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Logical Reasoning in Management: From "Philosopher Kings" to Logical Managers?

Mohid Farooq Butt

WHU – Otto Beisheim School of Management

Abstract

To what extent does a manager's logical reasoning ability impact their managerial responsibility? This study delves into the significance of logical reasoning ability in the realm of management. To accomplish this objective, I developed a logical reasoning assessment whose internal consistency was confirmed. Subsequently, I conducted an online survey with a sample of 83 managers ($M_{age} = 39.6$; $SD_{age} = 11.77$). The econometric model ($R^2_{adj} = 0.431$) revealed a cubic relationship, indicating an influence that logical reasoning ability might have on management responsibility. Notably, managers who pursued formal science education exhibited the highest proficiency in logical reasoning. Conversely, neither age nor GPA exhibited any significant correlation with logical reasoning ability among managers. A comparative analysis of managers' logical reasoning performance against previous studies involving students yielded noteworthy findings, indicating that university students outperformed their managerial counterparts. Whilst acknowledging the study's limitations, these findings shed light on the relevance of logical reasoning ability in the management domain, offering valuable insights and a starting point for both researchers and practitioners.

Keywords: Logical reasoning; Managerial decision making; Formal logic; Management research.

1. Scope and Problem

Plato famously proposed the notion of the "philosopher king". "Making political decisions requires judgement and skill", thus the role of the leader should be performed by philosophers (Wolff, 2006, p. 67) Relating Plato's argumentation to business context – with logic being the fundamental philosophical method (Burgess, 2016) - it would be interesting to know if there is a relationship between logical reasoning ability and a manager's success.

Although there is a lot of literature on managerial decision making, investigations focusing on the special managerial decision-making domain of logical reasoning (Suedfeld, 1992) are rare. This paper wants to make first findings and build first intuitions concerning logical reasoning in management. Consequently, taking management responsibility as a proxy of success and seniority of a manager - because of its uncomplicated observability and intersubjective comparability - following research question is posed.

Research Question *How logically sound is managerial decision making and how does it influence management responsibility?*

2. Background and Related Work

Before exploring the proposed research question quantitatively, I intensively researched available literature. However, as already touched on in the introduction, there is very limited academic research on managers' logical reasoning ability and its relationships. Subsequently, the following literature review for the econometric model will - in some cases – refer to studies concerning intelligence (or: IQ). In those cases, intelligence will be taken as an indicator for logical reasoning ability and its relationships; as intelligence tests also test mental abilities and partly consist of logical reasoning assessments (Wechsler, 1958).

2.1. Quantitative Research and Hypotheses

Beginning with the research question; there has been no research on logical reasoning ability's influence on management responsibility or similar. However there have been

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several investigations on intelligence (IQ) and its causal relationship with management success. Firstly, Hunter and Hunter (1984) have shown that IQ has been a valid predictor of job performance in all academic investigations. Moreover, Schmidt and Hunter (1998) found out that general intelligence can not only predict job performance of low-qualified workers, but also job performance of highly qualified managers. And intelligence is a good predictor of performance because – according to Schmidt, Ones, and Hunter (1992) – more intelligent workers are able to acquire more job-relevant knowledge (at a faster speed) than less-intelligent workers. According to (Schmidt & Hunter, 1998, p. 270), the managerial career advancement resulting from managerial performance can be measured in "management rank" which can be interpreted as management responsibility. Therefore, my first hypothesis is that logical reasoning ability can be associated as a predictor of management responsibility.

> **Hypothesis 1** *Logical reasoning ability influences management responsibility.*

Apart from the relationship between logical reasoning ability and management responsibility, studies concerning related influential relationships have been found. For example, a 2021 study published in *Brain Imaging and Behavior*, connected participants to MRI (Magnetic Resonance Imaging) devices and requested them to solve logical reasoning tasks (which were very similar to the ones proposed in this paper). Not only it was found out that the score was related to their age. But also, the relationship could be traced back to age-related differences in the anterior cingulate cortex and inferior frontal gyrus (Ziaei, Bonyadi, & Reutens, 2020). As the managers brain structures should be equivalent to the test subjects in the mentioned study, we can expect strong correlation between a manager's logical reasoning ability and age. responsibility.

> **Hypothesis 2** *There is a correlation between a managers age and his/her logical reasoning ability.*

As a manager's logical reasoning ability could be highly related to the educational background, I additionally convey research on logical reasoning ability's educational dynamics. One recent study shows that altering logical reasoning ability is difficult, even if people are exposed to formal logic. Studying formal logic in college for one semester does not significantly increase logical reasoning ability for students who have had no/little contact to formal logic. However, if the participants were already experienced in formal logic, the study indicates a significant increase in logical reasoning ability through a one semester class on formal logic (Inglis, Attridge, & Aberdein, 2016). Therefore, I assume, if managers went through years of studying a formal science discipline (Mathematics, Analytic Philosophy, and similar) they should be performing better at deriving valid and sound inferences.

> **Hypothesis 3** *Managers who majored in formal science are the best in logical reasoning.*

Furthermore, Lehman and Nisbett (1990) found that (4-year) university-level education on natural science significantly increases the (conditional) logical reasoning ability. This effect is apparently mostly explained by the increased number amount of mathematics classes in natural science programs. Expanding the set of managers from Hypothesis 3, it is also assumed that managers who have majored in highly mathematical subjects (STEM: Science, Technology, Engineering, Mathematics) will perform better at logical reasoning than managers who do not have this analytical background.

> **Hypothesis 4** *Managers majored in STEM are better at logical reasoning than other managers.*

As several studies have shown a positive relation between GPA and IQ (Deary, Strand, Smith, & Fernandes, 2007; Sternberg, 1999), there may be a strong correlation between logical reasoning ability and GPA.

> **Hypothesis 5** *GPA score and logical reasoning ability are correlated.*

Finally, research regarding the seniority of educational degrees obtained or year of schooling is very clear. Firstly, there has been ongoing research claiming very high correlation between IQ and the years of education attained (Neisser et al., 1996). And secondly, one recent study even claimed having above-average IQ comes with a 10 times higher chance of receiving a Masters degree (Bergman, Corovic, Ferrer-Wreder, & Modig, 2014). Conclusively, the increased seniority of a degree that a manager obtained is assumed to come with an increased logical reasoning ability.

> **Hypothesis 6** *The more senior the degree the higher the logical reasoning ability.*

Due to the limited quantitative research on logical reasoning ability's or deductive reasoning ability's influence on management responsibility or management success, the literature review will in the following focus on theoretical research about logical reasoning in management and the assessment of logical reasoning ability.

2.2. Logical Reasoning in Management

Logical reasoning is essential for professional decision making in management (Holvikivi, 2007). According to Thompson Heames and Harvey (2006), a 21st Century Global Manager must be rigorously trained in logical reasoning. Most prominently, Braverman (1971) derived that real life managerial situations, independent of their complexity, can be unraveled and broken down to their core elements through a reduction process, where logical reasoning can be applied to find solutions. The sum of those partial solutions yields an overall solution. But what exactly is logical reasoning? Human reasoning has been described as a mental process that "yields conclusion from percepts, thoughts, or assertions" (Johnson-Laird, 1999, p. 110). Its subcategory

- logical reasoning - can be seen as a thought act yielding *truthful conclusions*, given premises (Halpern, 2013, p. 176). Logical reasoning relies on formal logic, like George (Boole, 1854, p. 1; Ch. 1) described in his groundbreaking work on mathematical logic.

> *The design of the following treatise is to investigate the fundamental laws of those operations of the mind by which reasoning is performed; to give expression to them in the symbolic language of a Calculus"*
>
> *∼ George Boole, An Investigation of the Laws of Thought (1854)*

The role of formal logic in logical reasoning will be explained in the following.

2.2.1. Formal Logic

Terms like "that sounds logical" or "I don't understand your logic" are frequently used in everyday conversations. Now, one might ask what logic actually entails. This subchapter will give a very basic conception of the formal logic abstractions to be dealt with when discussing logical reasoning (ability). When scientifically investigated and formalized, logic is called formal logic. It found its first formal scientific treatment by ancient philosopher Aristotle, differentiating deductive reasoning from "intuitive reasoning" and describing it with attention on form (Aristotle & Irwin, 2019; Kleene & Rasiowa, 1954).

Today, formal logic is a subdivision of philosophy (and other formal sciences like mathematics) and a modern-day definition would see formal logic as "*the science of deduction*" (Jeffrey & Burgess, 2006, p. 1), or more precisely "*the systematic evaluation of arguments for internal cogency*"; with internal cogency as "*deductive validity*" (Smith, 2003, p. 1). The next subchapter will answer what an argument – according to Kahane, Hausman, and Boardman (2021) – and deductive validity entails.

Argument

An argument in formal science is a set of statements, consisting of premises and a conclusion. An exemplary argument, informally stated:

> *"Since it's wrong to kill a human being, it follows that abortion is wrong, because abortion takes the life of a human being." (Kahane et al., 2021)*

It can be deconstructed to a set of statements;

> *1. It's wrong to kill a human being.*
>
> *2. Abortion takes the life of a human being.*
>
> *∴ 3. Abortion is wrong. (Kahane et al., 2021)*

where 1. and 2. are premises that lead to the conclusion 3 (symbolized by the "∴" symbol which stands for "therefore"). To get a better understanding of the context, following statements would not qualify for making an argument.

> *Open the door.* (command)
>
> *Who's the boss here?* (question)
>
> *Thank goodness!* (expression of emotion) *(Kahane et al., 2021)*

Some special statements that imply a conditional relationship between propositions and will be important later on, are called conditional statements (e.g. "If A then B."). In the case of "If A then B." A is called the antecedent and B the consequent.

Coming back to "deductive validity"; what makes an argument valid? An argument is valid when it fulfills one central condition. Its conclusion must be true in every case in which all its premises are true. So, the validity of an argument is independent of whether the premises are true or not. Furthermore, arguments can have another important property, "soundness". An argument is "sound" if it is valid, **and** its premises are true (Jeffrey & Burgess, 2006, p. 5). Therefore, soundness ensures the truth of the conclusion. For a true argument, validity can be seen as necessary and soundness as sufficient condition.

Deduction and Induction

Deduction has been mentioned frequently; but what exactly does deduction – or a deductive argument - describe? A deductive argument is a type of argument that can – given its premises are true – guarantee the conclusion to be true. Consequently, deductive arguments can be valid (and sound). A prominent example for a deductive argument is a syllogism which is a deductive argument consisting of two premises that lead to one conclusion (Kahane et al., 2021). Most deductive arguments in this paper will be in the form of syllogisms.

A key distinction between two types of logical arguments is made, with the first one being just discussed and the second one being "inductive" arguments. Inductive arguments **do not guarantee** truth of the conclusion assuming true premises; instead, they **just provide evidence** for the truth of the conclusion. In contrast to rule-based inference (deduction), induction is based on cumulating observations to create general rules. Following table explains both types of arguments in a comparison.

The deductive argument in this example clearly illustrates that if the premises 1 and 2 are true, the conclusion 3 must true. In contrast, the conclusion argued in the induction example is not necessarily true, given the truth of its premises. Assuming, 1. the brake is hit and 2. the car is slowing down, we cannot assert the conclusion to be a general rule. What if this (or any other) car has a defective break? Then this conclusion would not hold true. Even if – instead of one car - all cars manufactured to date would be considered for the premises, there would never be complete certainty that the rule holds for the next car to be tested. Inductive arguments can be strong or weak, depending on the quality evidence that comes with the premises. Only deductive arguments can

Table 1: Deductive and Inductive Argument examples

Deduction	Induction
1. When you hit the brake of a car, it will slow down. 2. This car's brake is hit. ∴ 3. This car is slowing down.	1. This car's brake is hit. 2. This car is slowing down. ∴ 3. When you hit the break of a car, it will slow down.

be sound (or valid). The point to be made was that due to the "problem of induction", in the rational science of formal logic, there is only place for deduction.

2.2.2. Rules of Inference & Formal Fallacies

Deduction assures truth in conclusions given true premises. But how exactly is this guaranteed? By Rules of Inference. They describe fundamental laws for valid and sound inference in formal logic. Conditional syllogisms are syllogisms whose premises contain conditional statements (such as "if... then..."). Being in the main focus of studies on logical reasoning (Johnson-Laird, 1999) and being important in later stages of this paper, two rules for conditional syllogism inference and their respective fallacies are explained. As the usual denotation in formal language (propositional and predicate logic language) is out of scope of this work, the following is described in informal fashion and illustrated by examples.

Table 2 displays the most frequently used inference rules, Modus Ponens and Modus Tollens and their formal fallacies (Inglis & Simpson, 2007). In this syntax, with p and q represent any proposition, so that proposition p is the antecedent and q the consequent of the argument. The "Affirmation of the consequent" fallacy misleads reasoners to think that Modus Ponens can be inversely applied, just as "Denial of the antecedent" misleads to think that Modus Tollens can be inversely applied. In both cases the conclusion is wrong. The right conclusion is that we cannot know. Applied to the examples, firstly we cannot know if the pandemic is over or not, as the economic uprise could be caused by something else than the end of the pandemic. Secondly, we cannot know if Elon Musk is in regret or not, as there could be other regret causing factors.

2.2.3. Deductive Reasoning Ability

Deductive Reasoning is the process of finding conclusion through mental inference rules and premises. The implicit proofs formed in the process, are analogous to explicit proofs of formal logic (Rips, 1983, p. 40). With deduction logical truth of conclusions can be objectively verified. And propositional inference can be derived by following propositional calculus (rules of inference); which is proven to be complete (Johnson-Laird, 1999). That is why – in empirical research – logical reasoning ability is almost without exception measured in the form of deductive reasoning ability (Johnson-Laird, 1999; Niu, Zhang, & Yang, 2007; Yang & Bringsjord, 2003).

2.3. Assessing logical reasoning ability

Logical Reasoning Ability is measured by assessing a person's ability to reason deductively. In the following, different ways of assessment established by previous research are discussed.

Particular/Universal & Affirmative/Negative Syllogisms for Children

Kathleen Galotti and her team investigated the development of deductive (and inductive) reasoning ability in children from grade 2, 4 and 6 (Galotti, Komatsu, & Voelz, 1997). 16 syllogisms with child-appropriate content were offered, differentiated in two dimensions, 1. "particular" or "universal" and 2. "affirmative" or "negative". Particular syllogisms yielded a conclusion that referred to a single case, in comparison to universal syllogisms where conclusions referred to all cases. As a second step syllogisms were divided into ones with negating and affirming premises. Exemplary questions are displayed in Table 3.

Conditional Syllogisms based on Rules of Inference

In his book *The Development of Cognitive Anthropology*, D'Andrade (1995) offers a section on "Logic and the psychology of reasoning". He not only describes numerous logical reasoning tasks, but develops his own test based on rules of inference & formal fallacies.

Tasks are based on conditional syllogisms and divided into four categories: Modus Ponens, Modus Tollens, Affirmation of the consequence, and Denial of the antecedent. In total, 25 different tasks of all categories (with arbitrary and realistic content) were introduced to participants (American undergraduate students). Four exemplary tasks are visualized in Table 4. D'Andrade followed a popular approach, creating a testing methodology similar to Rips (1983), St.B.T. Evans et al. (1995) (influencing Inglis and Simpson (2007)) and Dugan and Revlin (1990). More so, Holvikivi (2007) was influenced by D'Andrade's approach. Testing Finnish university students, she borrowed three questions (out of four) from D'Andrade.

Categorical Syllogisms and Logical Ordering

Bronkhorst, Roorda, Suhre, and Goedhart (2019) and his team conducted a logical reasoning study without conditional syllogisms. Instead, logical ordering and categorical syllogism tasks were used. Categorical syllogisms are syllogisms that contain categorical propositions (propositions of

Table 2: Modus Ponens, Modus Tollens, Affirmation of the consequence, and Denial of the antecedent examples

	Modus Ponens	Modus Tollens
Rule of Inference	1. If p then q 2. p ∴ 3. q	1. If p then q 2. Not q ∴ 3. not p
Example	1. If this paper is exceptional, the readers will be more than happy. 2. This paper is exceptional. ∴ 3. The readers will be more than happy.	1. If Guido Imbens wins his second Noble Prize, Stanford honours it with a statue. 2. Guido Imbens is not honoured with a statue. ∴ 3. Guido Imbens did not win his second Noble Prize.
Corresponding Fallacy	"Affirmation of the consequence" 1. If p then q 2. q ∴ 3. p (Right conclusion: ∴ 3. Maybe p, maybe not p.)	"Denial of the antecedent" 1. If p then q 2. not p ∴ 3. not q (Right conclusion: ∴ 3. Maybe q, maybe not q.)
Example	1. If the pandemic is over, economies face uprise. 2. Economies are facing uprise. ∴ 3. The pandemic is over.	1. If Elon Musk buys Twitter, he regrets it. 2. Elon Musk does not buy Twitter. ∴ 3. Elon Musk is not in regret.

Table 3: Questions from Galotti et al. (1997)

	Particular	Universal
Affirmative	1. All Poggops wear blue boots Tombor is a poggop. Does Tombor wear blue boots?	2. All daxlets are squishy. All squishy animals like to yell. Do all daxlets like to yell?
Negative	3. No risomes play checkers. Zapp is a risome. Does Zapp play checkers?	4. All berbers wiggle. No wiggly animals wear hats. Do all berbers wear hats?

the form "all" or "some"). These tasks were presented to pre-university students with and without content; and are summarized in Table 5. The logical ordering example finds its solution in a) and the categorical syllogism – being invalid - can be answered with "No".

The Selection Task

In 1968 Wason (1968) famously proposed the "selection task", a comprehensive task based on conditional inference rules. One popular version, illustrated by D'Andrade (1995) is described in Figure 1.

Between 80 and 90 percent of undergraduate students fail to find the correct solution: turning over 3 and E (D'Andrade, 1995; Wason, 1968; Wason & Johnson-Laird, 1972).

3. Methodology

As to my best knowledge, no research has been conducted on the relationship between logical reasoning ability and management responsibility and no data regarding logical reasoning ability of managers is publicly available, a survey was conducted. This survey was designed to not only collect observational data on logical reasoning ability, but also other variables that are essential to answer the hypotheses.

3.1. Data Collection

I collected the data through a web survey published via Google Forms. However, audience (the sample) that was obtained this way is heavily dependent on the researcher's own network (people with whom researcher is connected with on the platform). This is in no means random. Thus, I chose to abandon the first dataset; and after extensive academic review, the survey was redistributed via *Amazon Mechanical Turk*. *Amazon Mechanical Turk* is a crowdsourcing marketplace that offers businesses and individuals to outsource intellectual tasks, inter alia, survey participation[1]. Requesters" publish tasks (called "Human Intelligence Task" or "HIT") – for instance, a research survey - which is being filled out by "MTurkers". This way of observational data aggregation has

[1] https://www.mturk.com

Table 4: D'Andrade (1995) questions

	Modus Ponens	Modus Tollens	Affirmation of the consequent	Denial of the antecedent
Task	1) GIVEN: If James is a watchman then James likes Candy. SUPPOSE: We find out that James is a watchman. THEN: (a) It must be the case that James likes Candy. (b) Maybe James likes Candy, maybe he doesn't. (c) It must be the case that James doesn't like Candy.	2) GIVEN: If this rock is a garnet then it is a semiprecious stone. SUPPOSE: This rock is not a semiprecious stone. THEN: (a) It must be the case that this rock is a garnet. (b) Maybe this rock is a garnet or maybe this rock is not a garnet. (c) It must be the case that this rock is not a garnet.	3) GIVEN: If it is raining then the roof is wet. SUPPOSE: The roof is wet. THEN: (a) It must be the case that it is raining. (b) Maybe it is raining and maybe it is not. (c) It must be the case that it is not raining.	4) GIVEN: If Jim cut himself then Jim would be bleeding. SUPPOSE: We found out that Jim did not cut himself. THEN: (a) It must be the case that Jim is bleeding. (b) Maybe Jim is bleeding and maybe he is not. (c) It must be the case that Jim is not bleeding.
Solution	(a) It must be the case that James likes Candy.	(c) It must be the case that this rock is not a garnet.	(b) Maybe it is raining and maybe it is not.	(b) Maybe Jim is bleeding and maybe he is not.

Table 5: Categorical Syllogisms and Logical Ordering

	Logical Ordering	Categorical Syllogism
No Content	1) If $P > Q$, $R < Q$, and $R > S$ What does apply to P and S? a) $P > S$ b) $P < S$ c) Cannot be determined.	2) Premise 1: All A are B. Premise 2: Some B are C. Conclusion: Some A are C.
With Content	3) We know the following about the ages of Peter, Quint, Rosie, and Sally: - Peter is older than Quint - Rosie is younger than Quint - Rosie is older than Sally What can be said about Peter and Sally? a) Peter is older than Sally b) Peter is younger than Sally c) You cannot tell	4) Premise 1: All roses are flowers. Premise 2: Some flowers fade quickly. Conclusion: Some roses fade quickly. Indicate whether this conclusion necessarily follows from the given premises.

been applied and discussed frequently by fellow researchers. According to a review commissioned by the Journal of Management, Mechanical Turk offers 4 main advantages to researchers: "(a) large and diverse participant pool, (b) ease of access and speed of data collection, (c) reasonable cost, and (d) flexibility regarding research design choice" (Aguinis, Villamor, & Ramani, 2020). In the same breath it is prone to a diverse set of problems. In this study, appropriate mitigation techniques to these concerns, as proposed by Aguinis et al. (2021) and Hauser, Paolacci, and Chandler (2019), will be applied.

Firstly, participants' (referred to as "MTurkers") lack of attention can lead to measurement errors. Thus, an attention check was integrated to the survey and 15% additional partic-

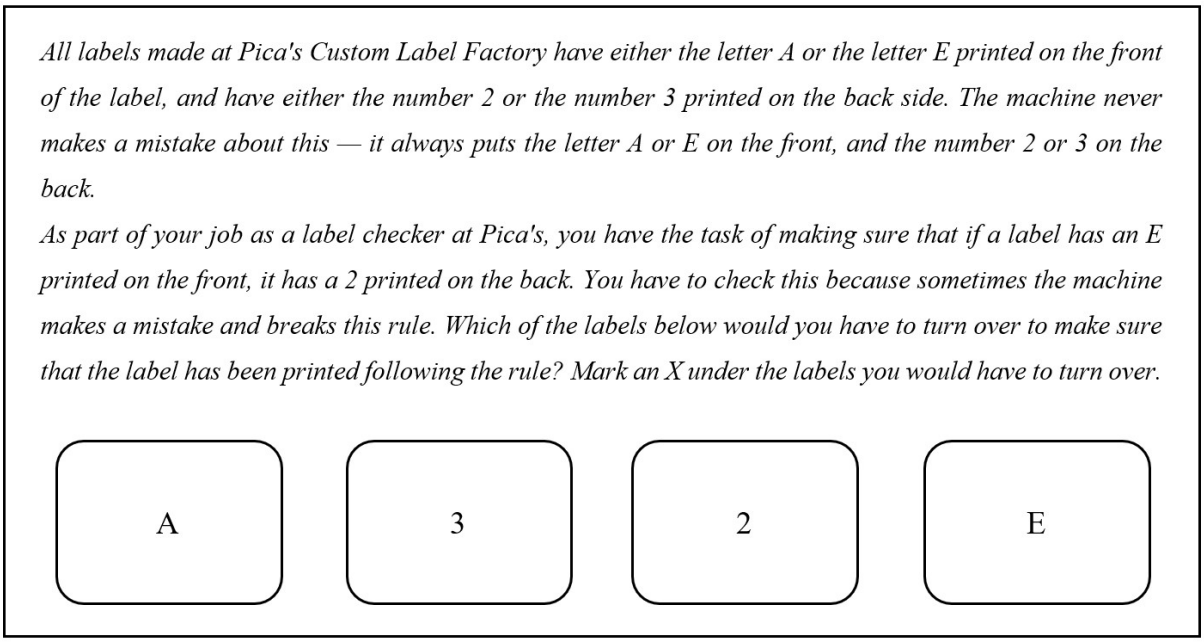

Figure 1: Selection Task

ipants were acquired to compensate for potentially excluded participants. To avoid bots, qualitative open-ended questions were included as qualitative attention checks. A last countermeasure to inattention was the conciseness of the survey; aiming at 5-7 minutes working time. Inconsistency in English language fluency within the participant base is another frequent concern. To ensure consistency, the participant pool was restricted to the United States.

And in order to avoid sample selection bias, the pool was not only limited to "Job Function – Management", but participants were also paid above minimum wage.

Moreover, nonnaiveté is a big issue when conducting surveys with "professional participants who have completed many social science studies and are likely to respond differently because of this experience.". As there is not a lot research on logical/deductive reasoning ability, in our case it can be assumed that exceedingly few participants have frequently done a similar test. Accordingly, this study is not susceptible to nonnaiveté. Lastly, only MTurkers with a HIT Approval Ratio of over 97% were displayed the survey. The HIT approval ratio describes how often a MTurker's tasks were approved (as done correctly) by the requesters, from all tasks the MTurker did. Peer, Vosgerau, and Acquisti (2013) suggests a threshold of a minimum of 95% HIT approval ratio to ensure data quality and attentiveness. All in all, most prominent problems with data collection via *Amazon Mechanical Turk* could be overcome. And due to random assignment of managers, the survey data can be seen as sampled randomly.

3.2. Econometric Model

To understand if and how logical reasoning ability influences management responsibility, an econometric regression model is established.

Dependent Variables

The dependent variable is the amount of management responsibility. It is conceptualized as the number of employees a manager has supervisory power over, if the manager does not actively interact with the employee. As seen in (1), if the manager directly manages i employees and those employees themselves manage j employees, the manager has Management Responsibility over all those employees, i over j; until the lowest level k-th employee is reached.

$$Management\_Responsibility = \sum_{i,\ j,\ldots,k=1}^{n} employee_{i,j,\ldots,k} \tag{1}$$

Independent Variables

The first independent variable to be considered is logical reasoning ability ("LRA"). Its exact measurement scheme will be discussed in 3.2.2. Furthermore, following independent variables were included in the model, to avoid omitted variable bias, or in broader terms, endogeneity.

Age: As a person's age is correlated with its logical reasoning ability (Ziaei et al., 2020) and Age can be assumed to be a predictor of management responsibility, Age is included as independent variable.

Gender: Ehindero (1982) found out that depending on the content, men or women can be better in logical reasoning tasks. Therefore, there might be some relationship between

gender and logical reasoning ability. As gender might also have an effect on management responsibility, it is included as a binary variable "Male".

Major & Highest Degree Obtained: As the educational background is a determinant of management responsibility and – as derived in Chapter 2 - might be correlated with logical reasoning skills, the primary major and highest degree obtained are entered as binary variables. Following Dummy Variables were included for major were included: "Natural" (Natural Science: Physics, Chemistry, Biology & related), "CS" (Computer Science), "Formal" (Formal Science: Mathematics, Analytic Philosophy & related), "SocialSci" (Social Science) "Engin" (Engineering) and "Humanities" (Liberal Arts & Humanities); with "Biz"(Business) as reference line. And for major these dummy variables were included: "Bachelor", "Master", "MBA", "PhD" and "No_Degree", with "HighSchool" (High School Diploma / Abitur) as reference line.

GPA: The effect educational background has on management responsibility (Schmidt & Hunter, 1998) – and the likely high correlation between logical reasoning skill and educational success (as derived for Hypothesis 5) - wouldn't be fully accounted for if the GPA wouldn't be taken into account. "GPA" is measured on the American scale, with 4.0 (A) as best and 1 (D-) as worst.

Parents Academic Background: If genetic influence wouldn't be considered in the model, the estimators would be biased because it is likely parental academic background a) has an explanatory effect on management responsibility and b) correlates with logical reasoning ability. Dummy variables for the parental degrees include: "P_Bachelor", "P_Master", "P_PhD" and "P_No_Degree"; with "P_HighSchool" (Parental High School Diploma / Abitur) as reference line.

Control Variables

Circumstances in which the manager was raised: The circumstances in which the manager was raised could be highly correlated with logical reasoning ability (due to differing quality of education) and predict management responsibility (e.g., due to parents' business relationships). In order to compensate for this effect, the control variable "Circumstances" is included to the regression. On a scale from 1 to 5 participants are requested to indicate the circumstances they were raised in (relative to their country of residence).

Career Motivation: As the general motivation to have a successful management career most likely predicts management responsibility and could be correlating with logical reasoning ability, it must be introduced to the model as independent variable. However, motivation is hard to observe objectively by an online survey. Therefore, the amount of average work hours per week "WorkHours" – likely highly correlated to general motivation - is included as control variable. The possible simultaneity (between average hours of work and management responsibility) is negligibly as it is not modeled as exogenous explanatory, instead as endogenous control variable.

All variables are summarized in Table 6 and the resulting regression model is displayed in equation (2).

$$\begin{aligned} &ManagementResponsibility_i \\ &= \beta_0 + \beta_1 \times LogicalReasoningAbility_i + \beta_2 \times Age_i \\ &+ \beta_3 \times Male_i + \beta_4 \times Natural_i + \beta_5 \times C5_i + \beta_6 \\ &\times Formal_i + \beta_7 \times SocialSci_i + \beta_8 \times Engin_i + \beta_9 \\ &\times Humanities_i + \beta_{10} \times Bachelor_i + \beta_{11} \times Master_i \\ &+ \beta_{12} \times MBA_i + \beta_{13} \times NoDegree_i + \beta_{14} \times GPA_i \\ &+ \beta_{15} \times P\ Bachelor_i + \beta_{16} \times P\ Master_i + \beta_{17} \\ &\times P\ Phd_i + \beta_{18} \times P\ No\ Degree_i + \beta_{19} \\ &\times\ Circumstances_i + \beta_{20} \times Work\ Hours_i + u_i \end{aligned} \quad (2)$$

3.2.1. Internal Validity

In the following, biggest threats to the statistical model's internal validity and (the resulting) legitimacy of the Least Squares Assumptions will be discussed. The consequent process is heavily influenced by the approach of Stock and Watson (2014, Chapter 9).

1. Omitted Variables

After extensive research and reflection, variables which were likely to be correlated with an independent variable and explaining the dependent variable were included to the model. In this way it can be assumed the estimators won't be biased because of omitted variables.

2. Misspecification of Functional Form

To avoid functional form misspecification, the functional form will be estimated analyzing the scatterplots of the dependent variable and independent variables, and by introducing other types of functions if needed.

3. Measurement Error in the Regressors

Errors in independent variables – i.e., caused by participants' misunderstanding about the format of answers - are mitigated by pre-formatting answers. For example, Age is limited to integers in the range 18 – 99.

4. Sample Selection

The sample drawn for this investigation consists of "Managers" from "United States of America". Importantly the participants are not selected by the examiner, as the survey is displayed to random managers on the platform. This is only true insofar Amazon Mechanical Turk represents the (Managers from United States) population well. Going further, another limitation to sampling might be that the survey platform was not chosen randomly.

5. Simultaneous Causality

Simultaneous Causality refers to the issue which arises when independent variables not only cause the dependent variable, but also vice versa. Following relationships are prone to simultaneity.

Logical Reasoning Ability & Management Responsibility: It can be argued that management responsibility is not only caused by logical reasoning ability but also causes the independent variable. For instance, it could be presumed that increasing management responsibility leads better problem solving and logical reasoning skills. However, there is evidence indicating that logical reasoning ability is not very

Table 6: Econometric Model Variables

Dependent Variable	Numerical Independent Variables	Binary Variables	Control Variables
Management_ Responsibility	*LRA*	Gender: Male	*Circumstances*
	Age	Major: *Natural, CS, Formal, SocialSci, Engin, Humanities*	*WorkHours*
		Degree: *Bachelor, Master, MBA, PhD, No_Degree*	
		Parental Degree: *P_Bachelor, P_Master, P_PhD, P_No_Degree*	

prone to environmental factors. D'Andrade summarizes that a majority of cognitive scientist are convinced of a "inbuilt capacity" to "logical reasoning" (D'Andrade, 1995). As logical reasoning ability seems to be an innate ability that is unlikely to be altered through external factors, ergo I assume this ability is very unlikely to be caused by management responsibility.

Educational Background & Management Responsibility: The key assumption made here is that primary education is finished before management career. Some managers attain executive education. This education after becoming manager could be caused by management responsibility, as managerial incentive to gain an executive degree may be increase management responsibility ex post. However, it is assumed that executive degrees are very uncommon, thus negligible. This assumption assures that educational background is not simultaneously caused by management responsibility. This assumption is very much confirmed by the study as we will see in the results.Parental Educational Background & Management Responsibility: Another key assumption is made. Parents ended their primary education before start of manager's career. Similar to the potential issue measured above a managers career success (and corresponding management responsibility) could influence the parents decision to choose a degree. Nevertheless, it is assumed that parents studying after their children started their managerial career is very rare, thus negligible.

OLS Validity

Assumption 1: *The error term (given the independent variables) has conditional mean of zero*: Simultaneous causality and omitted variables are avoided - as all endogenous variables are eliminated. The first OLS Condition is satisfied.

Assumption 2 *The Random Variables are independently and identically distributed:* Survey participants are independent of the examiner. Random persons from the "American Manager" population are observed. Insofar *Amazon Mechanical Turk*'s sample is representative of the population, our observational data can be construed randomly sampled. Ergo, the second OLS Condition is satisfied.

Assumption 3 *Large outliers are rare*: As all numerical independent variables are capped by a maximum value; LRA, Age, GPA and Cicumstances_Raised all have finite kurtosis. In contrast, the numerical dependent variable Management_Responsibility does not necessarily have a finite kurtosis. Large outliers will be avoided by analyzing the visualized data (boxplot). The third OLS Condition is satisfied.

3.2.2. Logical Reasoning Ability Test

For the Logical Reasoning Ability Assessment, the previously discussed research (2.3) is considered. As a matter of fact, the 7-item test exclusively contains questions that were developed as part of peer-reviewed research. Four questions consider conditional syllogisms associated with "Modus Ponens", "Modus Tollens", "affirming the consequent", "denying the antecedent", as most studies on deductive reasoning feature conditional syllogisms of these four types (Johnson-Laird, 1999). The questions are identical to the ones presented in Table 4.

In order to diversify the set of deductive inference tasks, the logical ordering and categorical syllogism tasks (with content) from Bronkhorst et al. (2019) are included.

Question 7 is an attention check. All participants failing to solve it correctly will be excluded from the analysis. Finally, participants must solve the selection task, as illustrated in Figure 1. The complete survey is available in Appendix A, whereas the answers keys for logical reasoning test are denoted in Table 7.

3.3. Survey Method

Subjects As explained above, participants were pooled from *Amazon Mechanical Turk*, and filtered by a. HIT Approval Rate greater than 97%, b. Job Function: Management, and c. Location is the US. Cost per HIT consisted of \$0.5 remuneration and \$0.4 bonus for the job function "Management", plus 20% Amazon Mechanical Turk Platform Fee. Assuming 5 minutes working time per task, the MTurkers were paid \$10.8/h.

Design The survey was created and published on the *Google Forms* platform, with all questions being presented in English.

Materials and Procedure After a short but precise introduction, it consists out of several demographic inquiry questions

Table 7: Answer Keys for the Logical Reasoning Test

Question	1	2	3	4	5	6	7	8
Answer	2.	1.	3.	2.	2.	1.	3.	1. & 4.

and leads to the 7-item logical reasoning ability assessment discussed before. The logical reasoning ability test section was clearly separated from the rest and had its own introduction, covering an example.

> *In the following tasks you are given 2 pieces of information that you must assume to be true.*
>
> *Having those in mind, you must decide which of the conclusions follows logically.*
>
> ————-
>
> *Example*
>
> *GIVEN: If my job is boring, I will quit. SUPPOSE: My job is boring.*
>
> *-> It must be the case that I will quit.*

Both introductions ensured misunderstandings to be rare and data reliability to be guaranteed. The complete survey can be obtained from Appendix A. After finishing the survey, they were given a "survey code" via Google Forms which had to be submitted on Amazon Mechanical Turk and validated, so that every participant could be traced back.

4. Results

In total n=83 managers participated in the survey. After dummy coding, the data was analyzed with the R statistical software (R Core Team, 2021). As discussed in 3.2.1.1, Management Responsibility is not guaranteed to be outlier-free. Therefore, firstly, the scatterplot of management responsibility is analyzed to eliminate potential outliers.

The outliers are identified as Management_Responsiblity > 100 and are excluded from the analysis. Furthermore, all entries with failed attention check are excluded.

With N=80 descriptive statistics of all investigated numerical variables are summarized in Table 8.

Comparing these preliminary descriptive findings to other research, can act as another indicator of the representative validity of the *Amazon Mechanical Turk* sample. For example, the average age of 39.6 years (SD = 11.77) is similar to the 44 years (Shore, Cleveland, & Goldberg, 2003) or 43.35 years (Scandura & Lankau, 1997) observed by fellow researchers. Also, the average amount of work per week, 40.42 hours (SD = 12.05), was similar to 48.9 hours (SD = 1.5) observed by Scandura and Lankau (1997). Lastly, participating managers' educational background – with 58.75% Bachelor, 18.75% Master and 1.25% for both MBA and No Degree (Appendix B) - seems to be similar to existing literature (Bachelor 49.1% and Master 13.75%) (Scandura & Lankau, 1997). Another important observation is that company size has a disproportionately high standard deviation of 158772.67. This was likely caused by outliers and will be considered if analyzed. GPA only has n = 70 observations, as some participants didn't respond with a GPA in the 1.0 – 4.0 scale. Finally, it is interesting to observe that on average managers achieved a bit more than half of the points possible in the Logical Reasoning Ability Assessment.

4.1. Internal Consistency

To continue the analysis a valid LRA variable, as a first step the logical reasoning ability assessment's internal consistency must be tested. Internal consistency– describing the extent to which items in a test measure the same phenomenon - is important when conducting (psychological) assessments of human capabilities (Tavakol & Dennick, 2011).

In this case Cronbach's Alpha, a prominent model in psychometrics, is computed as quality criterion to examine the internal consistency. It ranges from 0 to 1, with a score between 0.7 and 0.95 seen as acceptable indicator for internal consistency (Tavakol & Dennick, 2011).

The equation from Cronbach (1951), with n as number of questions, V_i as the variances of the score on each question and V_t as the variance of the total score, is indicated below.

$$\alpha = \frac{n}{n-1}\left[1 - \frac{\sum_i V_i}{V_t}\right] \tag{3}$$

The resulting $\alpha = .71$ (95% CI [0.61, 0.81]) of the 7-item test can be associated with good internal consistency (Streiner, 2003). Therefore, the data on LRA can be used as representative assessment of logical reasoning ability in the further analysis.

4.2. Econometric Model Findings

Before running the regression, to mitigate bias caused by inappropriate standard errors, the regression model must be tested for heteroskedasticity. The Breusch-Pagan Test for heteroskedasticity (Breusch & Pagan, 1979) yields p = 0.04; so that the nullhypothesis, assuming homoskedasticity, can be rejected. This finding can be corroborated by the visualization above (Figure 4). Comparing the observations LRA=3 with LRA=4, shows that equal variances of error terms cannot be assumed. Accordingly, the linear regression will be computed using heteroskedasticity-robust standard errors.

Although the model itself is statistically significant ($F(19, 50) = 3.55$, $p < .01$), surprisingly only five regressors are significantly different from zero (Table 10). And as the adjusted R^2 of 0.413 can be perceived as low; indicating the model to being prone to functional form misspecification, new nonlinear models are tested in order prevent this misspecification of the functional form. Next to the below mentioned

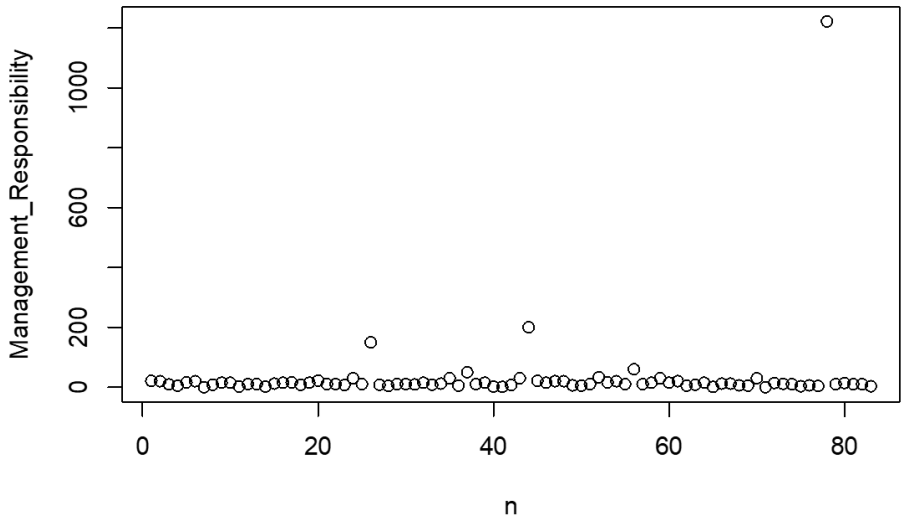

Figure 2: Management Responsibility Scatterplot

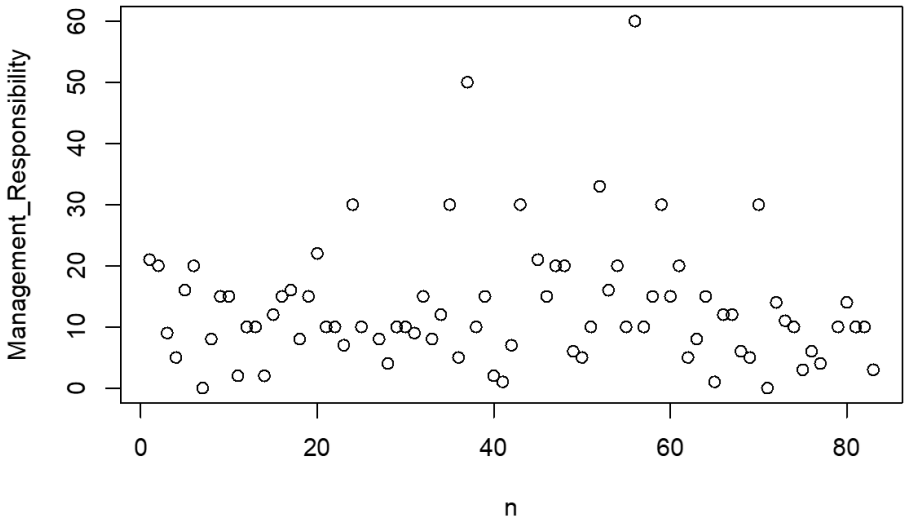

Figure 3: Management Responsibility Scatterplot without Outliers

Table 8: Overview – Numerical Variables

	n	*Mean*	*SD*	*Min*	*Max*	*Range*	*SE*
Management Responsibility	80	13.11	10.18	0	60	60	1.14
LRA	80	3.17	1.95	0	7	7	0.22
Age	80	39.60	11.77	24	63	39	1.32
GPA	70	3.46	0.66	1	4.90	3.9	0.08
Circumstances	80	3.26	1.08	1	5	4	0.12
WorkHours	80	40.42	12.05	10	100	90	1.35
Company_Size	80	33439.57	158772.67	1	1000000	999999	17751.32
Company_Age	80	31.60	31.52	1	150	149	3.52

Table 9: Output of Cronbach's Alpha computation

Lower	Alpha	Upper
0.61	0.71	0.81

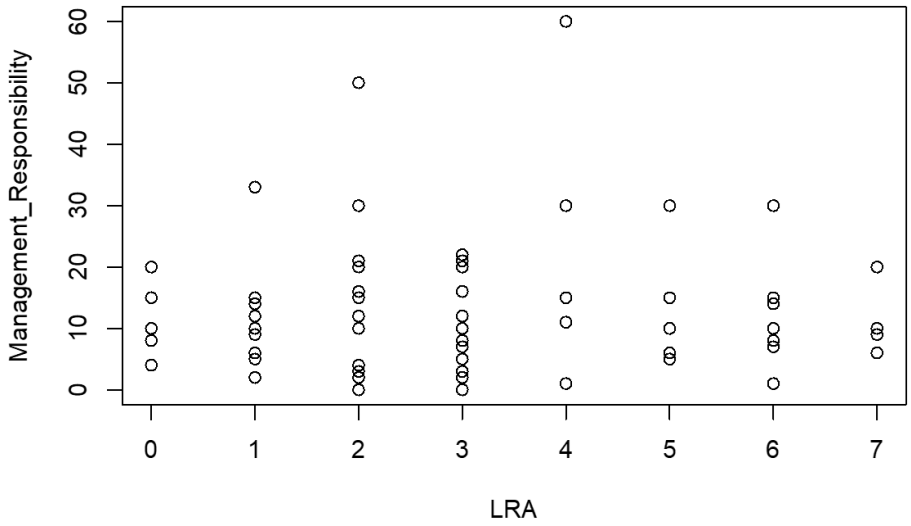

Figure 4: Management_Responsibility mapped against LRA

Table 10: Regression Output Model 1

Regression Analysis

t test of coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-0.2192	7.4465	-0.03	0.9766	
LRA	0.4857	0.5635	0.86	0.3929	
Age	0.1112	0.0947	1.17	0.2460	
Circumstances	2.5553	1.1000	2.32	0.0243	*
WorkHours	0.2059	0.1106	1.86	0.0686	.
Male	2.1124	2.6680	0.79	0.4322	
CS	-1.8718	2.9549	-0.63	0.5293	
Natural	-2.1841	4.3030	-0.51	0.6140	
Formal	-0.0623	4.0629	-0.02	0.9878	
Engin	-3.9128	3.2638	-1.20	0.2362	
Humanities	-8.1564	3.9182	-2.08	0.0425	*
SocialSci	3.5158	3.2479	1.08	0.2842	
Bachelor	-4.6511	4.0782	-1.14	0.2595	
Master	-3.0174	4.3789	-0.69	0.4940	
No_Degree	-10.6549	6.5233	-1.63	0.1087	
MBA	38.9675	4.6315	8.41	3.8e-11	***
GPA	-1.7827	1.8294	-0.97	0.3345	
P_Bachelor	1.7516	3.3457	0.52	0.6029	
P_Master	-11.2146	3.2580	-3.44	0.0012	**
P_No_Degree	19.3329	13.2042	1.46	0.1494	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 8.04 on 50 degrees of freedom
(10 observations deleted due to missingness)
Multiple R-squared: 0.574, Adjusted R-squared: 0.413
F-statistic: 3.55 on 19 and 50 DF, p-value: 0.000169

general quadratic (4), general cubic (5) and depressed cubic (6) function, a log-lin/lin-log/log-log function was not formulated due to zero values in LRA and Management Responsibility resulting in discontinuous functions.

$$\begin{aligned} Model2: Management\ Responsibility_i \\ = \beta_0 + \beta_1 \times LRA_i + \beta_2 \times LRA_i^2 + \beta_3 \times GPA_i \\ + \beta_4 \times Circumstances_i + \beta_5 \times WorkHours_i \\ + Binary\ Variables + u_i \end{aligned} \quad (4)$$

$$\begin{aligned} Model3: Management\ Responsibility_i \\ = \beta_0 + \beta_1 \times LRA_i + \beta_2 \times LRA_i^2 + \beta_3 \times LRA_i^3 \\ + \beta_4 \times GPA_i + \beta_5 \times Circumstances_i \\ + \beta_6 \times WorkHours_i + BinaryVariables + u_i \end{aligned} \quad (5)$$

$$\begin{aligned} Model4: Management\ Responsibility_i \\ = \beta_0 + \beta_1 \times LRA_i + \beta_2 \times LRA_i^3 + \beta_3 \times GPA_i \\ + \beta_4 \times Circumstances_i + \beta_5 \times WorkHours_i \\ + BinaryVariables + u_i \end{aligned} \quad (6)$$

Table 11 shows that all models are significant at 1%-level (F_{Model2} (20, 49) = 3.56; $F_{Model\ 3}$ (20, 49) = 3.61) but have slightly differing values for Adjusted R Squared. Most variance in Management Responsibility can be explained by the variance in the independent variables of the (depressed) cubic model 4 (adjusted R squared = 0.431). Unfortunately, even with this best model less than 50% of the variation in the output can be explained. Despite this the cubic model yields LRA∧3 as estimator at the 10%-level (SE = 0.025, p = .051) Although it is not significant at the 5%-level convention, with p = .051, in our application the estimator can be interpreted as statistically significant. Logical Reasoning Ability is an estimator of Management Responsibility. The regression coefficient estimate of 0.049 indicates a positive relationship between. Thus, Hypothesis 1 cannot be rejected. Age (SE = 0.094, p = .096) and Circumstances (SE = 1.090, p = .077) are other explanatory variables that are significant at the 10%-level, with both having a positive relationship with management responsibility. According to the model, aging 1 year increases management responsibility by 0.157 employees on average. Furthermore, the amount of work per week (SE = 0.116, p = .032) is significant at the 5%-level, positively influencing management responsibility.

Finally, four binary variables are found to be significant; *Humanities* (SE = 3.92, p = .018) and *No_Degree* (SE = 6.36, p = .02) at a 5%-level, and *MBA* (SE = 4.42, p < .01) and Parents' Master (SE = 3.19, p < .01) at a 1%-level. Therefore, managers with the major *Humanities* have significantly different management responsibility as the reference category (*Business* major managers), analogically management responsibility of managers with *No_Degree* & *MBA* is different from High School Diploma managers and managers with a parental Masters degree are different from managers with parental High School Diploma. Otherwise put, on average, 1. managers with a humanities degree have 9 employee lower management responsibility than ones with business degrees, 2. managers with no degree have a 14 employee lower, 3. managers with an MBA have a 39.5 employee higher management responsibility than ones with high school diplomas, and 4. managers with parents that received a Masters degree have 11.6 employee less management responsibility.

4.3. Descriptive Statistics Findings

After discussing and computing the econometric model, remaining hypotheses will be answered through descriptive statistics.

4.3.1. Comparing Means

H3 Are managers majored in formal science the best logical reasoners?

The ANOVA-Test yields that the difference in LRA means between all majors is statistically significant (F (6, 73) = 4.3; p < .01). As seen in Appendix C, on average, managers with a formal science degree score highest on LRA ($\bar{x}$ = 5.57; SD = 1.72). Consequently, Hypothesis 3 cannot be rejected.

How much better are managers majored in formal science at logical reasoning?

A T-Test is executed, to investigate the mean difference between managers with formal science background and all other managers. Assuming equal variances (Levene's-Test: F (1, 78) = 0.72; p = .4), the T-Test yields that the compared means are statistically significant from each other (t (7) = -4; p < .01). Managers majored in formal science ($\bar{x}$ = 5.57; SD = 1.72) on average have a 2.52 point higher LRA score than other managers ($\bar{x}$ = 2.95; SD = 1.82)

To examine the effect size of these 2.52 points (telling how big the 2.52 point difference is in relation to the pooled standard deviation), *Cohen's d* is computed (Cohen, 2013). With d = 1.46 the LRA score difference between groups of managers is large (Lakens, 2013).

H4 Do STEM-major managers have higher logical reasoning ability than others?

STEM is computed as a binary variable of which value "1" can be associated with Natural Science, Computer Science, Formal Science and Engineering and "0" with all other majors. The mean in LRA between STEM managers and non-STEM managers has to be compared. The same procedure as above applies. First, it is ascertained if equal variances between the two samples can be assumed. Levene's-Test (Levene, 1960) indicates that the nullhypothesis of variance equality can be rejected (F (1, 78) = 7.67; p = .007). The subsequent T-Test yields that the compared means are statistically different with a confidence level of 10% (t (69) = -2; p = .09). Managers majored in STEM ($\bar{x}$ = 3.56; SD = 2.22) on average have a 0.759 point higher LRA score than Non-STEM managers ($\bar{x}$ = 2.8; SD = 1.6). Cohen's d = 0.4 shows that

Table 11: Regression overview, Model 1-4

Regression Results

	Dependent variable:			
	Management Responsibility			
	(1)	(2)	(3)	(4)
LRA	0.486	-2.320	1.260	-1.390
	(0.564)	(1.900)	(4.360)	(1.180)
	p = 0.389	p = 0.224	p = 0.773	p = 0.240
LRA_squared		0.437	-1.020	
		(0.272)	(1.530)	
		p = 0.109	p = 0.506	
LRA_cube			0.149	0.049*
			(0.146)	(0.025)
			p = 0.305	p = 0.051
Age	0.111	0.152	0.155*	0.157*
	(0.095)	(0.094)	(0.091)	(0.094)
	p = 0.241	p = 0.107	p = 0.088	p = 0.096
Circumstances	2.560**	2.060*	1.780*	1.930*
	(1.100)	(1.100)	(1.050)	(1.090)
	p = 0.021	p = 0.062	p = 0.089	p = 0.077
WorkHours	0.206*	0.242**	0.253**	0.249**
	(0.111)	(0.117)	(0.114)	(0.116)
	p = 0.063	p = 0.039	p = 0.027	p = 0.032
Male	2.110	2.280	3.130	2.570
	(2.670)	(2.530)	(2.810)	(2.520)
	p = 0.429	p = 0.368	p = 0.265	p = 0.309
CS	-1.870	-1.480	-1.700	-1.520
	(2.960)	(2.820)	(2.730)	(2.810)
	p = 0.527	p = 0.599	p = 0.536	p = 0.589
Natural	-2.180	-3.160	-2.600	-3.060
	(4.300)	(4.410)	(4.280)	(4.270)
	p = 0.612	p = 0.474	p = 0.544	p = 0.474
Formal	-0.062	-2.400	-3.250	-2.880
	(4.060)	(4.670)	(4.310)	(4.570)
	p = 0.988	p = 0.608	p = 0.451	p = 0.530
Engin	-3.910	-5.290	-6.080*	-5.670
	(3.260)	(3.570)	(3.500)	(3.580)
	p = 0.231	p = 0.139	p = 0.083	p = 0.114
Humanities	-8.160**	-9.050**	-9.590**	-9.300**
	(3.920)	(3.840)	(4.100)	(3.920)
	p = 0.038	p = 0.019	p = 0.020	p = 0.018
SocialSci	3.520	4.870	6.770	5.610
	(3.250)	(4.410)	(5.610)	(4.750)
	p = 0.280	p = 0.269	p = 0.228	p = 0.238
Bachelor	-4.650	-4.370	-5.350	-4.670
	(4.080)	(3.920)	(4.060)	(3.900)
	p = 0.255	p = 0.265	p = 0.188	p = 0.232
Master	-3.020	-3.020	-4.670	-3.560
	(4.380)	(4.260)	(4.420)	(4.260)
	p = 0.491	p = 0.479	p = 0.290	p = 0.404
PhD				
No_Degree	-10.700**	-14.000**	-15.700**	-14.800**
	(6.520)	(6.250)	(6.830)	(6.360)
	p = 0.022	p = 0.026	p = 0.022	p = 0.020
MBA	39.000***	39.500***	39.500***	39.600***
	(4.630)	(4.450)	(4.450)	(4.420)
	p = 0.000	p = 0.000	p = 0.000	p = 0.000
GPA	-1.780	-1.690	-1.530	-1.630
	(1.830)	(1.920)	(1.890)	(1.910)
	p = 0.595	p = 0.379	p = 0.419	p = 0.394
P_Bachelor	1.750	3.040	3.920	3.440
	(3.350)	(3.440)	(3.330)	(3.420)
	p = 0.591	p = 0.377	p = 0.239	p = 0.315
P_Master	-11.200	-11.600***	-12.800***	-12.000***
	(3.260)	(3.140)	(3.630)	(3.190)
	p = 0.396	p = 0.0003	p = 0.0005	p = 0.0002
P_PhD				
P_No_Degree	19.300	20.000	18.900	19.700
	(13.200)	(12.800)	(12.600)	(12.600)
		p = 0.118	p = 0.136	p = 0.119
Constant	-0.219	0.377	-1.070	-0.042
	(7.450)	(7.810)	(8.320)	(7.680)
	p = 0.977	p = 0.962	p = 0.898	p = 0.996
Observations	70	70	70	70
R2	0.574	0.592	0.600	0.596
Adjusted R2	0.413	0.426	0.424	0.431
Residual Std. Error	8.040 (df = 50)	7.960 (df = 49)	7.960 (df = 48)	7.920 (df = 49)
F Statistic	3.550*** (df = 19; 50)	3.560*** (df = 20; 49)	3.420*** (df = 21; 48)	3.610*** (df = 20; 49)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 12: Correlation Overview LRA-Age and LRA-GPA

		Age	GPA
LRA	*r*	0.00418	0.0196
	t	0.04	0.2
	df	78	68
	p	1	0.9

Table 13: Overview of strong significant correlations

		r	p
HighSchool	Bachelor	- 0.573	<.001
Bachelor	Master	- 0.573	<.001
Humanities	No_Degree	0.436	<.001
HighSchool	P_HighSchool	0.419	<.001
HighSchool	P_Bachelor	- 0.523	<.001
P_HighSchool	P_Bachelor	- 0.85	<.001
HighSchool	Circumstances	- 0.417	<.001
P_Bachelor	Circumstances	0.463	<.001
MBA	Management_Responsibility	0.499	<.001

this difference is small (Cohen, 2013; Lakens, 2013). Consequently, Hypothesis 4 is supported.

H6 The more senior the degree the higher the logical reasoning ability?

Appendix C displays managers with a master's degree on average score highest on Logical Reasoning Ability ($\bar{x} = 4$, SD = 1.93), whereas managers with high school diploma score lowest ($\bar{x} = 2.88$, SD = 2.19); with MBA and No_Degree being excluded from the comparison as n=1. However, the ANOVA-Test (F (4, 75) = 1.55; p = .2) yields that the difference in means is not statistically significant. Hypothesis 6 can be rejected.

4.3.2. Correlations

To validate Hypotheses 2 and 5, Pearson Correlation Coefficient *r* and its statistical significance measures for a. LRA & Age and b. LRA & GPA are computed (Table 12). Unfortunately, both correlations a. (t (78) = 0.04 & p = 1) and b. (t (68) = 0.2 & p = .9) are not significant at all. Hypotheses 2 and 5 can be rejected.

To explore potentially important findings that were not part of the initially stated hypotheses, the correlation analysis is expanded. Table 13 represents a correlation matrix of all numerical variables from our dataset, filtered by Pearson Correlation Coefficient $r > 0.4$ and significance at the 5%-level.

Interestingly, MBA and Management Responsibility have a moderate (Schober, Boer, & Schwarte, 2018) but significant and positive correlation of r = 0.499 (p < .01). This means– to some extent - increased Management responsibility comes with increased likelihood of attaining a MBA, vice versa. Another finding is that better circumstances in which a manager was raised are associated with a higher likelihood attaining a bachelor's degree (r = 0.463; p < .01). Inversely, worse circumstances are associated with a higher likelihood only attaining a high school degree (r = -0.417; p < .01), vice versa.

4.4. Task Performance

Table 14 displays the percentage of correct answers per question. Managers performed best on question 2 (66.2%), 3 (58.8%) and 6 (65%), whilst only around a third of the participants could answer question 1 (36.3%) and question 4 (35%) correctly. The by far lowest score is associated with Question 8 where 91.25% of the managers were unable to solve correctly. This implies that managers did particularly well with Modus Ponens, Modus Tollens and logical ordering but faced great hurdles with the affirmation of the consequent and, especially, with the selection task. In the next chapter it will be discussed how far these results deviate from previous studies

4.5. External Validity

Data collection being executed with *Amazon Mechanical Turk*, following assumption has to be made to ensure external validity: The *Amazon Mechanical Turk* participant pool is a valid representation the population of U.S. managers. Apart from the assumption, "U.S. managers" can be generalized to "managers" which usual in management science (Hunter & Hunter, 1984; Slaski & Cartwright, 2002; Sternberg & Wagner, 1992)

On a final note, it is important to mention the limited external validity in regard to management responsibility. As the sample (excluding outliers) consists only of managers with responsibility of less than 100 persons, the sample does not represent more senior managers.Conclusively, the sample is externally valid – representing managers and their logical reasoning ability – insofar they have management responsibility of less than 100.

Table 14: Performance per Question

Question	Answered correctly (in %)
1	36.2
2	66.2
3	58.8
4	35
5	47.5
6	65
8	8.75

5. Discussion

In this section, the findings from chapter 4 will be discussed and set into the context of current literature as presented in section 2. Additionally, the limitations of this research will be critically considered, and potential further research will be proposed.

5.1. Comparing Results to Literature

After covering the first part of the research question, namely the influence logical reasoning ability has on management responsibility, this section is dedicated to the second part. How logically sound is managerial decision making in comparison to other populations?

As the logical reasoning ability assessment includes multiple questions that are identical to ones that were featured and applied in peer-reviewed papers, task performance can be compared.

Table 15 displays the results of this study, together with the findings of other studies focused on students' logical reasoning ability.

The results from last chapter can be confirmed by the other studies. US students also did well with the Modus Ponens task and Modus Tollens (96% correctly answered each).

And just like the managers, students struggled with the affirmation of the consequent task (53% of Finnish & 80% of US students answered correctly) and faced their biggest challenge in the selection task (which only 20%, respectively 10%, of US undergraduate students could master).

However, what comes to a surprise is the strong underperformance of managers. In every compared question, far less managers (on a relative scale) were able to answer correctly.

In conclusion, managers are worse than students in logical reasoning.

5.2. Summary of Results

All in all, a diverse set of findings could be made. Firstly, the developed logical reasoning assessment proved to be internally consistent. Secondly, although the proposed statistical model has low explanatory power, the econometric analysis yielded a positive cubic relationship between logical reasoning ability and management responsibility. Moreover, managers majored in formal science score highest in logical reasoning ability. The difference in LRA scores, comparing managers with formal science background to all other managers, is large. More so, managers with STEM majors perform better in logical reasoning tasks than others.

Thirdly, neither age nor GPA are correlated to the logical reasoning ability of managers. Instead with moderate significant correlation, it could be found that better raising conditions are associated with a higher likelihood attaining a bachelor's degree. Inversely, worse conditions are associated with a higher likelihood only attaining a high school degree.

Finally, comparing sample to literature the managers score worse than students. In every compared dimension, the managers from this study scored worse than university students that were exposed to the same tasks in previous studies. All implications the analysis gave us regarding the in the beginning argued hypotheses are summarized in Table 13.

5.3. Limitations

Omitted Variables

Endogeneity could not only stem from simultaneity, but also from omitted variables. To be considered as omitted, variables must necessarily be a) highly correlated with exogenous variables, like logical reasoning ability, and b) an predictor of management responsibility. Variables that could have been omitted include the following.

Tacit Knowledge & Emotional Intelligence: Both, tacit knowledge and emotional intelligence (referred to as "EQ") have not been included to the regression. Emotional intelligence is a predictor of management responsibility (Cavazotte, Moreno, & Hickmann, 2012). Unfortunately, there is no research on the relationship, not to mention the correlation, between emotional intelligence and logical reasoning ability. In contrast, the relationship (correlation) between emotional intelligence and IQ is researched; but there is equivocality whether the correlation is strong, weak, positive, negative or can be disregarded (Arteche, Chamorro-Premuzic, Furnham, & Crump, 2008; Furnham, 2009; Nath, Ghosh, & Das, 2015). Plus, although there has been research on the relationship between emotional intelligence and age, it only yielded weak a correlation between the two variables (Nikolaou & Tsaousis, 2002; Sjöberg, 2001). In light of those indications, together with the limited resources of this paper

Table 15: Logical Reasoning Assessment resuls in comparison to literature

Answered correctly (%) / Question	Managers	Finnish University Students (Holvikivi, 2007)	US University Students (D'Andrade, 1995)	US Undergraduate Students (Wason, 1968, from D'Andrade, 1995)	US Undergraduate Students (Wason & Johnson-Laird, 1972)
1	36.2	53	80	/	/
2	66.2	/	96	/	/
3	58.8	92	96	/	/
4	35	/	/	/	/
5	47.5	53	82	/	/
6	65	/	/	/	/
8	8.75	/	/	20	10

Table 16: Answered Hypotheses Overview

Hypothesis 1	Logical Reasoning Ability can be associated with management responsibility. The relationship is cubic.
Hypothesis 2	A manager's age is not correlated to his/ her logical reasoning ability.
Hypothesis 3	Managers majored in formal science score highest in logical reasoning ability. Additional Finding: There is a significantly large difference in LRA scores when managers with formal science background are compared to all other managers.
Hypothesis 4	STEM majored managers have higher LRA scores than other managers. However, this difference has limited statistical significance and has a small effect size.
Hypothesis 5	A manager's GPA is not correlated to his/ her logical reasoning ability.
Hypothesis 6	There is no significant LRA difference between managers with differing seniority in their degrees.

in mind, the idea of conducting an additional emotional intelligence test was discounted. Like emotional intelligence, tacit knowledge has been identified as predictor of management success by literature. However, researchers also discovered the correlation between managerial tacit knowledge and IQ to be negligible (Sternberg & Wagner, 1992). Assuming those findings represent the reality, no omitted variable bias would result from excluding these variables from the regression. Though, as the assumptions on tacit knowledge and emotional intelligence don't come with high certainty, their exclusion from analysis can be seen as limitation.

General Intelligence: General intelligence (Spearman, 1961) is very likely highly correlated with logical reasoning ability and age. It could also be an explanatory variable of management responsibility. Especially the second condition must have had been tested in order to rule out potential bias. However, conducting an extra intelligence test would be out of scope of this paper.

Genetic Factors: Although genetic influence has been controlled for, by including parental education to the regression, there may be genetic unobservable confounders correlated to logical reasoning ability and predicting management responsibility.

Data Collection

There are two limitations. Firstly, although approaching the data collection meticulously methodological, the sample of US-Managers from *Amazon Mechanical Turk* may not be representing the population. Secondly, due the limited resources the renumeration was around $10/h. This fact carries a big limitation. Critics could argue the data is biased

as managers with higher pay claims were excluded from the analysis. This can be considered as the biggest limitation of this paper.

Simultaneity

The findings are limited to the two assumptions made regarding reverse causality of managers' and their parents' educational backgrounds.

Causal Inference

All methods described in this paper are based on observational data and come with important limitations. Conclusively, assertions on causality are strictly denied.

Unobservable Time-Dependent Confounders

Unobservable factors like time-dependent changes in the educational system or time-dependent trends in the managerial job market may influence the established econometric models.

5.4. Further Research

Firstly, research could be conducted with the same research question as in this paper, but with extended resources. This would imply a) an inclusion of tacit knowledge and emotional intelligence assessments (and commensurate extension of the econometric model) plus, b) a larger sample including a representative number of managers with management responsibility over 100 people.

Secondly, and most prominently, an investigation of the importance of logical reasoning ability for managers is recommended. This would include the question whether logical reasoning ability is important for other measures of management success (apart from management responsibility). And further, it includes an investigation in which a) industries and b) managerial roles logical reasoning is most essential.Thirdly, combining quantitative with qualitative data, researchers could investigate the way the managers reason and how they solve logical reasoning tasks, depending on their background and current occupation.

Moreover, the significant and strong difference in LRA between managers who studied formal science manager in comparison to other managers was explored. But a causal statement cannot be made. The resulting recommendation is finding out if the formal science educational background leads to strong logical reasoning ability or if the relationship is inverse. Lastly, it would be crucial to know why managers in this study performed way worse when compared to students and their results from other studies.

6. Conclusion

Quantitative studies on logical reasoning in management are rare to non-existent. Accordingly, the relationship between management responsibility (or success) and logical reasoning ability of managers has not found lot of attention in literature so far. Making groundbreaking causal inference claims was not the aspiration of this paper. Instead, it aimed at finding first intuitions in this less researched yet important area of management literature.

Going back to the philosopher king metaphor, it could be shown that increased logical reasoning ability can be associated with increased management responsibility with limitations in mind (low R^2, low effect-size of the estimate). Moreover, managers with formal science experience seem to perform better in logical reasoning. Figuratively speaking, being experienced to think like a philosopher might be beneficial for a management career. After building first grounds in this field of study, it would be great if fellow researchers would investigate this or an adjacent topic (with the aim to explore causal relationships); with more resources, thus less limitations.

References

Aguinis, H., Villamor, I., & Ramani, R. S. (2020). MTurk Research: Review and Recommendations. *Journal of Management*, *47*(4), 823–837.

Aristotle, A., & Irwin, T. (2019). Nicomachean ethics. In (Third Edition ed.). Hackett Publishing Company, Inc.

Arteche, A., Chamorro-Premuzic, T., Furnham, A., & Crump, J. (2008). The relationship of trait ei with personality, iq and sex in a uk sample of employees. *International Journal of Selection and Assessment*, *16*(4), 421–426.

Bergman, L. R., Corovic, J., Ferrer-Wreder, L., & Modig, K. (2014). High IQ in early adolescence and career success in adulthood: Findings from a Swedish longitudinal study. *Research in Human Development*, *11*(3), 165–185.

Boole, G. (1854). *An Investigation of the Laws of Thought: On Which Are Founded the Mathematical Theories of Logic and Probabilities* (1st ed.). Dover.

Braverman, J. D. (1971). Probability, logic, and management decisions. In (1st ed.).

Breusch, T. S., & Pagan, A. R. (1979). A Simple Test for Heteroscedasticity and Random Coefficient Variation. *Econometrica*, *47*(5), 1287–1294.

Bronkhorst, H., Roorda, G., Suhre, C., & Goedhart, M. (2019). Logical Reasoning in Formal and Everyday Reasoning Tasks. , *18*, 1673–1694. (ADS Bibcode: 2020IJSME..18.1673B)

Burgess, J. P. (2016). Logic & philosophical methodology. In (1st ed., pp. 607–621). Oxford University Press.

Cavazotte, F., Moreno, V., & Hickmann, M. (2012). Effects of leader intelligence, personality and emotional intelligence on transformational leadership and managerial performance. *The Leadership Quarterly*, *23*(3), 443–455.

Cohen, J. (2013). *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.). Taylor & Francis.

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika*, *16*(3), 297–334.

D'Andrade, R. G. (1995). *The Development of Cognitive Anthropology*. Cambridge University Press.

Deary, I. J., Strand, S., Smith, P., & Fernandes, C. (2007). Intelligence and educational achievement. *Intelligence*, *35*(1), 13–21.

Dugan, C. M., & Revlin, R. (1990). Response Options and Presentation Format as Contributors to Conditional Reasoning. *The Quarterly Journal of Experimental Psychology Section A*, *42*(4), 829–848.

Ehindero, O. J. (1982). Correlates of sex-related differences in logical reasoning. *Journal of Research in Science Teaching*, *19*(7), 553–557.

Evans, J. S., Clibbens, J., & Rood, B. (1995). Bias in conditional inference: implications for mental models and mental logic. *The Quarterly Journal of Experimental Psychology Section A*, *48*(3), 644–670.

Furnham, A. (2009). Sex, IQ, and Emotional Intelligence. *Psychological Reports*, *105*(3_suppl), 1092–1094.

Galotti, K. M., Komatsu, L. K., & Voelz, S. (1997). Children's differential performance on deductive and inductive syllogisms. *Developmental Psychology*, *33*(1), 70–78.

Halpern, D. F. (2013). *Thought and knowledge: An introduction to critical thinking, 5th ed*. Psychology Press.

Hauser, D., Paolacci, G., & Chandler, J. (2019). Common concerns with MTurk as a participant pool: Evidence and solutions. *Handbook of Research Methods in Consumer Psychology*, 319–337.

Holvikivi, J. (2007). Logical Reasoning Ability in Engineering Students: A Case Study. *IEEE Transactions on Education*, *50*(4), 367–372.

Hunter, J. E., & Hunter, R. F. (1984). Validity and utility of alternative predictors of job performance. *Psychological Bulletin*, *96*, 72–98.

Inglis, M., Attridge, N., & Aberdein, A. (2016). DOES STUDYING LOGIC IMPROVE LOGICAL REASONING. In *40th conference of the international group for the psychology of mathematics education, szeged.*

Inglis, M., & Simpson, A. (2007). Conditional inference and advanced mathematical study. *Educational Studies in Mathematics*, *67*(3), 187–204.

Jeffrey, R. C., & Burgess, J. P. (2006). *Formal logic: its scope and limits* (4th ed ed.). Hackett Pub.Co.

Johnson-Laird, P. N. (1999). Deductive reasoning. *Annual Review of Psychology*, *50*(1), 109–135.

Kahane, H., Hausman, A., & Boardman, F. (2021). *Logic and Philosophy: A Modern Introduction* (30th ed.). Hackett Publishing. (Google-Books-ID: crMPEAAAQBAJ)

Kleene, S. C., & Rasiowa, H. (1954). Stephen cole kleene. introduction to metamathematics. north-holland publishing co., amsterdam, and p. noordhoff, groningen, 1952; d. van nostrand company, new york and toronto 1952; x + 550 pp. *Journal of Symbolic Logic*, *19*(3), 215–216.

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, *4*, 863.

Lehman, D. R., & Nisbett, R. E. (1990). A longitudinal study of the effects of undergraduate training on reasoning. *Developmental Psychology*, *26*, 952–960.

Levene, H. (1960). Robust tests for equality of variances. contributions to probability and statistics. In (pp. 278–292,). Stanford Univ. Press, Stanford, Calif.

Nath, S., Ghosh, S., & Das, S. (2015). Relation between intelligence, emotional intelligence, and academic performance among medical interns. *Open Journal of Psychiatry & Allied Sciences*, *6*(2), 96.

Neisser, U., Boodoo, G., Bouchard Jr., T. J., Boykin, A. W., Brody, N., Ceci, S. J., ... Urbina, S. (1996). Intelligence: Knowns and unknowns. *American Psychologist*, *51*, 77–101.

Nikolaou, I., & Tsaousis, I. (2002). Emotional intelligence in the workplace: Exploring its effects on occupational stress and organizational commitment. *The International Journal of Organizational Analysis*, *10*, 327–342.

Niu, W., Zhang, J. X., & Yang, Y. (2007). Deductive Reasoning and Creativity: A Cross-Cultural Study. *Psychological Reports*, *100*(2), 509–519.

Peer, E., Vosgerau, J., & Acquisti, A. (2013). Reputation as a Sufficient Condition for Data Quality on Amazon Mechanical Turk. *Behavior Research Methods*, *46*(4), 1023–1031.

R Core Team. (2021). R: A language and environment for statistical computing (4.2.0) [software]. r foundation for statistical computing. (https://www.R-project.org/)

Rips, L. J. (1983). Cognitive processes in propositional reasoning. *Psychological Review*, *90*, 38–71.

Scandura, T. A., & Lankau, M. J. (1997). Relationships of Gender, Family Responsibility and Flexible Work Hours to Organizational Commitment and Job Satisfaction. *Journal of Organizational Behavior*, *18*(4), 377–391.

Schmidt, F. L., & Hunter, J. E. (1998). The validity and utility of selection methods in personnel psychology: Practical and theoretical implications of 85 years of research findings. *Psychological Bulletin*, *124*, 262–274.

Schmidt, F. L., Ones, D. S., & Hunter, J. E. (1992). Personnel selection. *Annual Review of Psychology*, *43*, 627–670.

Schober, P., Boer, C., & Schwarte, L. A. (2018). Correlation Coefficients: Appropriate Use and Interpretation. *Anesthesia & Analgesia*, *126*(5), 1763–1768.

Shore, L. M., Cleveland, J. N., & Goldberg, C. B. (2003). Work attitudes and decisions as a function of manager age and employee age. *Journal of Applied Psychology*, *88*(3), 529–537.

Sjöberg, L. (2001). Emotional intelligence: A psychometric analysis. *European Psychologist*, *6*(2), 79–95.

Slaski, M., & Cartwright, S. (2002). Health, performance and emotional intelligence: An exploratory study of retail managers. *Stress and Health*, *18*, 63–68.

Smith, P. (2003). *An introduction to formal logic*. https://books.google.de/books?id=bX91C6GOBkcC: Cambridge University Press.

Spearman, C. (1961). "General Intelligence," Objectively Determined and Measured. *Studies in Individual Differences: The Search for Intelligence*, *15*(2), 59–73.

Sternberg, R. J. (1999). The Theory of Successful Intelligence. *Review of General Psychology*, *3*(4), 292–316.

Sternberg, R. J., & Wagner, R. K. (1992). Tacit Knowledge: An Unspoken Key to Managerial Success. *Creativity and Innovation Management*, *1*(1), 5–13.

Stock, J. H., & Watson, M. W. (2014). *Introduction to econometrics, update, global edition* (3rd ed.). Pearson Education. (Google-Books-ID: 3BJrwAEACAAJ)

Streiner, D. L. (2003). Starting at the beginning: an introduction to coefficient alpha and internal consistency. *Journal of Personality Assess-*

ment, *80*(1), 99–103.
Suedfeld, P. (1992). Cognitive managers and their critics. *Political Psychology*, *13*, 435–453.
Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. *International Journal of Medical Education*, *2*, 53–55.
Thompson Heames, J., & Harvey, M. (2006). The Evolution of the Concept of the 'Executive' from the 20th Century Manager to the 21st Century Global Leader. *Journal of Leadership & Organizational Studies*, *13*(2), 29–41.
Wason, P. C. (1968). Reasoning about a rule. *Quarterly Journal of Experimental Psychology*, *20*(3), 273–281.
Wason, P. C., & Johnson-Laird, P. N. (1972). *Psychology of reasoning: Structure and content*. Harvard U. Press.
Wechsler, D. (1958). *The measurement and appraisal of adult intelligence, 4th ed*. Williams & Wilkins Co.
Wolff, J. (2006). *An Introduction to Political Philosophy* (New Edition, Fourth Edition, New Edition, Fourth Edition ed.). Oxford University Press.
Yang, Y., & Bringsjord, S. (2003). Mental metalogic and its empirical justifications: The case of reasoning with quantifiers and predicates. In (Vol. 25).
Ziaei, M., Bonyadi, M. R., & Reutens, D. C. (2020). Age-related differences in structural and functional prefrontal networks during a logical reasoning task. *Brain Imaging and Behavior*, *15*(2), 1085–1102.