovative behavior as a global construct (Basu & Green, 1997; Bunce & West, 1995; Janssen, 2000; Manzi-Puertas et al., 2024; Scott & Bruce, 1994; Spreitzer, 1995).

Only a few studies have examined the relationship between innovative behavior at work and personality traits (Abdullah et al., 2016), even though personality traits are, by definition (Roberts et Yoon, 2022) behaviors tendencies that are generally consistent across time and situations. As in research focusing on innovators' personalities, certain personality dimensions correlate positively with innovative behavior. Openness and Extraversion are positively correlated with innovative behavior (Chen et al., 2010; Olakitan, 2011). Chen et al.'s (2010) study also identifies Agreeableness as a dimension positively correlated with innovative behavior.

Nevertheless, studies examining the link between innovative behavior and personality traits report differing results. This discrepancy can be explained by the type of innovators observed: for example, Olakitan (2011) focuses on entrepreneurs, whereas Chen et al. (2010) examines innovative employees. Consequently, these studies do not identify the necessary conditions, in terms of personality, for behaving innovatively, regardless of the category of innovators concerned. Moreover, they fail to demonstrate whether an individual can be innovative without exhibiting these specific traits. In other words, the link between personality traits and innovative behavior is established but remains insufficiently rigorously explored (Abdullah et al., 2016).

1.3. Necessary Personality Conditions for Innovative Behavior

The preceding paragraphs highlight that studies exploring the relationship between Innovative Behavior and personality traits have identified personality dimensions specific to innovators. These research used qualitative or quantitative studies such as regression (*e.g.* Antoncic et al., 2015; Chen et al., 2010) or statistic distribution tests (*e.g.* Kwang & Rodrigues, 2002). While these methods are widely used and have proven to be useful, authors often prone managerial recommendations following a logic of necessity, *e.g.* having a high score on Openness to new experience is needed to be an innovator. However, the results do not demonstrate this, they simply show that one specific trait or model can predict a higher level of innovation. Even though these results are interesting, speaking of necessity is an abuse of language.

The use of the Necessary Condition Analysis (NCA) would allow to prove or disprove the necessity of specific traits. Indeed NCA is an approach and method that can be used to identify conditions that are necessary for a given outcome, and that differs from classical methods, such as linear regression, which allow for compensations between variables (Dul et al., 2023). NCA

offers new research perspectives in innovation management (Dul et al., 2023a; Linder et al., 2023; Lyu et al., 2022), particularly for studying the personality traits of innovators.

Thus, this research raises different questions:

What are the necessary conditions—in terms of personality traits—for innovative behavior? And to what extent?

Beyond the theoretical implications of this question—especially in addressing the limitations of existing literature—it also carries significant practical implications (Dul et al., 2023). Specifically, identifying the necessary conditions for innovative behavior could optimize and support human resource management processes related to innovation. For this purpose, based on this literature, we have formulated the following five hypotheses:

H1: Openness is a necessary condition for innovative behavior.

H2: Extraversion is a necessary condition for innovative behavior.

H3: Conscientiousness is a necessary condition for innovative behavior.

H4: Agreeableness is a necessary condition for innovative behavior.

H5: Emotional Stability (low Neuroticism) is a necessary condition for innovative behavior.

METHODS

1.4.POPULATION

We carried out four complementary studies, the populations and samples are described in the following table.

Table 1: Studies and sample characteristics

	Study 1	**Study 2**	**Study 3**	**Study 4**
Population	Apprentice - professional in purchasing	Apprentice - professional in purchasing	Army professional (206 innovator & control sample)	Navy professional (attending to innovation day)
N	366	340	354	97
Male	215	144	300	81
Age	24	24.1	41.5	40.4
Tenure	1.7	1.7	18.8	17.4

The first two studies were carried out on student apprentices in purchasing. The first one investigated the behavior of 366 students in the class of 2023, aged between 21 and 43 (m = 24 and sd = 2.21) and with an average seniority of 1.7 years (sd = 1.14), with a feminization rate of 41.26%. The second study focused on 340 students of the class of 2024, aged between 21 and 35 (m = 24.1, sd = 1.85) and with an average seniority of 1.7 years (sd = 0.81), with a feminization rate of 57.65 %. The third and fourth studies were conducted on military personals. Study 3 was caried out on 354 active military personnel in 2023, aged between 21 and 61 (m = 41.5, and sd = 9.59) and with an average seniority of 18.8 years (sd = 10.4), with a feminization rate of 15,25 %. The last study (4) investigated the behavior of 97 sailors taking part in a conference dedicated to innovation during 2024, aged between 19 and 62 (m = 40.4, sd = 11.2) and with an average seniority of 17.4 years (sd = 11.8), with a feminization rate of 16,5 %.

1.5.DATA COLLECTION PROCEDURE

All respondents completed an online questionnaire on Qualtrics that measured personality traits and innovative behavior at work. Personality traits were measured through the French validated version of the Big Five Inventory (Goldberg, 1990b; Plaisant et al., 2010). It consists of 45 items divided into five subscales (one for each personality trait). The innovative behavior at

work was measured thanks to 9 items covering activities related to creation and diffusion of innovation, based on the Janssen's model of Innovative Work Behavior (Janssen, 2000). Ratings were made on a 5-points Likert scales ranging from *Strongly disagree* to *Strongly agree.* Responses were anonymous, confidential and optional. This last procedure technique, combined with the separation of dependent and independent variables in the questionnaire, and the fact that the items were based on scales from separate sources, limited common method bias (Podsakoff et al., 2012).

We have adopted a replicability approach in order to check empirical findings by varying the sampling conditions between each study, based on the same data collection method (Uncles & Kwok, 2013). All four studies were conducted in the same country in order to maintain the cultural and national environment, which can have an influence on attitudes and apprehension towards innovative behavior and personality measurement (Stephan & Uhlaner, 2010), the Big Five model has been shown to be consistent across cultures (Allik and McCrae, 2002). The use of a single language also eliminates any translation bias induced by replication in different countries.

1.6. DATA CLEANING, SCALES VALIDATION AND ANALYSIS

We first conducted descriptive analyses of the data (minimum, maximum, mean, kurtosis, and skewness) for all the scales used in these studies. Overall, the results were in line with expectations, except for two items (A09 and O09), which showed unusually high means and standard deviations. These findings were confirmed by correlation matrices, which indicated unsatisfactory factor loadings (double loadings for these two items). We initially decided to retain these items in order to examine their consistency within their respective scales using Cronbach's alpha, KMO index (Tabachnick, Fidell, and Ullman 2007) and Bartlett's test of sphericity (Appendix A). The results indicated that removing these items significantly

improved the alpha of both scales, increasing from .73 to .79 for Openness and from .68 to .71 for Agreeableness.

Then, after carrying out a bivariate correlation analysis of each of our variables (Appendix B), we conducted necessary condition analysis, independently on each of the four study before comparing their results. Necessary conditions analysis consists in determining the extent to which a set of independent variables are necessary (but not sufficient) to obtain a given level of the dependent variable, assuming a causal relationship between them.

This is done first for each independent variable separately (in-kind necessity), by identifying, in the diagram representing the observations (e.g. Figure 1) according to the said variable and the independent variable, the absence of observations above a ceiling which marks the level of necessity. In order to determine such ceiling line, we used the Ceiling Regression - Free Disposal Hull (CE-FDH) technique, our variables being continuous with many levels (Dul, 2016; Dul et al., 2023a).

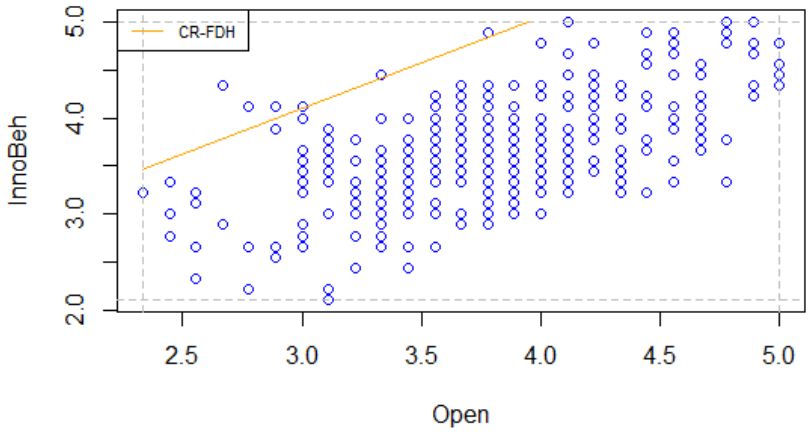

Figure 1: NCA scatterplot of Openness – Study 1

This visual analysis of the in-kind necessity of each independent variable is completed by examining the effect size of each condition*. It consists of the proportion of the scope, *i.e.* the total potential space with observations given the minimum and maximum values of the dependent and the independent variable, above the ceiling line divided by the total of the scope. When it is above 0.1, it identifies the extent to which the condition limits the result, and vice versa. We also consider the p-value of each variable that has to be over .05 – this p-value estimate from an "approximation permutation test" based on 10.000 random samples from the permutation distribution (Dul, 2019).

Once the in-kind necessity of each independent variable was defined, we determined the in-degree necessity of all the independent variables by creating a bottleneck table. This analysis identifies the minimum necessary level of the independent variables (personality traits) to reach each possible level of the dependent variable (innovative behavior at work) and its results are represented thanks to bottleneck tables..

Two types of tables were calculated: for one we expressed the innovative behavior at work as percentiles in order to comprehend the personality of the most innovative individuals; for the other we extracted only the targeted value (4, corresponding to a mean "I agree") and the mean value of the scale (3) of the innovation scale in order to compare results amongst different populations regarding the individuals who declare to behave innovatively. Each table can be interpreted as follows: to achieve this level of innovative behavior (left-hand column), each of the personality traits must be at least at the level shown - otherwise it is not achieved. And NN (not applicable) signifies the absence of necessary conditions.

In order to analyze the results of the replications, the comparison of in-kind necessity conditions on each of the 4 studies was carried out by comparing the absolute levels of significance and of effect size. To compare the results of in-degree necessity, we compared the results of bottleneck tables by calculating the ratio of the difference between the degree of necessity of each variable

Commenté [A1]: quelque soit le résultat ça te dit ça, non ? c'est pas plutôt que c'est un effet important si c'est supérieur à .1 ?

Commenté [A2R1]: En fait c'est supérieur à .3 qui est important. On considère que l'effet est trop léger sous .1

Commenté [A3]: en déciles plutôt ?

Commenté [A4R3]: Non ce sont des dizaines de percentiles - c'est ce que propose la méthodo - mais sur le fond on est ok 😊

Commenté [A5]: idéalement, ça serait bien de faire des hypothèses adaptées à ces différents cas de figure

Commenté [A6R5]: Oui mais en fait je ne vois pas sur quoi on pourrait se fonder pour faire des hypothèses aussi précises

Commenté [A7R5]: Petit ajout pour expliquer pourquoi 4

between two populations to the size of the scale, looking at the results of each study in relation to the other three.

Validation of the scales and of the relation between dependent and independent variables were realized using Jamovi (The jamovi project, 2023). Necessary condition analysis in kind and necessity in degree was realized mobilizing NCA methodology (Dul, 2015; Dul et al., 2023a) and using R with NCA package 4.0.2 (Dul & Buijs, 2024; R Core Team, 2022).

RESULTS

The results of the correlation analysis between the various elements measured (Appendix B) enabled us to confirm the statistical relationships between four personality traits and innovative behavior at work. In the 4 studies, Openness, Consciousness and Extraversion correlates with innovative behavior with a p-value < .001. In studies 1, 2 and 3, Neuroticism correlates with innovative behavior with a p-value < .001. Agreeableness and innovative behavior only correlate in study 3, with a p-value of 0.019. These results seem to support our hypotheses. And, given the negative estimate for Neuroticism for studies 1, 2 and 3, we reverted this variable for conducting the NCA analysis.

The results of the effect-size analysis are resumed in table 2.

Table 2: In-kind necessary condition analysis for the four studies.

	Study 1					**Study 2**				
Parameter	Openness	Conscientious-ness	Extraversion	Agreeableness	Emotional Stability	Parameter	Openness	Conscientious-ness	Extraversion	Agreeableness	Emotional Stability
Effect Size	**0.161**	**0.156**	**0.127**	0.072	0.037	Effect Size	**0.179**	**0.15**	**0.15**	0.068	0.057
c-Accuracy (%)	98.3	99.2	98.6	98.9	99.2	c-Accuracy (%)	98.2	98.8	97.4	98.5	99.4
p-Value	**0.0**	**0.001**	**0.004**	0.469	0.551	p-Value	**0.0**	**0.0**	**0.0**	0.27	0.188
p-Accuracy	0.0	0.0	0.001	0.01	0.010	p-Accuracy	0.0	0.0	0.0	0.009	0.008

	Study 3					**Study 4**				
Parameter	Openness	Conscientious-ness	Extraversion	Agreeableness	Emotional Stability	Parameter	Openness	Conscientious-ness	Extraversion	Agreeableness	Emotional Stability
Effect Size	**0.151**	0.062	**0.082**	0.044	0.031	Effect Size	**0.412**	**0.155**	**0.195**	0.1	**0.122**
c-Accuracy (%)	98.3	99.7	99.4	99.7	99.7	c-Accuracy (%)	94.8	97.9	96.9	96.8	95.8
p-Value	**0.0**	0.23	**0.015**	0.511	0.690	p-Value	**0.0**	**0.067**	**0.002**	0.365	0.089
p-Accuracy	0.0	0.008	0.002	0.01	0.009	p-Accuracy	0.0	0.005	0.0	0.009	0.006

For studies 1 and 2, Openness, Extraversion and Conscientiousness appear as necessary conditions, with high statistical significance ($p < .005$) and similar medium effect size ($d > .1$). Study 3 presents similar levels only for Openness ($p < .001$, $d > .15$). Extraversion also appears significant ($p < 0.05$) but the effect size is low ($d = 0.082$). In Study 4, Openness is also very significant ($p < .001$), and the effect size is large ($d = 0.412$). And there is similar level of significance and effect size than study 1 and 2 for Extroversion ($p < .005$, $d = .195$).

Openness and Extraversion are indeed necessary conditions for innovative behavior at work, confirming H1 and H2. Results for Conscientiousness are more variable, only partially confirming H3. H4 and H5 are not validated by our results.

The degree of necessity for all the conditions is given through the bottleneck tables (tables 3 and 4) which are represented for the three necessary traits in the 4 populations.

Table 3 enables us to identify the necessary conditions expected to be considered as highly innovative (80 and above). The first column shows the level of percentiles of each population for innovative behavior at work . Next columns have corresponding necessary values of the personality traits.

Table 3: Necessary condition bottleneck tables in percentile

Commenté [A8]: Proposition d'ajout - ou alors, je remets la stabilité pour les 4 populations - ce qu'il y a alors d'intéressant c que c'est nécessaire que pour la population 4 - mais à un niveau qui le même au 60ème percentile (1er niveau de nécessité) et au niveau 4 (soit 2,146) - sachant que dans l'étude 1 et 2 ils n'atteignent pas ce niveau, et que dans l'étude 3, cela correspond au dernier décile

Commenté [A9]: j'ajoute ça parce qu'il me semble qu'on n'a pas évoqué la barre des 80

Commenté [A10R9]: La barre des 80 on ne la regarde que pour la replication - là ce tableau nous donne tous les percentiles

Commenté [A11]: déciles ?

Commenté [A12R11]: Non 10ème, 20ème…. percentiles

Commenté [A13]: les deux étaient tableaux 4 dans le docs. je pense que les chiffres dans le texte sont bons mais à vérifier

Commenté [A14R13]: Non il y a bien 2 tableaux - c juste la forme du Y qui change

Commenté [A15]: Est-ce que je ne remettrai pas la stabilité émotionnelle ? Car c'est quand meme nécessaire pour la 4ème étude

Commenté [A16R15]: Et en même temps, c'est à 1,146 qui correspond aussi

Study 1

Innovative Behavior (percentile)	Openness	Conscientiousness	Extraversion
0	NN	NN	NN
10	NN	2.058	NN
20	NN	2.264	1.571
30	NN	2.333	1.664
40	2.426	2.401	1.757
50	2.543	2.470	1.850
60	2.661	2.539	1.943
70	2.778	2.608	2.036
80	3.013	2.745	2.222
90	3.248	2.883	2.408
100	3.953	3.295	2.966

Study 2

Innovative Behavior (percentile)	Openness	Conscientiousness	Extraversion
0	NN	NN	NN
10	2.568	2.007	NN
20	2.659	2.172	1.384
30	2.750	2.337	1.636
40	2.796	2.420	1.762
50	2.841	2.502	1.888
60	2.887	2.585	2.014
70	2.932	2.667	2.140
80	3.023	2.832	2.392
90	3.114	2.997	2.645
100	3.387	3.492	3.401

Study 3

Innovative Behavior (percentile)	Openness	Conscientiousness	Extraversion
0	NN	NN	NN
10	2.373	NN	NN
20	2.540	NN	NN
30	2.623	2.243	NN
40	2.790	2.370	NN
50	2.873	2.434	1.504
60	2.956	2.497	1.680
70	3.040	2.561	1.856
80	3.123	2.624	2.031
90	3.290	2.751	2.383
100	3.623	3.005	3.086

Study 4

Innovative Behavior (percentile)	Openness	Conscientiousness	Extraversion
0	NN	NN	NN
10	2.677	NN	NN
20	2.947	NN	NN
30	3.149	NN	NN
40	3.172	NN	NN
50	3.284	NN	1.872
60	3.396	NN	2.136
70	3.509	2.372	2.400
80	3.621	2.657	2.664
90	3.846	3.226	3.192
100	4.408	4.650	4.512

Table 3 shows that in Studies 1 and 2, which represent a similar population, the level of necessity for openness (3.01 vs. 3.02), conscientiousness (2.75 vs. 2.83), extraversion (2.22 vs. 2.39) and reverse neuroticism, i.e. emotional stability (1.58 vs. 1.74), are equivalent to reach the 80th percentile level. The range of results for Study 3 is relatively higher, but still less than 5 of the maximum scale value, for the first three personality traits (3.12, 2.62 and 2.03). On the other hand, the difference is over 5% for stability, compared with studies 1 (8.8%) and 2 (5.4%). In study 4, a population similar to that of study 3, with a strong attraction to innovation, conscientiousness shows a gap of less than 5% compared with studies 1 and 2, and less than 1% compared with study 3. On the other hand, openness (3.62), extraversion (2.66) and stability (2.53) are higher than in the other studies.

Commenté [A17]: Est-ce quo'n garde ça ou on met «but selected during an event dedicated to innovation»

Table 4 provides further information, taking as a threshold an innovative behavior at work level of 4, which corresponds to the respondent's agreement in adopting innovative behavior. The first column shows the values of the outcome – i.e. the level of declared innovative behavior.

Commenté [A18]: les deux étaient tableaux 4 dans le docs. je pense que les chiffres dans le texte sont bons mais à vérifier

Commenté [A19R18]: C'est bon

Table 4: necessary condition bottleneck tables for level 4 of dependent variable

Study 1

Innovative Behavior (actual)	Openness	Conscientiousness	Extraversion
3	NN	2.058	NN
4	2.896	2.676	2.129

Study 2

Innovative Behavior (actual)	Openness	Conscientiousness	Extraversion
3	2.568	2.007	NN
4	2.978	2.750	2.266

Study 3

Innovative Behavior (actual)	Openness	Conscientiousness	Extraversion
3	2.289	NN	NN
4	2.956	2.497	1.680

Study 4

Innovative Behavior (actual)	Openness	Conscientiousness	Extraversion
3	2.385	NN	NN
4	3.396	NN	2.136

We can see that in all 4 studies, the expected levels for the three personality traits (Openness, Conscientiousness and Emotional stability) are similar. The levels of necessary conditions are particularly close in studies 1 and 2, all with a difference of less than 5%. Study 3 shows similarities with Studies 1 and 2 on Openness (below 5%), Conscientiousness (3.6% and 5.1% respectively) and, to a lesser extent, Extraversion (9% and 11.7%). Study 4 showed superior results, with a difference of between 8% and 13% with Study 3 on Openness and Extraversion, and with Studies 1 and 2 on Openness and Emotional stability. On the other hand, the necessary level of Extraversion is similar to that of studies 1 and 2, with a difference of less than 5%.

DISCUSSION

The aim of this research was to look at the relationship between personality traits and the innovative behavior of individuals in the workplace from the perspective of necessity. If the literature in psychology and management demonstrates that this relationship exists and can be positive, it has neither adopted this perspective nor embraced a truly interdisciplinary approach to address this issue. The NCA method has enabled the adoption of a rigorous interdisciplinary

approach, drawing upon both innovation management literature and personality psychology to systematically assess this relationship.

Through a series of four studies based on the same methodology but with different samples, *i.e.*, exact and narrow replications (Uncles & Kwok, 2013), we show that that personality traits are indeed necessary conditions for innovative behavior. Across the four studies, Openness and Extraversion were unanimously found to be necessary. And conscientiousness in 3 of the 4 studies. Emotional stability, the opposite of Neuroticism, is only necessary in the last study, which is a sample of the population particularly interested in innovation. And Agreeableness never appeared to be necessary.

Our bottleneck analyses support these main findings. First, they provide a threshold for the necessary conditions we uncover that is common to the four studies to reach a level of innovative behavior that places the respondent among the 20% most innovative people in their population: Openness above 3, Conscientiousness above 2.6, and Extraversion above 2. Secondly, they suggest that within the same population, working on wide range of subjects without a direct *focus* on innovation and homogeneous in terms of their business culture, there could be a necessary level of Openness, Conscientiousness and Extraversion to ensure innovative behavior. This is the case between the populations in Studies 1 and 2, which are two populations of young professional buyers who are finishing their studies. And that these levels would vary slightly as soon as we changed the population, while remaining with a population of a different professional culture, also working on a wide range of subjects, as in Study 3, which represents a sample of armed forces personnel. On the other hand, as soon as we move to a population with a marked interest in innovation, even if it shares the same professional culture, the level of conditions required for the same level of innovative behavior increases.

These findings have implications for theories of personality at work and innovation, as well as methodological implications for the replication of NCA studies and practical implications. We

present and discuss these in turn, before highlighting the limitations of our work and suggesting avenues for future research.

1.7. PERSONALITY TRAITS AND INNOVATIVE BEHAVIOR

By using the perspective of the necessity to consider the link between personality traits and innovative behavior, we obtain results in line with numerous studies showing that corporate innovators are significantly more open, extraverted, and conscientious than managers (Bager et al., 2010). First, this confirms the importance of Openness and Extraversion for innovative behavior at work (Chen et al., 2010; Olikatan, 2011). These two personality traits are consistently necessary conditions for predicting innovative behavior, with a very large effect size. This means that, regardless of occupation, age, and other individual characteristics, these two personality traits are essential for demonstrating innovative behavior. The expected thresholds vary depending on the population, but a score greater than 3 in Openness and Extraversion seems necessary to predict belonging to the top 20% of the most innovative individuals in their population.

Then, results show that conscientiousness appears to be a necessary condition in studies 1 and 2, but not in studies 3 and 4. This result aligns with the literature, which struggles to reach a consensus on this dimension, alternatively advocating a positive correlation with innovators' personalities (Bager et al., 2010; Nguyen & Nga, 2024; Salmony & Kanbach, 2022), no significant relationship (Antoncic et al., 2015) or a negative correlation (Farrukh et al., 2016). It is interesting because the main difference between these groups is the work environment. Several hypotheses are possible. First, the professional context may compensate for this personality trait and provide the necessary rigor. The need to fill out documents, adhere to frameworks, and follow guidelines could change the importance of Conscientiousness. Thus, this trait might be carried out by the framework itself, and the individual, regardless of their

personality, would have no choice but to conform. Secondly, being a student *versus* being a professional might influence how one evaluates their conscientiousness. Indeed, the Big Five Inventory is a self-assessment, and individuals may have a different perspective on organization depending on their experience in the professional world. Finally, a third hypothesis is that working specifically in the military might lead an individual to rate their Conscientiousness lower for the same reason. Indeed, in a highly structured and bureaucratic environment (Heeren et al., 2024), generally filled with conscientious personalities, it may be easier to underappreciate this trait.

Our findings also provide a fresh perspective on the importance of these personality traits for identifying or encouraging innovative behavior at work, as well as for selecting innovators. Indeed, studies using both qualitative and quantitative approaches, based on statistical distribution tests or regression analysis approaches, when they identify the importance of the presence or influence of one or more of these traits in the population under consideration, imply that individuals with high levels of these traits should be sought (Chen et al., 2010; Farrukh et al., 2016; Mahmoud et al., 2020). Our results suggest that this is not necessary. In fact, the levels of necessity of the said personality traits are relatively average, between the two extremes of necessary personality trait, if we want to select the most innovative individuals in a population. These levels of necessity can even be considered low if we're looking for individuals who adopt innovative behaviors: the minimum level of necessity is thus on the side of Closeness, Introversion and Spontaneity. These results do not contradict the previous ones, but rather nuance them, indicating that individuals who do not display these traits at high levels may be serious potential candidates for innovation (Herbert et al., 2023).

These findings are consistent with rare qualitative studies of intrapreneurial profiles, which show that some intrapreneurs are more introverted and less spontaneous than the average (Georget, 2020; Herbert et al., 2023). They particularly support the results of Herbert and

colleagues (2023), who highlight that introverts possess advantageous qualities or characteristics for innovation, such as observation, introspection, a preference for complex tasks (Herbert et al., 2023), and a degree of autonomy driven by strong intrinsic motivation (Georget, 2020). This outcome underscores the need to move beyond negative *a priori* about certain personality traits, such as Introversion, which persist in Western cultures (McCord & Joseph, 2020). Overall, these various findings provide new insights into the relationship between personality and innovative behavior at work by proposing to move beyond the « binary » question of whether a personality trait is present or absent (Salmony & Kanbach, 2022). Instead, they emphasize examining the *continuum* or degree of presence or absence of such traits. In other words, this methodology transcends the limitations of simple correlation between personality traits and innovative behavior by addressing the question of the necessary conditions for adopting innovative behavior in the workplace.

1.8. METHODOLOGICAL CONTRIBUTION ON THE REPLICATION OF NCA

This research is also of methodological interest in the sense that it provided the opportunity to conduct several replication studies, analyzing the necessary conditions, proposing both exact replication and close replication (Uncles & Kwok, 2013), playing around with the target samples while maintaining the same data collection method, in the same national setting. Thanks to four studies conducted over 2 years, we were able to show that certain conditions were necessary for the different populations. Replication allowed us to confirm our overall findings from one study to the next - while adding a few nuances. In order to succeed in producing results with a broader scope than a single study, and to show how context could influence them (Uncles & Kwok, 2013), we had to propose not only to apply the same NCA method four times to each of our databases, but also to enrich the way we mobilized the possibilities it offered. A single method was used to compare the required in-kind conditions

for each of the 4 studies. Then, for the comparison of the results of the in-degree necessity, we created bottleneck tables with two modalities of reporting the results: in population percentile and in absolute target value. This approach provides two views of the degree of comparable need between populations and enriches the interpretation of the results. To this end, we have also proposed to evaluate the difference between two outcomes by calculating the ratio of the difference between the level of need of the two populations and the magnitude of the scale. This NCA replication method thus constitutes a first proposal for enriching future Necessary Condition Analysis studies, strengthening their robustness and their ability to propose empirical generalizations.

1.9. MANAGERIAL IMPLICATIONS

For HR and innovation managers, our results suggest the possibility of using a robust test – the Big Five Inventory – to detect personalities whose profile matches that of corporate innovators. This would give them a first indication of the potential of individuals, but also of the work still to be done for those whose profiles are too far removed from the personality traits of intrapreneurs. This kind of test requires the support of people trained in its interpretation, as well as an exchange with the individual. This exchange should enable to confirm and clarify the conclusions of the results, as well as the intrapreneurial intention. This mode of operation should not be forgotten, to limit the potential drift of a mechanical use of positioning test results. Indeed, our results show that it is necessary to start from a low level of Openness, Extraversion and Conscientiousness traits, as they can be precursors of a high level of innovative behavior, which will then need to be maximized by other levers.

Our results thus confirm what Dul and colleagues (2023) have said about the practical contribution of NCA in human resource management. And we extend it to the field of psychology. Typically, psychometric tools - especially personality assessment tools - are based

on dimensions that are measured along a continuum between two extremes. In other words, tests are concerned with the degree to which a personality trait is present in an individual. However, the literature shows strong links between personality traits (not degrees of personality traits) and behaviors. This causal approach implies that in order to motivate a behavior, it is necessary to have that personality trait, which encourages practitioners to look for that trait. However, this approach fails to measure the granularity of the different dimensions. The NCA approach allows for this.

Thus, for psychologists, these results allow us to consider the use of tests in a different way. Instead of looking for the "most" or "least" individuals, we're interested in a minimum threshold that allows us to have a more detailed exchange during interviews and potentially detect a broader and more diverse panel of individuals.

1.10. LIMITATION AND FURTHER RESEARCH

In addition to the classic limitations of this type of study on restricted samples, in the same country, this study presents the limitations of studies based on self-report measures. While our work has validated the replicability of the NCA through exact and narrow replications, it would also be interesting to establish it through differentiated replications, by varying more widely the conceptual, methodological and substantive domains of research (Uncles & Kwok, 2013), but also by seeking other populations in other countries and on other professions or professional environments. It would also be interesting to consolidate a method for evaluating and analyzing the significance coefficient of differences in NCA replication studies.

Furthermore, this research examines innovative behavior in the workplace in a global way, without taking into account its multidimensional approach (Dorenbosch et al., 2005; Krause, 2004). This limitation offers an interesting research perspective on the question of the potential existence of profiles of Necessary Personality Conditions for Innovative Behavior. To this end,

we encourage the production of studies that would focus on Necessary Personality Conditions profiles along the dimensions - generation, experimentation, and implementation of ideas (Dorenbosch et al., 2005; Krause, 2004)- that compose innovative behavior at work.

This research focuses on the individual level of necessary personality conditions for innovative behavior at work, implying that personality traits must be expressed and present in an individual. However, more and more research is focusing on teams of corporate innovators (Sakhdari, 2016). This opens up an interesting research perspective: to approach the necessary personality conditions for innovative behavior at work at a more collective level, that of the team of corporate innovators. This future research would then be an opportunity to look at other characteristics that have already been recognized as necessary for this or that dimension of innovative behavior, such as intelligence (Dechaume et al., 2024; Karwowski et al., 2016), project skills (Stek & Schiele, 2021) or work climate (Servajean-Hilst & Suurmond, 2023).

Finally, we would like to highlight a practical ethical limitation of our research, namely the potential deviation in the use of our findings. Indeed, this research shows that a panel of diverse and varied innovator profiles is possible from a minimum threshold in terms of personality traits. As such, it encourages opening up the recruitment process to other innovator profiles. However, the operationalization of the results must not have the opposite effect, i.e., to dedicate the recruitment process only to profiles that meet the necessary personality conditions, which would represent an ethical limit to the use of this research.

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