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Does working memory predict preference to use inherent explanations in scientific observations? A Bayesian Item Response Theory Approach

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Abstract

Understanding the cognitive processes that help people generate explanations is one of the fundamental questions in cognitive science and philosophy. In this study, we try to examine the extent to which working memory capacity can predict peoples' preference for scientific explanations under uncertainty. Specifically, we distinguish between possible explanations in terms of their focus on inherent vs. extrinsic entities associated with an observation. According to past findings, inherent vs. extrinsic properties of a phenomenon are different in terms of the ease of accessibility for cognitive processes. The results of this research indicate a significant association between people's tendencies to choose inherent properties of scientific observations and their working memory capacity as measured by operation span task.

DOES WORKING MEMORY PREDICT PREFERENCE TO USE INHERENT EXPLANATIONS IN SCIENTIFIC OBSERVATIONS?

A BAYESIAN ITEM RESPONSE THEORY APPROACH

by

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Contents

Introduction

One of the most important characteristics of human cognition and any living organism is the ability to identify, predict and utilize the complex patterns of the environment to adopt strategies which give rise to their survival (Cimpian & Salomon, 2014). Even the youngest members of a species can discern regular patterns of their environment, from perceiving changes in temperature or the cycle of days and nights in simple organisms, to detecting commonalities in sociocultural context and language acquisition in Homo Sapiens.

The ability to recognize patterns helps us predict and plan for our future. However, the most saliant characteristic of pattern recognition processes are that they are inherently ingrained in our cognitive capacities. Therefore, it can be possible to take advantage of the theories of cognition to explain more fundamental facets of our mental processes. The cognitive processes of pattern recognition require that the new information that we receive match with the information that we already have been stored in our memory or encode new memories. The result of these cognitive processes in turn acts as one of the basic cognitive components that lead us to form concepts and make decisions. This statement, however, poses the question of how these basic elements of cognition which arise from the information we experience mire within a direction towards a behavioral response.

Logic, probability, and heuristics are three predominant notions in the intellectual history of the mind that presuppose it as a cognitive system driven by logical, statistical, or heuristic approach towards investigating the world (Gigerenzer, 2008). Each of these notions envisions the purpose and underlying mechanisms of human behavior in a different way (Gigerenzer, 2008).

Logic emphasizes the properties of the human mind partly as a system which focuses on the act of inquiry about truth by maintaining consistency between premises and beliefs to draw conclusions based on a deductive scheme (Gigerenzer, 2008). A logical argument tries to generate good reasonings based on certain valid arguments. Logic, however, does not deal with questions like what a good reason in a more generic sense is, since it is only concerned with inferences that their validity is assessed by those "formal features" of specific representations that are acknowledged in a specific inference (Hofweber, 2021). Those representations are different manifestations of the phenomenon of interest in different forms of perception such as a mental or linguistic or visual representation (Hofweber, 2021).

This conception of logic, however, differentiates between "validity" And "formal validity". In a logical construct, validity can be understood as consistency between certain representative aspects of a phenomenon expresses in a specific form like language in a way that "the truth of the premises guarantees the truth of the conclusion, or alternatively if the premises are true then the conclusion has to be true as well, or again alternatively, if it can't be that the premises are true, but the conclusion is false" (Hofweber, 2021). To be able to consider an inference as formally valid, is only guaranteed by the presumption that certain words or attributes have a fixed, concrete meaning which consequently constructs a solid set of representations of that phenomenon (Hofweber, 2021). Therefore, subscribing to a logical assumption inevitably requires ignoring the meaning or contribution of other representations associated to that phenomenon (Hofweber, 2021).

These notions about logic define it as a system of thought that in many cases does not deal with the truth in general. However, a sentient organism, does not always form these "fine grained hyper intentional notions" in terms of daily interactions with the world. Therefore, it is counterintuitive to identify mental processes as solid mechanistic machines that communicate with reality consistent with a logically relevant agenda.

Another notion about the mind is predicated on the statistical theory which predominantly emphasizes properties of mind that resemble a statistician who performs inductive rather than deductive inference which presupposes our assumptions as samples of error-prone information that makes "risky bets" about the world instead of deducing true conclusions about error-free assumptions (Gigerenzer, 1991). Finally, models of heuristic cognition consider the world as an environment in which people live and react to, based on their own capacities, a world that imposes temporal and physical constraints on human's perception (Gigerenzer, 2008).

The models of heuristic cognition hypothesize that in light of the unlimited possibilities of gathering data through observation and interaction with natural circumstances, with respect to the ephemeral essence of timing, cognitive processes naturally resemble heuristics (Gigerenzer & Engel, 2006). Heuristics are defined as decision rules that generate intuitive insights about the world in a "fast and frugal" way (Gigerenzer & Engel, 2006).

Heuristics are frugal which means that they neglect part of the information and unlike statistical methods, they do not try to optimize (find the best solution), but instead "satisfice" (find a good-enough solution) (Simon, 1956). As Simon (1956) explains, maximizing is an effort to examine every single possibility before choosing the best option whereas, satisficing tends to be a more limited effort in terms of the range of possibilities which ceases to try as soon as a satisfactory solution is discovered (Simon, 1956).

One phenomenon that can be explained under the umbrella of heuristics is psychological essentialism. Essentialists assume that humans and generally any object embody a set of qualities that are essential to their identity and determine the basis for their category membership (Neufeld, 2022). Essentialism can result in different intuitive presumptions about social and natural categories: for instance, categories are unobservable and homogenous meaning that all category members share a common hidden essence and there are concrete defining boundaries between them (Neufeld, 2022).

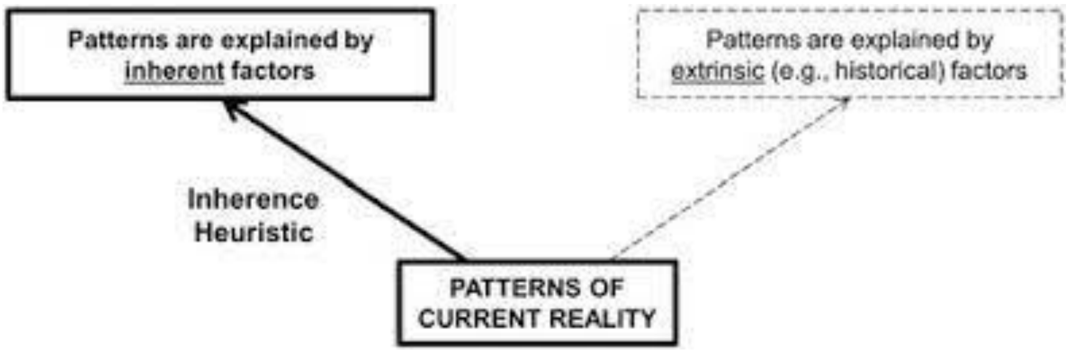
Empirical findings proved that stronger advocacy for essentialist beliefs is associated with stronger acceptance for stereotypes (Bastian & Haslam, 2006), stronger endorsement of racial discrimination (Williams & Eberhardt, 2008) and, more shameless prejudice towards minorities (Keller, 2005).

There have been many debates about what causes essentialist beliefs in humans. Although, many philosophers like Hillary Patnm and Saul Kripke argued that "natural kinds have essences, which are discovered by science, and which determine the extensions of our natural kind terms and concepts", many empirical researchers in various fields of natural sciences believe that the categories endorsed by essentialist criteria, do not necessarily embody the essences attributed to them (Leslie, 2013). Looking at this influential notion in in philosophy, gives rise to several questions about the nature of essentialism in cognitive systems. Hat is the source of essentialism? Do we learn to be essentialist throughout our development? Even though, these questions have been widely discussed (e.g., Leslie, 2013; Maglo, 2011; Gelman, 2003), there is not a lot of agreement in terms of "nature vs nurture" origin of essentialism.

Aside from these debates, Cimpian and Salomon (2014), took a step forward in explaining the psychological aspects of essentialism by taking a more formal approach. In an study Salomon and Cimpian (2014), empirically demonstrated that essentialism arise from a more general heuristic called "inherence heuristic" or "inherence bias" which leads people to explain many observed patterns in terms of the inherent features of the properties that instantiate these patterns" (Cimpian & Salomon, 2014, p.1) (see Fig. 1). For instance, most people in Western cultures might think that girls wear pink because pink naturally represents stereotypical Western feminine qualities like delicacy and sensitivity (Cimpian & Salomon, 2014), or that we eat ice cream for dessert because its inherent qualities might be the cause that makes it a good choice after finishing a meal. Similar to the output of other types of heuristics, this pathway of inference can also go astray (Cimpian & Salomon, 2014).

Many patterns that are perceived as the essential structure of our world are the outcome of intricate sequences of historical and evolutionary events instead of simply being the result of the innate quality of the entities involved, although humans might overlook this possibility (Cimpian

Figure 1. Schematic representation of the inherence heuristic (Cimpian & Salomon, 2014).



& Salomon, 2014). Therefore, the mere recognition of patterns in nature cannot automatically shed light on the factors that gave rise to them. According to this premise, people frequently interpret perceived regularities in their surroundings as "an inevitable reflection of the true nature of the world" as opposed to the output of a chain of events that would come to an end differently (Cimpian & Salomon, 2014, p.462).

As an example, consider the color/gender mapping example mentioned above. Although the colors pink and blue are extensively gendered in the Western world, they used to be considered as replaceable "nursery colors" meant to exemplify the young age of the children who wore them during the nineteenth and early twentieth centuries, but not necessarily their gender (Paoletti 2012). Therefore, in general, assuming that girls wear pink due to reasons "extrinsic" to the gender and color (e.g., it's just a social norm) would be as valid as assuming girls wear pink because of some properties inherent to pink or girls (e.g., pink naturally implies delicacy; girls have an ingrained desire for pink). Hence, a consistent theory assumes that observed patterns are explained by inherent, rather than extrinsic, components of the entities involved may be the result of a systematic use of a “rule of thumb” called the inherence heuristic, that shapes the ways that people make sense of the world either in everyday experiences or scientific reasoning (Cimpian & Salomon, 2014 and Horne, 2017).

To understand the possible mechanisms involved with inherence heuristic, we need to scrutinize the processes related to heuristics in general. According to past research, the term “heuristics” defines two separate mental processes (e.g., Evans, 2009; Frederick, 2002; Gilovich & Griffin, 2002).

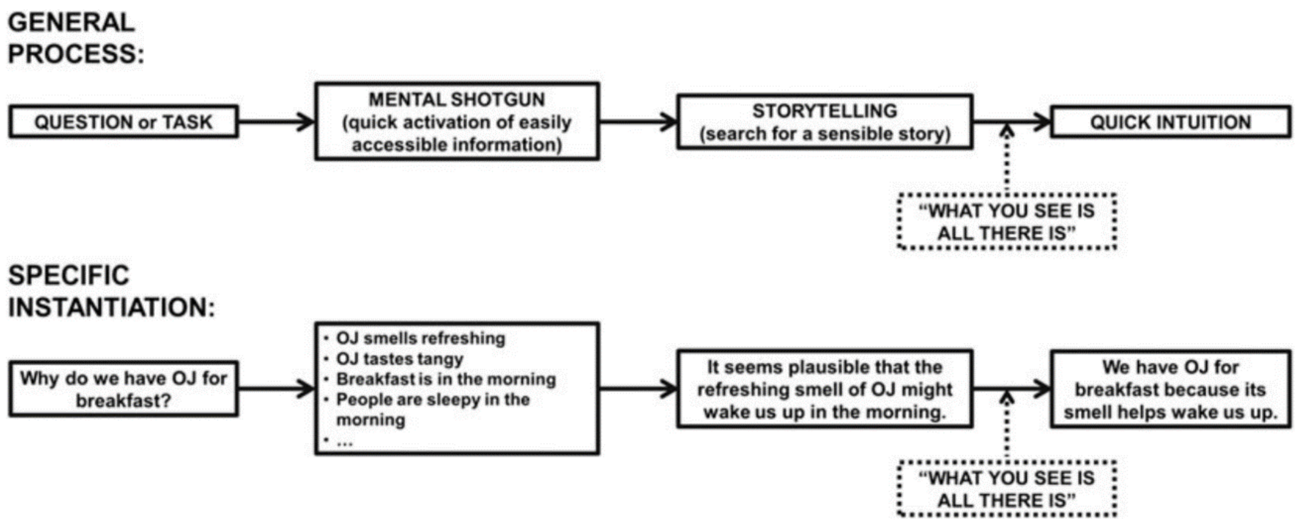
Some heuristics are proposed to operate as deliberate strategies to simplify complex problems. For instance, when trying to purchase a product in, one might decide to only count on online reviews instead of troubling themselves to stop by multiple stores to examine its quality.

Contrary to those types of deliberate decision-making strategies, intuitive heuristics are sometimes considered to be implicit qualities. For example, the preference towards a specific car may be influenced by spontaneous impressions that come into one’s mind with no deliberate effort. Although both of these intuitions try to narrow down the answers to the problems, it is proposed that they operate through different cognitive processes to save effort: the deliberate heuristic is the result of conscious decision making and the intuitive heuristic is the result of implicit, automatic and fast processes prompted by the problem in hand (e.g., Frederick, 2002; Kahneman, 2011).

The proclivity towards inherent explanations, regardless of being deliberate or intuitive, is proposed to happen partially because inherent characteristics of a perceived phenomenon are more accessible than relevant extrinsic factors which can lead us to consider them as an example of availability heuristic (Hussak & Cimpian, 2018; Tversky, & Kahneman,1973). To delineate this proposition, we apply the accounts proposed by Kahneman (2011) and Gigerenzer (2008) on the cognitive mechanisms involved with the information processing aspects of heuristics.

When the search for an explanation is triggered at a specific pattern (e.g., why do girls wear pink?), the next phase of the heuristic procedure will be activated. Kahneman (2011) calls this phase the “mental shotgun”: the process of quick activation of any easily accessible information that is possibly relevant to the question under consideration. Contingent upon the inherence heuristic, the process of mental shotgun is likely to consist of a quick, shallow search for information (Higgins, 1996), that might be suitable for the task of constructing explanations for the perceived pattern of events (see Fig. 2). This process will terminate at this point if the answer is already known. However, in most circumstances, the shotgun search will peak not in the retrieval of the stored information, but rather in the construction of a variety of mental schemas that are potentially relevant to detecting the answer (Cimpian & Salomon, 2014).

Figure 2. The general process involved in generating an intuitive judgment (top), and a specific instantiation of this process that leads to an inherence-based explanatory intuition (bottom) (Cimpian & Salomon, 2014).



Even though the content promoted by the mental shotgun may differ depending on the perceived pattern to be explained, this content might be constructed upon predictable mechanisms. Because the speed and ease of access are prioritized by the mental shotgun, it is more likely that this process initiates its search with entities that are more dominant in the mind at the point that the heuristic process is activated. In the case of the inherence heuristic these entities are usually the components of the detected pattern that we are trying to explain (Cimpian & Salomon, 2014). For example, when we ask why we drink orange juice for breakfast, one might assume that because of some innate properties it might be a proper drink for breakfast. In this case two types of information related to this question will be retrieved spontaneously and simultaneously when they wonder about what explains their association, information about orange juice and breakfast. In other words, the mental shotgun will probably first concentrate on the focal points of the question alongside with any other information that can be easily associated with those central features.

One might therefore ask what information might be relevant to the focal points of attention? Since an object's representation in semantic memory often consists of information about its stable, inherent qualities (e.g., McRae & Jones, 2013), the mental shotgun's output is in turn expected to be dominated by the stable, inherent features of the entities in a relevant pattern (e.g., OJ smells refreshing; breakfast is in the morning). It has been claimed that semantic-associative information of this sort is highly accessible to implicit cognitive processes (e.g., Devine, 1989) and has in fact been implicated in the functioning of other intuitive heuristics (e.g., Gilovich et al., 2002; Kahneman, 2011; Sloman, 1996). It is therefore important to investigate why the inherent features of entities in an explanandum might be more accessible in memory?

First, these inherent qualities may happen to be in the focus of attention when the process of inquiry for an explanation is activated, in this case they would be more likely to act as the first retrieval cue in memory (e.g., Spiller, 2011; Weber et al., 2007).

Second, the extrinsic features of relevant entities might be slower to be accessed through our mental faculties because they are less prominent in comparison to the information perceived as the focal point of the observed phenomena. In addition, even if those extrinsic characteristics are detected, they may necessitate more effort to describe them by means of language (e.g., Cimpian, Brandone, & Gelman, 2010).

The third hypothesis is predicated upon a theory inspired by "empirical database in cognitive psychology and the current neural net models of relational knowledge which indicate that processing capacity is limited not by the amount of information or number of items per se but by the number of independent dimensions that can be perceived simultaneously by the observer. Relational complexity, defined as the number of independent sources of variation that are related, constitutes a major factor underlying the difficulty of higher cognitive processes". According to this hypothesis extrinsic information is less accessible because it involves searching for more complex relations. Information that is more relationally convoluted is also more cumbersome to process (e.g., Halford, Wilson, & Phillips, 1998) and thus, might be retrieved less easily in memory and integrated into an explanation (Hussak & Cimpian, 2018).

Although reasoners require access to the knowledge stored in long-term memory when trying to make sense of their observations (e.g., Lombrozo, 2006, 2012), the research on the cognitive basis of explanation has rarely aimed to systematically investigate the influence of basic cognitive processes on how people generate explanations (Hussak & Cimpian, 2018; Horne et al., 2019). If accessibility of information plays a significant role in shaping the search environment during attempts to explain a phenomenon, the capacity of the working memory might in turn play a significant role in determining people's tendency to focus on the inherent factors of an explanandum.

Working memory capacity has been proved to be an important component of general fluid intelligence and it represents a domain free constraint in ability to manage attention. Also, working memory capacity is important since any cognitive task can be accomplished only if one can sufficiently redeem relevant information while undergoing higher level processes (Cowan, 2010). Another crucial characteristic of working memory storage is that its capacity is limited and varies across individuals (Cowan, 2010). Hence, we hypothesize that the working memory capacity in individuals might be correlated with their tendency to primarily focus on inherent features of a phenomenon rather than extrinsic factors, when evidence related to both sides of the story include a similar level of uncertainty. In this study, we aim to examine this relationship.

It is crucial to understand the cognitive mechanisms behind explanations especially in the context of scientific reasoning which inevitably requires “deliberate” reflection as the main characteristic of scientific inquiry as an objective intellectual system. This deliberation has been considered what makes science prosperous however, many studies prove that even in the context of deliberate reasoning, psychological limitations affect the ways by which scientists explain observations. As an example, Dunbar (1997) noticed that even world class, experienced biologists tend to apply analogical reasoning based on more superficial representations of a phenomenon such as featural similarities of a source to the target rather than more abstract conceptual structures.

Research Methods

The main goal of this study is to test the hypothesis that working memory capacity as measure by the operation span task (OST) can predict the bias toward inherent explanations. For this purpose, we combined two different experimental paradigms including an operation task to measure working memory capacity and a set of vignettes adopted from Horne (2017) to measure people’s tendency to use inherent factors related to scientific observations when generating explanations. In this study, which was conducted across 1,455 children and adults, participants were asked to explain the reason behind unfamiliar scientific explanations in fields of biology, physics, and chemistry.

The results of this study proved a significant bias towards explaining those scientific observations in terms of their inherent capacities (Horne, 2017). Therefore, the scientific vignettes used in this study could substantiate people's tendency to use inherence bias which could be potentially used in the current study.

Participants

We collected data from 114 subjects recruited from undergraduate students in Syracuse university that received research credit in return. The experiments were conducted in-person and online through Syracuse University's SONA system.

Materials and Procedure

This experiment includes two main parts. A survey and a working memory task. The materials in this experiment include a working memory task and a multiple-choice survey which is adopted from Horne (2017) (see Appendix B). The survey includes 12 questions about different scientific observations based on factual examples presented in random order. Participants were initially required to read the scientific vignettes and answer a question about the cause of the scientific observation. The following vignette is an example:

Chemists working in the humid jungle of Cambodia were looking to develop a new pain reliever using extracts from local plants -- Globba Graminifolia and Gardenia Godefroyana. In a strange turn of events, these chemists found that when they attempted to develop a pain reliever using these extracts, it led to a result that completely defied their expectations. Instead of creating a low-cost pain reliever the extracts gave rise to a chemical that produces muscle spasms. This is despite the fact that these scientists had more than 40 years of experience between them. Which one do you think might be the cause?

1. Jungle

2. Plant extract

In this example jungle represents the extrinsic and the plant extract is considered an inherent explanation.

After the first phase finished, the instructions for the operation span task similar to Oswald et al (2014), appeared on the screen. The OST test used for this research was initially coded by Luthra, M., & Todd, P. M. (2019). The operation span task includes a few different practice trials before the test phase starts. After participants finish the practice phase, the test phase which includes three trials appeared on the screen. In each trial 4 to 7 letters and a few simple math problems were presented. First a letter appeared on the screen and then a math problem which came with a True/False option underneath. Participants had to decide if the math problem was True or false. Then another letter appeared on the screen. This process repeated for 4 to 7 rounds with letters randomly chosen from a pool of twelve letters which included F, H, J, K, L, N, P, Q, R, S, T, V, and randomized math problems throughout the operation span task. This process repeated for three times.

At the end of each round, participants had to recall the letters that appeared during the task by choosing the letters they remembered from the pool of twelve letters. After finishing each round, participants were provided with feedback which informed them about the number of letters presented and number of correctly recalled letters. The order of letters was another factor that determined their score. For instance, if they recalled the correct letters but not in order, they would not be counted as correct. If they remembered the letters in the correct order but missed some of the letters in between, only the recalled letters would be counted towards the final score.

In the end of operation span task, the average of operation span score was calculated by dividing the number of remembered letters by 66 which is total number of to be remembered letters. Therefore, the final OPT score ranged from zero to one.

Data Analysis

The results of this study showed that participants evaluated 53% of the scientific explanations as inherent and 47% as extrinsic; even though the proportion of inherent responses were different across the twelve vignettes (see Fig. 3.). This means that some questions naturally accentuate the inherent aspects of the observation and vice versa which can act as a confounding factor resulting in more bias towards certain answers according to innate capacities of each study item.

Figure 3. The proportion of inherent vs extrinsic responses within 12 study items

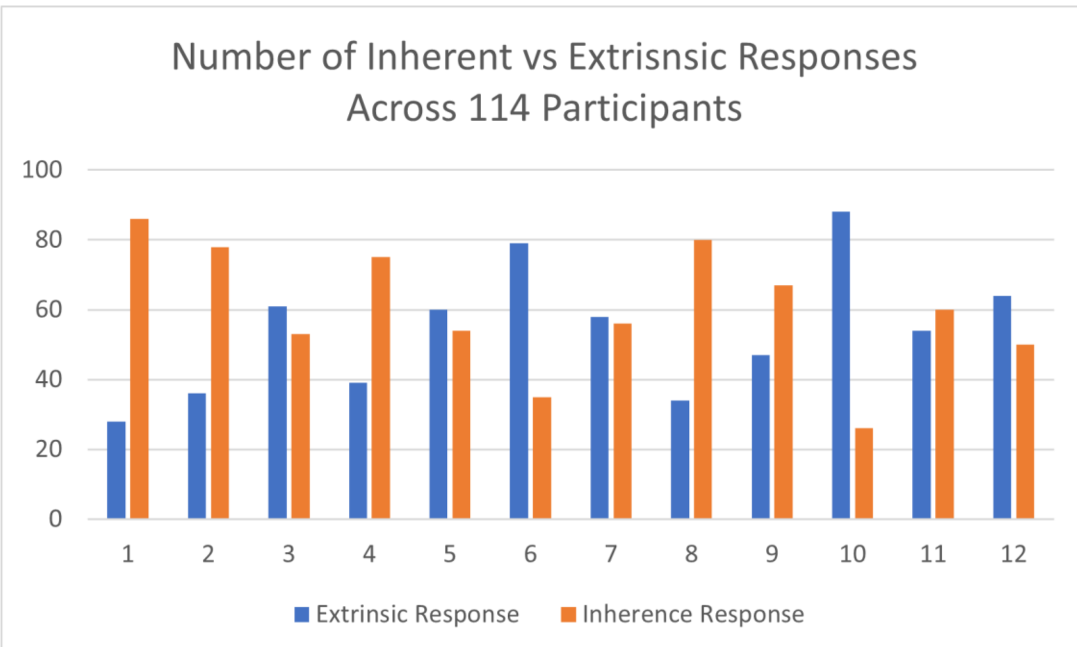
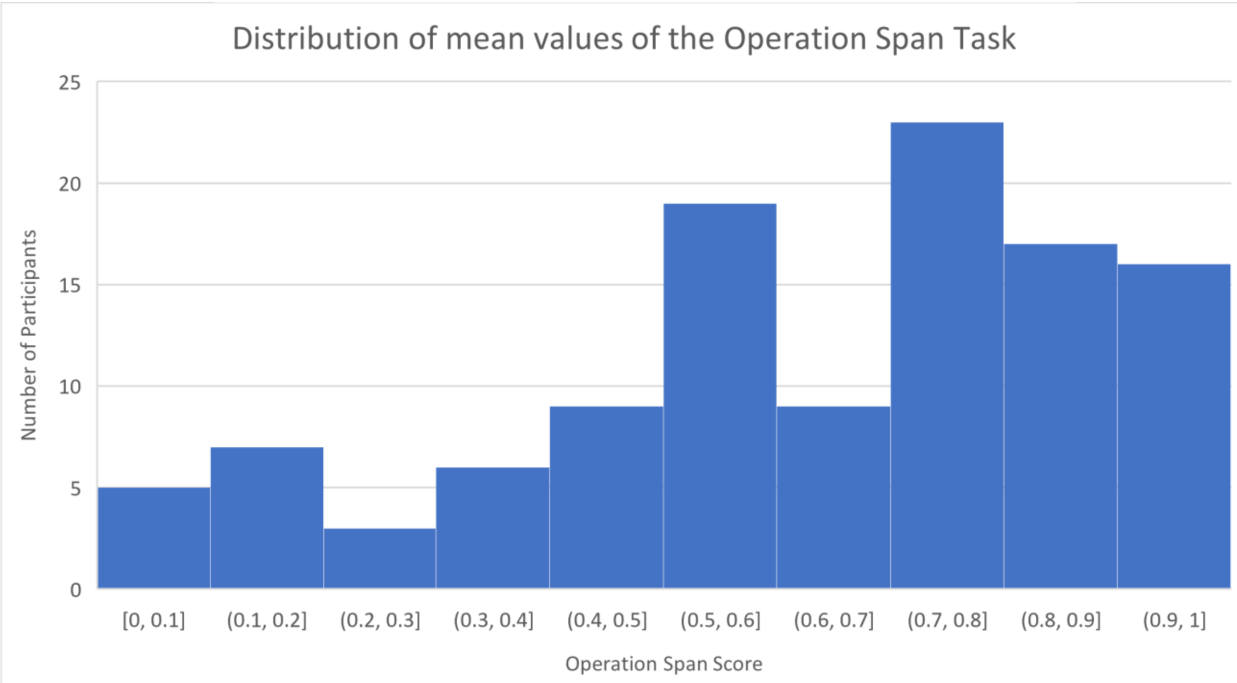


Figure 4. The distribution of average operation span score across 114 participants.



To solve this problem, we used item response theory (IRT), also known as the latent response theory which encompasses a variety of mathematical models designed to explain the relationship between the latent characteristics (unobservable traits or attributes) of a behavior and its external presentation which manifest through different measurements and observations (Edwards, 2009). These models basically attempt to evaluate the overall performance on a test, based on the interrelation between everyone's performance on each test item and participants' overall level of performance on a comprehensive measure of ability of an item to elicit a certain response that was originally designed to evoke.

One advantage of these models that make it stand out from simpler alternatives is that it does not presuppose each item in a test is equally difficult as opposed to, for example, Likert scaling which assumes that all items are perfect replications of each other. On the contrary, IRT considers the difficulty as an important piece of information that can be incorporated in scaling each item (Edwards, 2009).

In item response theory, each item or question in a survey is analyzed by means of a logistic function to predict a few parameters (see Figure 5 and, Equation1). There are different versions of IRT which try to predict different numbers of parameters. In this study a two-parameter version of IRT has been used which uses three estimates including ability, difficulty, and discrimination, to predict the probability of a successful response.

The ability refers to the probability that a person will answer a dichotomous question correctly. People with higher ability are more likely to answer the questions correctly than individuals with lower ability. In theory the ability ranges from $-\infty$ to $+\infty$ however, in practice the range of possibilities are more restricted and in the case of this study we assign values from 0 to 100 (Kruschke, 2015). Item difficulty determines how a question acts across the ability scale. In other words, the ability of an item is established according to the overall measure of the ability scale (Edwards, 2009).

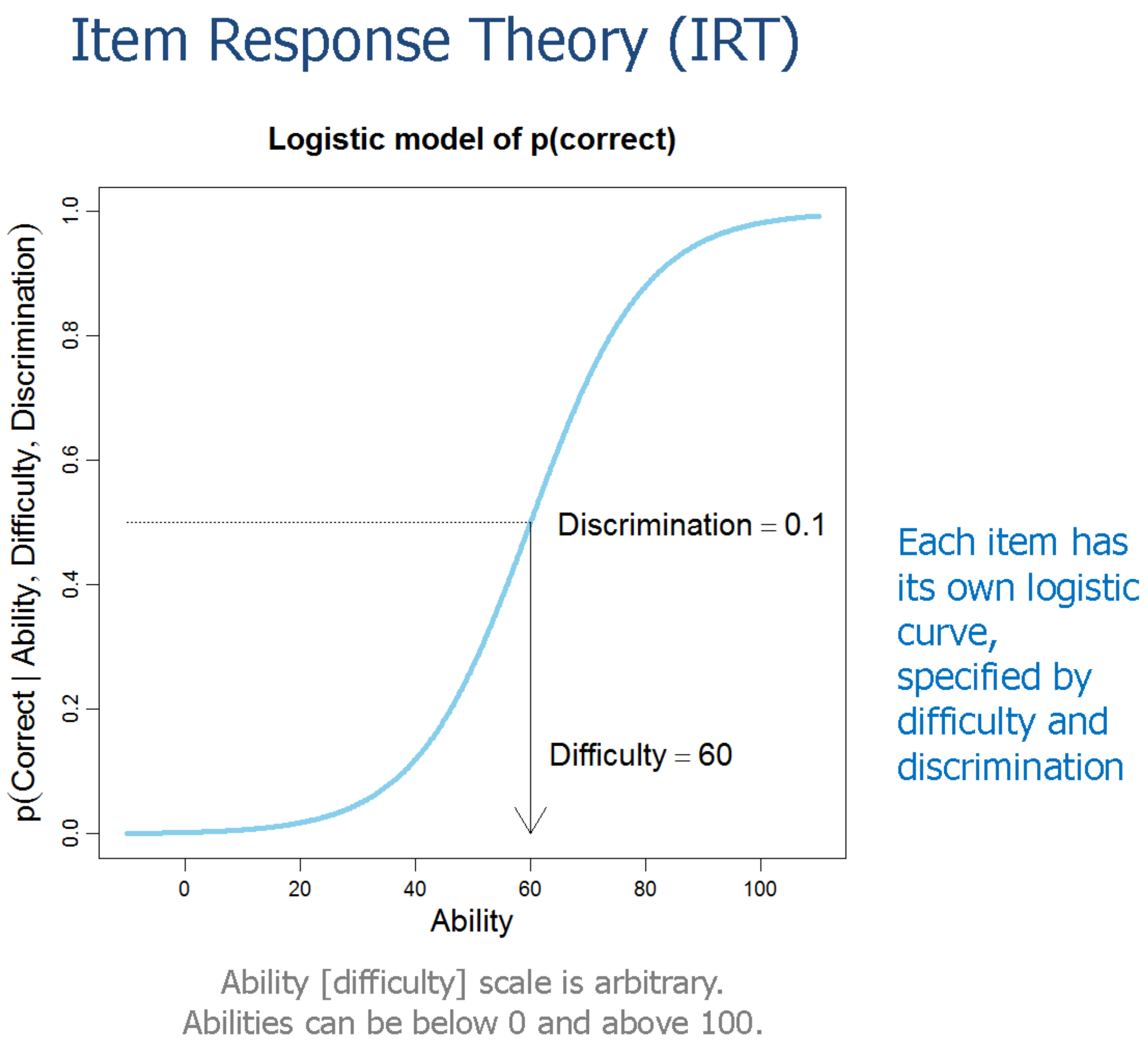
Item difficulty is determined at the point of median scale in which 50% of the participants inscribed the correct response (Edwards, 2009). In an item characteristic curve, those items that are more difficult are shifted towards the right side of the scale, suggesting the higher ability to respond to the item correctly and vice versa. In other words, we expect that the easiest item has difficulty fixed at 0, and the most difficult item has difficulty fixed at 100 (Kruschke, 2015). In this case a set of study items that can reflect various levels of difficulty would be favorable as provide a more fluid and inclusive tool to measure the probability of a correct response across participants.

Item discrimination determines the extent to which the probability of endorsing the correct response in a question fluctuates given the ability scale. This parameter is determined by the slope of logistic curves in IRT The higher the slope, the more quickly the probability of endorsement fluctuates (Edwards, 2009).

The discrimination parameter is informative in terms of the inherent capacity of each study item to examine the subtle differences above and below the threshold of difficulty between individuals who have similar traits that represent the latent characteristics of interest (Edwards, 2009). In other words, participants who are above and below the threshold value for a high slope item are more likely to behave differently (Edwards, 2009).

Consequently, the level of an item's discrimination implicates the aptitude of an item to examine the difference across respondents with similar range of ability. In IRT, a higher the level of discrimination represents a higher capacity of an item to draw out minute variations in each subject's judgment.

Figure 5. An example of an IRT logistic curve, Kruschke, (2015).



Equation1.

$$P(Correct \mid Ability, Difficulty, Discrimination)$$

$$= Logistic\big(Discrimination_{Item} \times (Ability_{Subject} - Difficulty_{Item})\big)$$

$$= P\big(Discrimination_{Item} \times (Ability_{Subject} - Difficulty_{Item}\big)$$

$$= \frac{exp[\,Discrimination_{Item} \times (Ability_{Subject} - Difficulty_{Item})]}{1 + \; exp[Discrimination_{Item} \times (Ability_{Subject} - Difficulty_{Item})]}$$

In the current study we tried to take advantage of the mathematical assets of item response theory within a Bayesian statistics framework with minor conceptual modifications. For instance, in the current data the ability parameter which is defined as a characteristic of an individual subject, manifests as subject bias ranging from 0 to 1 in which 0 indicates a subject's bias towards inherent responses and 1 indicates bias towards extrinsic responses. Also, the difficulty of an item represents an item's innate bias towards more inherent or more extrinsic responses in which 0 and 100 roughly represent the ends of the spectrum of the ability parameter, even though the estimates of this parameter can go beyond 0 to 100 (see equation 2).

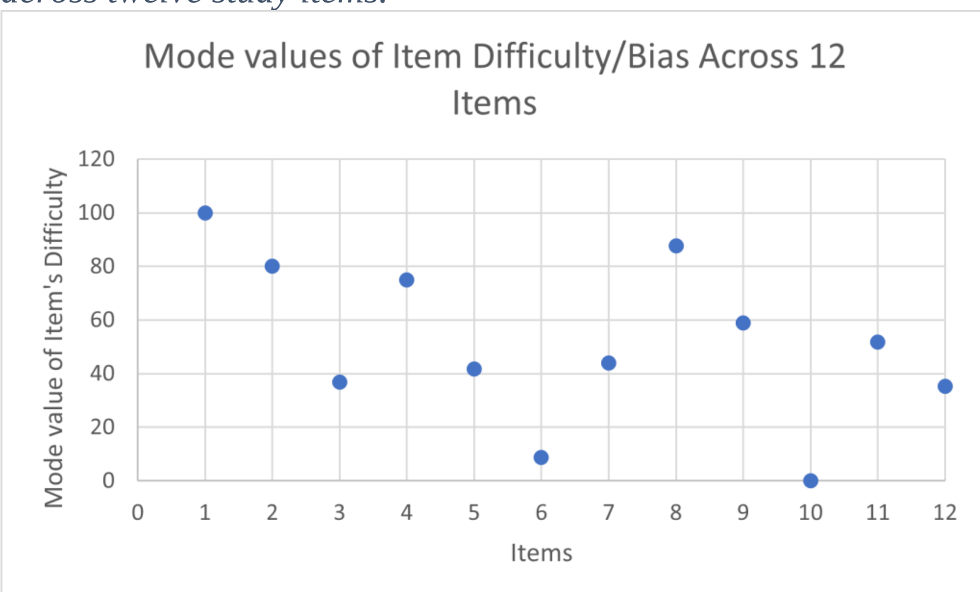
Equation 2.

$$P\big(Bias \mid Bias_{Subject}, Bias_{Item}\,, Discrimination_{Item}\big)$$

$$= Logistic\big(\,Discrimination_{Item} \;\times\; (Bias_{Subject} - Bias_{Item}\,\big)$$

The main goals of this analysis are to first, calculate each study item's bias to explore any discrepancies in terms of the innate capacities of the questions used in this research. We expect to see some level of variance in terms of item level biases/difficulty to make sure we are using an impartial estimator to measure the probability of an inherent response across participants. The results of this analysis were consistent with this criterion as we observed variance in item bias in twelve survey questions used in this study (see appendix A and, Figure 6).

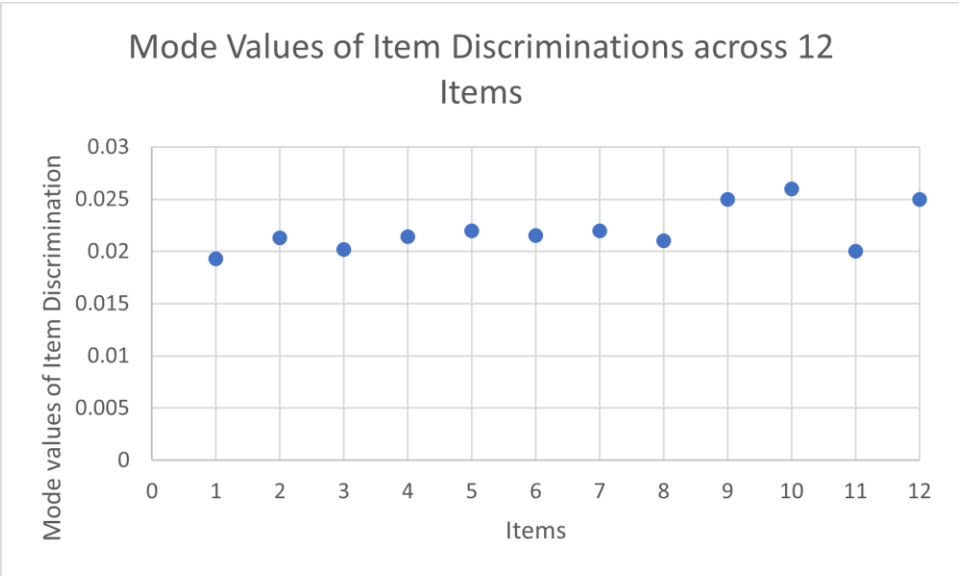
Figure 6. Mode values of the posterior probability distribution of item level bias across twelve study items.



In addition, this observation justifies the necessity of using IRT as a helpful measurement tool since it can exclude the disparate influence of each item on each subject's judgment. Therefore, we can have two different parameters associated with Bias, Item Bias/difficulty, and subject bias/ability to take into account only subject bias/ability as a solid representative of the inherent cognitive capacity of each participant.

Another IRT parameter that represents an inherent aspect of study items is item discrimination (see Appendix A and, Figure 7). The results of this model demonstrate a roughly similar range of mode values associated to item discrimination rating from 0.0193 to 0.0259 on the scale of 0 to 1 which is favorable as we need to be cautious about any negative estimates.

Figure 7. Mode values of the posterior probability distribution of item discrimination across twelve study items.



The second goal of this analysis is to calculate each subject bias/ability. And the final goal is to measure the relationship between each subject's bias and their average score in the operation span task.

There are different ways to approach the third goal of this analysis since a Bayesian framework outputs the distribution of many possible values generated through at least 1000 simulations through MCMC chains (Kruschke & Liddell, 2018) meaning that we cannot simply take into account only a simple value for each subject's bias. One possibility would be to only include the measures of central tendency (mode or mean) for each distribution and calculate the linear regression between the mean/mode of subject bias and the mean of operation span scores.

Another possibility is to directly integrate a linear regression in the Bayesian IRT model. This strategy provides a more sophisticated tool compared to the previous method since it enables the final regression to account for the entire distribution of possible values associated with participant's subject level bias instead of simply using the measures of central tendencies. For this purpose, we used a hierarchical Bayesian model of IRT in JAGS that was originally developed by Kruschke (2015).

Equation 3 delineate the final version of our model after implementing a few interventions.

Equation 3.

$P\left(Y_{subject,item} = 1\ \right) \sim \text{Bernoulli}\left(\theta_{subject,item}\right)$

$\theta_{subject,item} = \text{logistic}\ \left(Discrimination_{Item} \times \left(Bias_{Subject} - Bias_{Item}\right)\right)$

$Bias_{Subject} = ß0 + ß1 \times WMC_{Subject},$

$ß1 \sim \text{Normal}\ (0, \frac{1}{25^2}\ ),$

$ß0 \sim \text{Normal}\ (50, \frac{1}{25^2}\ ),$

The prior values for the intercept (beta0) and slope (beta1) of the regression were set on zero and 50 respectively which reflects very low level of certainty

$Discrimination_{item} \sim \text{Normal}\ (0.1, \frac{1}{50^2}\ ),$

$Bias_{Item} \sim \text{Normal}\ (50, \frac{1}{50^2}\ ),$

$Bias_{Subject} \sim \text{Normal}\ (50, \frac{1}{50^2}\ )$

On the other hand, the prior probability value for the subject level bias and item level bias was fixed on 50 which also represents an impartial standpoint according to the scale of these parameters which ranges from 0 to 100 (see Appendix A). Also, the prior probability of discrimination was very low but positive.

The high credibility interval (HDI) was set on 95%. The credibility interval plays a similar role to confidence interval in frequentist statistics which determines the extent to which the posterior probability distribution of a parameter of interest is credible with high level of certainty. If the posterior probability distribution of a parameter which falls into a certain HDI, excludes zero, we can conclude that the parameter can be considered as a credible estimate.

However, the Bayesian framework, unlike the frequentist approach emphasizes on a probabilistic account to evaluate the level of uncertainty involved with a parameter estimate. this means that Bayesian statistics do not only test a hypothesis against the null but also takes into account the probability of each estimate including the probability of the effect and the null hypothesis. Accordingly, we can only claim that an effect is present if the probability of an effect was strong enough to invalidate the probability of the null hypothesis.

For this purpose, Bayesian approach defines a range of values with no practical effect as region of practical equivalence (ROPE) which centers around the null values (J. Kruschke, 2014; J. K. Kruschke & Liddell, 2018). In Bayesian analysis ROPE is used to examine the percentage of the credible interval (CI) around the posterior probability distribution of predicted values that fall into the region of null values or ROPE (J. Kruschke, 2014; J. K. Kruschke & Liddell, 2018).

In this study, we defined the ROPE for the slope of linear regression (beta1) around -2.75 to +2.75 which is estimated according to the following guideline proposed by Kruchke & Liddlell (2018) in which SD stands for standard deviation of the predicted value.

Equation 4.

$$[-0.1 \times SD_y, +0.1 \times SD_y]$$

As we can see in the figure 8, the HDI distribution of the slope of this regression (beta1) does not include zero and does not overlap with the ROPE, meaning that this estimate is credible. In addition, the modes of intercept (beta0) and slope (beta1) have positive values indicating a positive relationship between working memory capacity in operation span task and subject level bias towards Extrinsic responses. Accordingly, we can infer that there is a negative relationship between working memory capacity and the tendency to choose inherent responses.

Figure 8. Posterior probability distributions of beta0 and beta1.

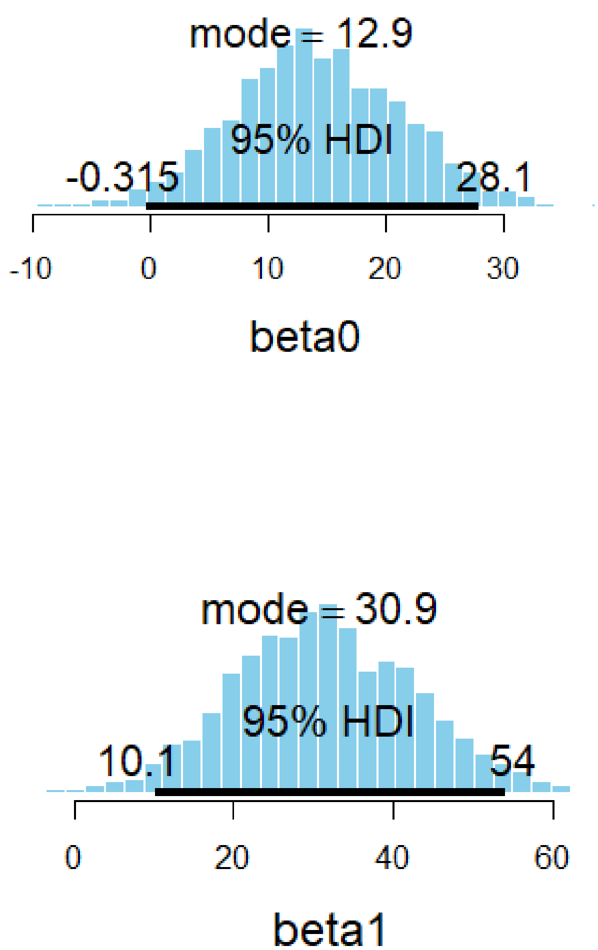
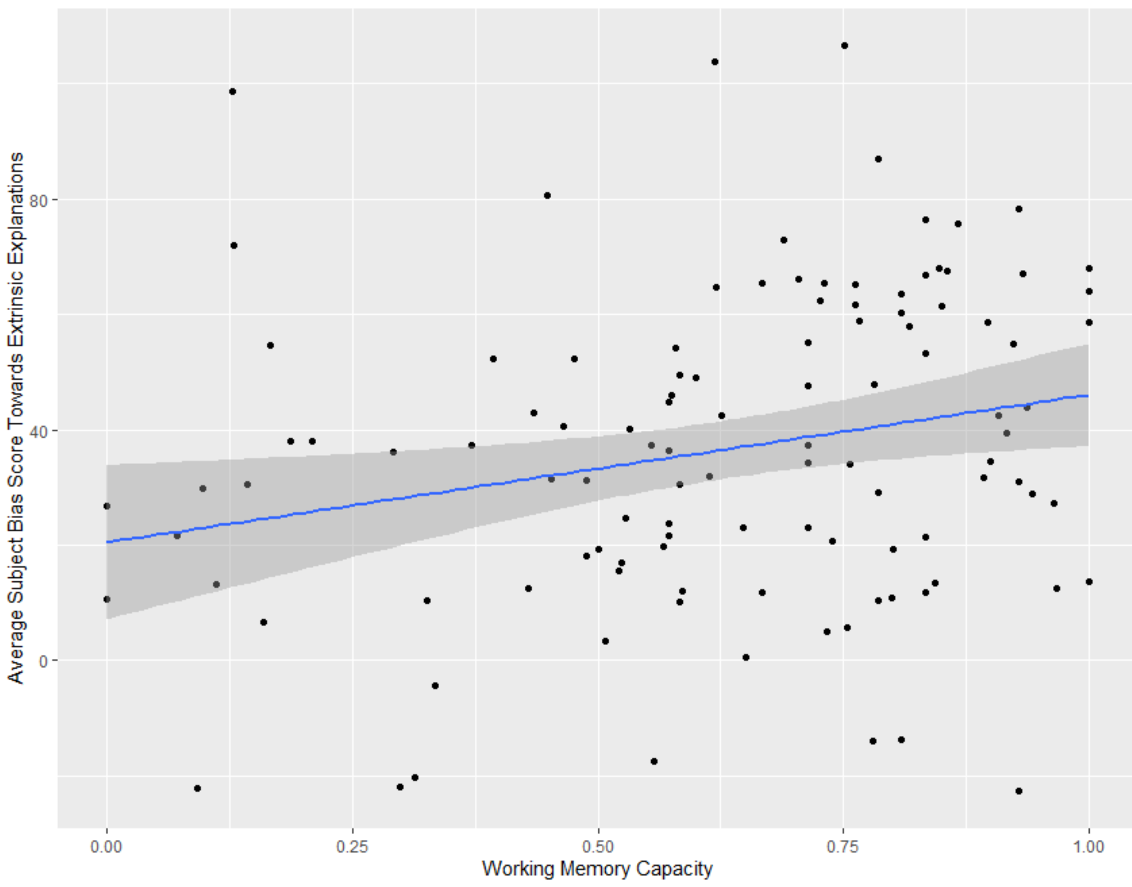


Figure 9. The relation between Average Working Memory Capacity scores and Average Subject Bias Score towards Extrinsic Explanations across 114 participants.



This model also, sampled posterior values from three MCMC chains. The effective sample sizes (ESS) which represents the number of effectively independent samples from the posterior distributions generated by the MCMC chains for the intercept and slope were 2144.296 and 1205.346 respectively.

Finally, we can conclude that the results of Bayesian linear regression integrated to the IRT model, strongly indicated a credible and positive relationship between the average score in the operation span task (WMC) and inclination towards Extrinsic explanations (subject Bias). This observation is in alignment with our hypothesis since it also indicates in negative relationship between the tendency towards inherent responses and working memory capacity.

General discussion

Despite the fact that the role of memory in the procedure of generating explanations has been extensively studied, little research has been dedicated to investigating the influence of working memory capacity in this process when both possible sides of the explanation involve similar levels of uncertainty.
Consistent with the key assumptions of the inherence heuristic account, it has been suggested that “the inherent facts are more easily accessible to memory than noninherent facts and that this accessibility difference in turn biases the content of everyday explanations toward inherence” (Hussak & Cimpian, 2018, p.85).
Regarding the previous findings, this research aimed to take a more fundamental approach towards understanding the influence of memory by simply comparing participants’ working memory capacity with the frequency of attributing inherent reasons to observations under uncertainty.

Although the results of this experiment strongly supported our main hypothesis, several questions remain unanswered. Since these results cannot bolster any causal relations, we cannot make any claims about the processes which determine this biased attention towards inherent entities of a phenomenon.

If the hypothesis about memory accessibility as a key competitor that draws attention towards inward components of an event holds true, then the rest of the data that comes from a bigger world which includes all the extrinsic factors would be neglected. However, when it comes to observations about social phenomena, different factors regardless of being considered as intrinsic or extrinsic, hold more psychological and emotional undercurrents which makes it difficult even for a scientist to categorize the observed factors as a possible contributor to the events under observation (Hertwig & Hoffrage, 2013; Gaucher & Jost, 2014).

Ecological perspectives of cognitive science try to address similar concerns in a more holistic manner which assume that cognition and the environment in which cognition arises from should be considered as one integral system (Gigerenzer, 2008). This narrative also distinguishes between "simple heuristics" and "heuristics and biases" in terms of their utilities. The heuristic and biases program defines bias as a "systematic discrepancy" between one's perception of reality and a "norm" or an accepted rule of statistics, whereas the simple heuristics account does not accept a narrow conception of a correct solution as it examines correctness based on the ambiance of the environment (Gigerenzer, 1991). "Environment" in this context is understood as a world that is relatively bounded to the sensational and perceptual capacities of the beholder (Gigerenzer, 1991).

Consistent with this viewpoint, it is important to examine how information processing capabilities relevant to our hypothesis manifest in more ecologically valid settings. Within a series of experiments, Gilbert, Pelham & Krull (1988) showed that it is not only the accessibility of information in memory that determines one's attentiveness towards the innate entities related to a phenomenon to be explained but the cognitive business can also determine the inclination towards inherence bias (Gilbert, Pelham & Krull, 1988). In this paradigm, they tried to examine the difference between people's ability to use situational constraints that may have influenced an actor's behavior within two groups. One group was asked to rehearse some information related to situational constraints contributing to someone's behavior to increase cognitive business.

On the other hand, the control group did not need to engage in this task while they were trying to make judgments about the same scenario. The results of this experiment showed that the group that was engaged in the rehearsal task as a distractor, was more inclined to draw dispositional inferences about the observed behavior even though they were explicitly exposed to relevant situational information about that scenario through cognitive rehearsal and memorization (Gilbert, Pelham & Krull, 1988).

These findings imply that it is not merely the accessibility of the information in memory that dictates the type of reasoning strategy that a reasoner uses, but also cognitive busyness plays a significant role in the person-perceivers' judgment even though imposed by rehearsing relevant information for the task at hand.

This evidence appears to contradict our initial hypothesis about the role of memory accessibility; however, it can potentially direct future research towards more detailed experimental paradigms.

Another matter in question is related to the role of memory in shaping judgment. Does the association between working memory capacity and people's tendency to use inherence heuristic mean that one's lower working memory capacity will limit their ability to make correct judgments? Apart from relative absence of solidarity on the nature of correctness, how can the mechanics of memory expound our understanding of our inferences? Schooler and Hertwig (2005) offer one way to answer these questions. Their study, which took an ecological approach, proves that forgetting can improve performance in simple heuristics inferences like recognition and fluency tasks (Schooler & Hertwig, 2005).

These results suggest that it is not only the ability to retain a higher magnitude of information that aids making more accurate inferences, but also eliminating irrelevant information through the processes of forgetting that can be considered as an advantageous strategy to process information (Schooler & Hertwig, 2005). Taking into account this approach can help us design more sophisticated, strategic experimental approaches to find out if working memory capacity is beneficial for or hindering our judgments under uncertainty.

Moreover, Horne (2017), found that participants who had to generate their own explanations for a scientific observation were more likely to use inherent qualities than participants in a forced choice condition where the extrinsic entities are more salient however, in both conditions people used inherent explanations to some extent. This observation also suggests that it is not only the salience or accessibility of information that can explain the inherence bias but also, how the entities of an explanation and the environment interact to account for an observation (Horne, 2017).

Beyond the theoretical relevance, the results of this research could have implications within the domain of knowledge representation and heuristics and their influence on judgment and reasoning under uncertainty. In particular, these results can help explain the mechanisms of social stereotyping, prejudice (Bigler & Clark, 2014), and scientific reasoning from a formalized cognitive framework.

Elucidating these social phenomena is particularly important in light of the growing concerns about misinformation and disinformation and how they impact the key aspects of human life, perhaps best exemplified in the context of the Internet and social media (Tacheva, 2022).

Appendix A:

Figure 1. Bias and discrimination in Item 1.

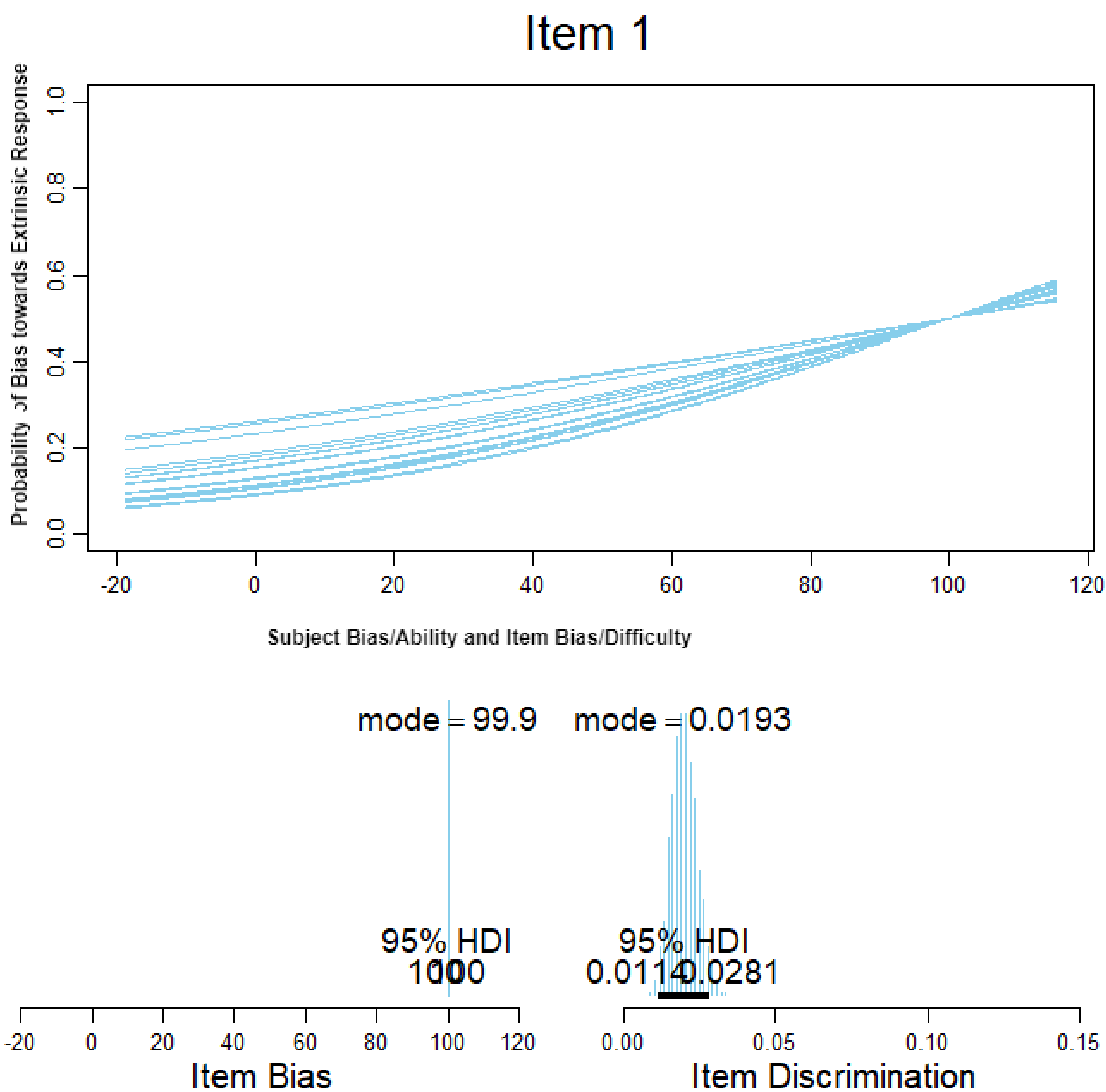


Figure 2. Bias and discrimination in Item 2.

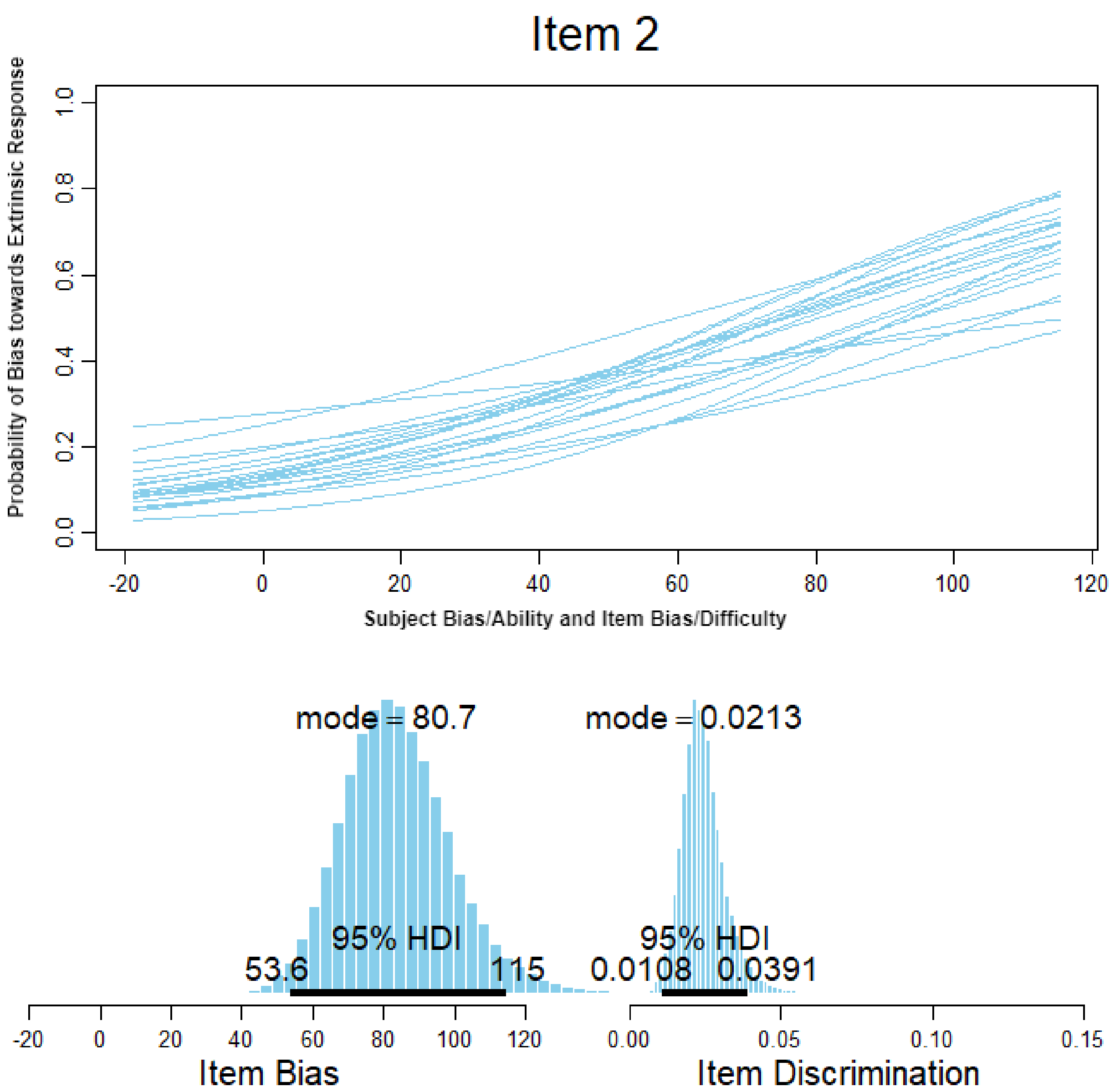


Figure 3. Bias and discrimination in Item 3.

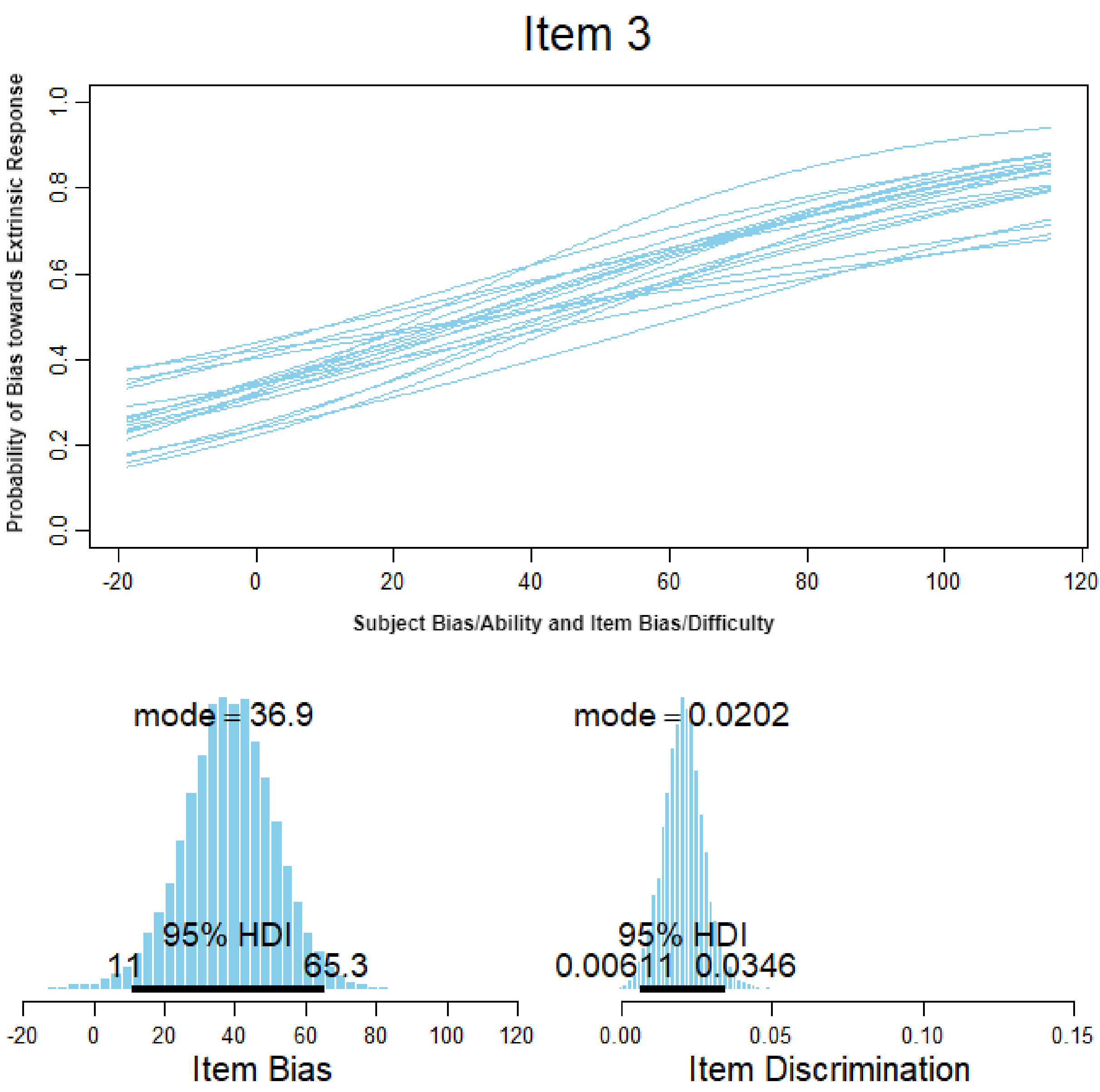


Figure 4. Bias and discrimination in Item 4.

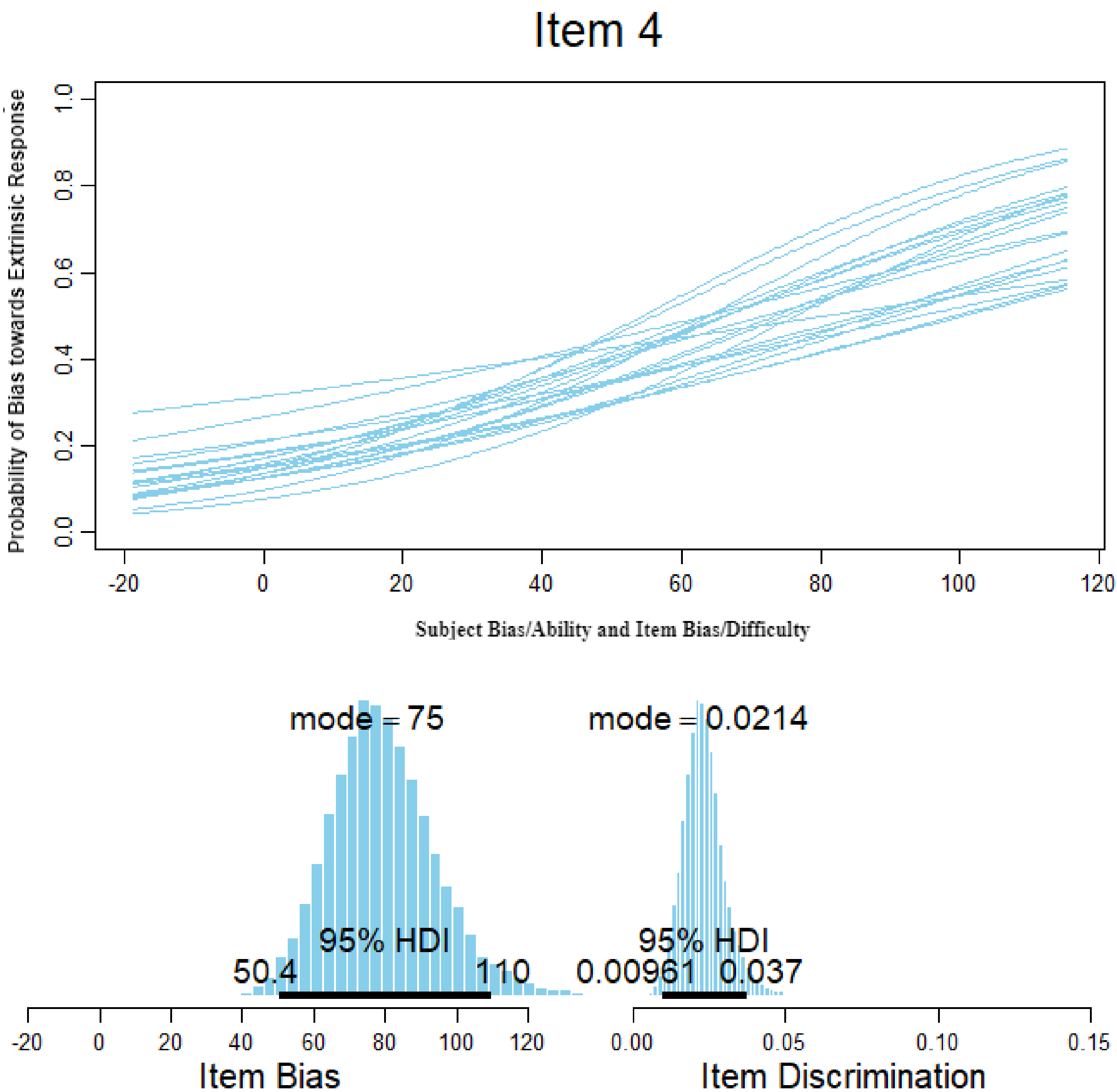


Figure 5. Bias and discrimination in Item 5.

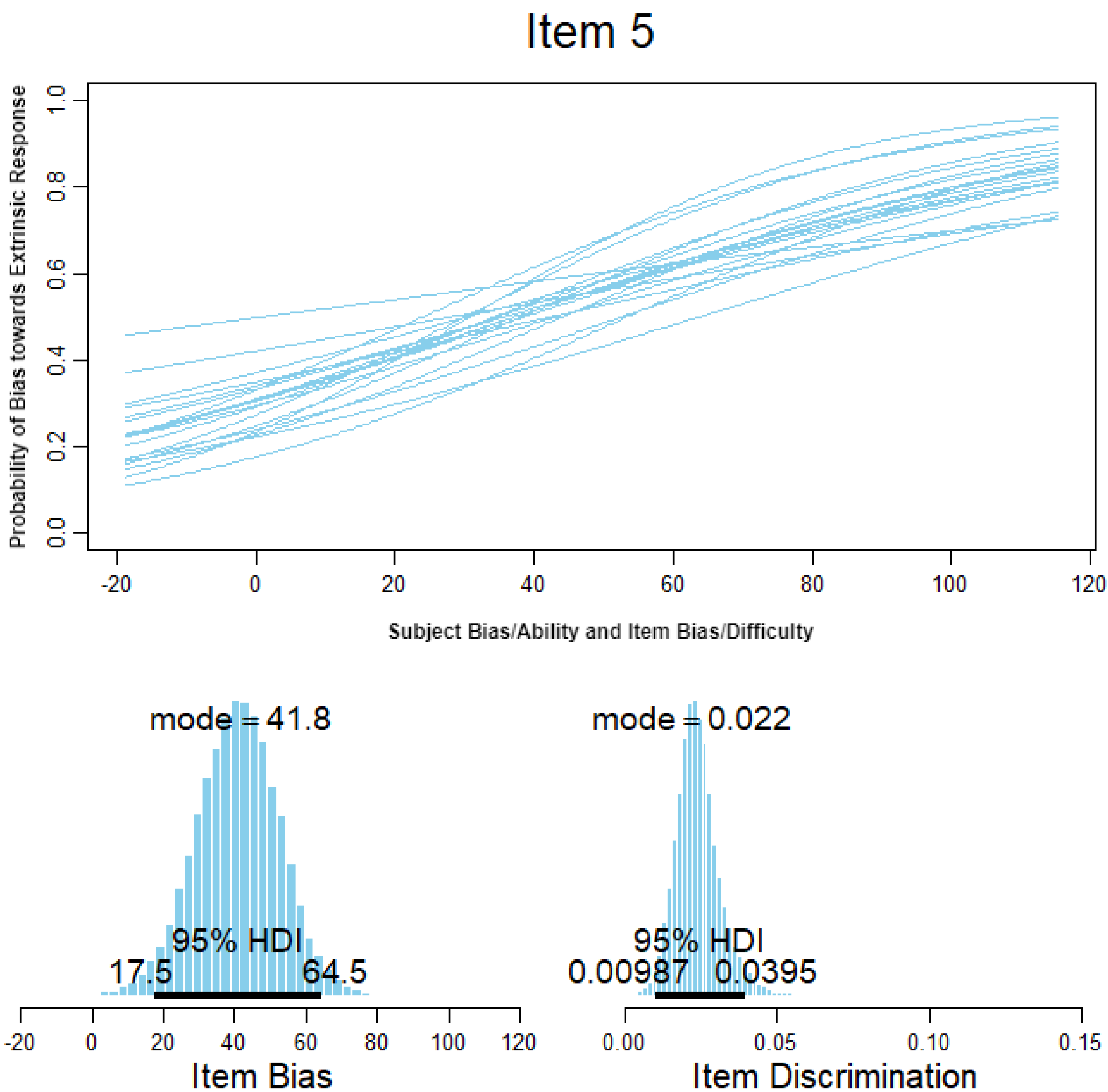


Figure 6. Bias and discrimination in Item 6.

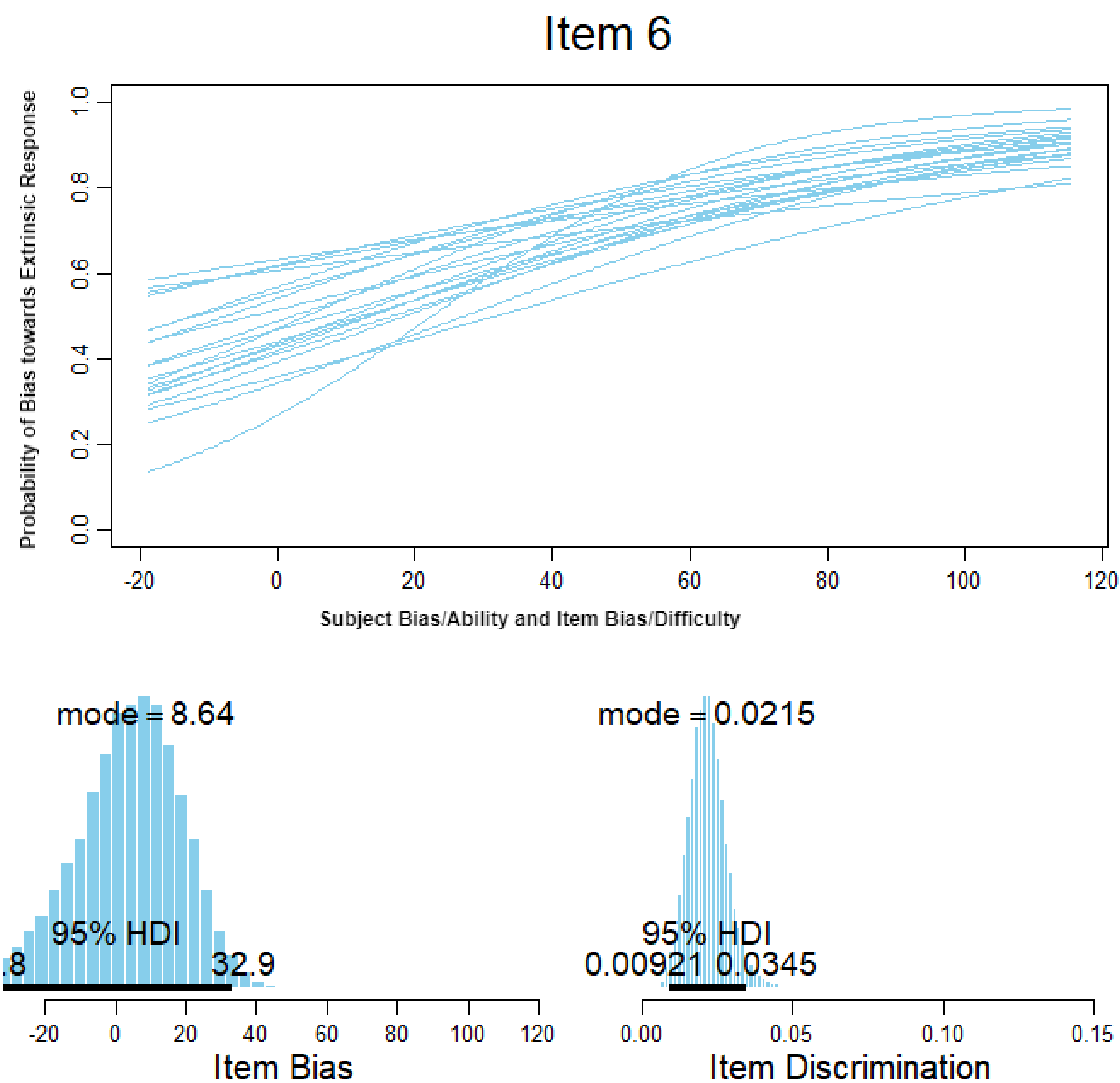


Figure 7. Bias and discrimination in Item 7.

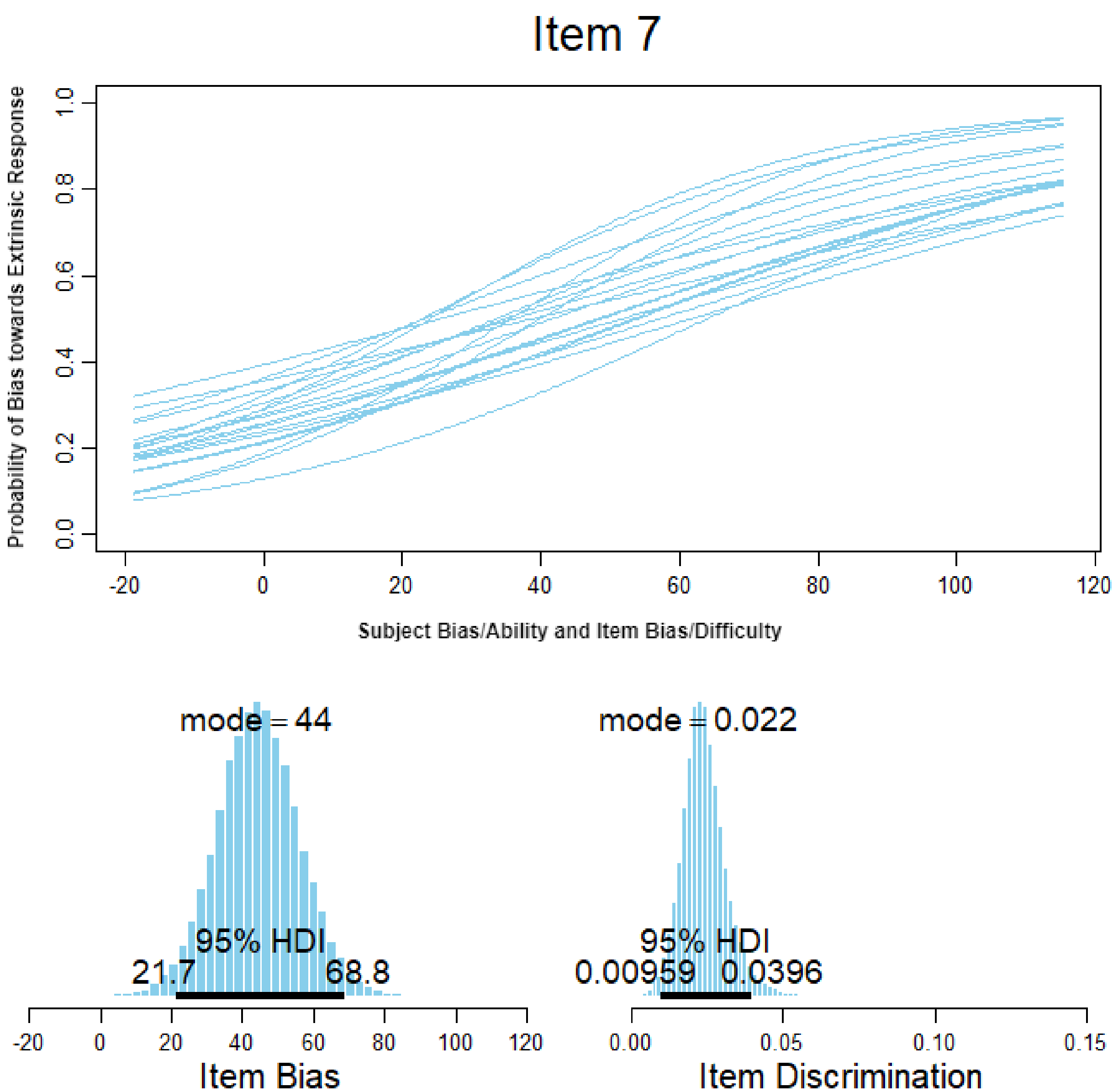


Figure 8. Bias and discrimination in Item 8.

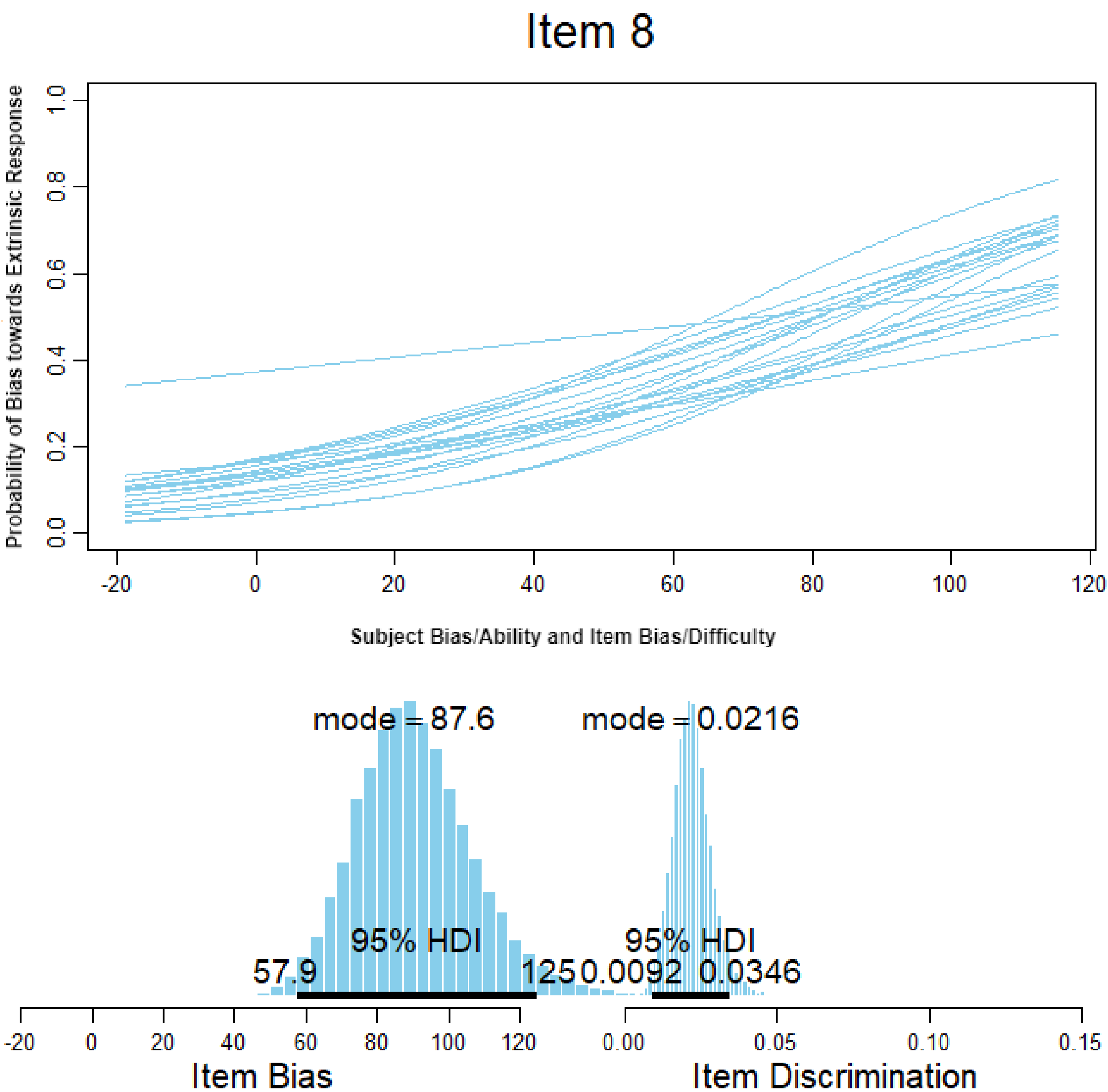


Figure 9. Bias and discrimination in Item 9.

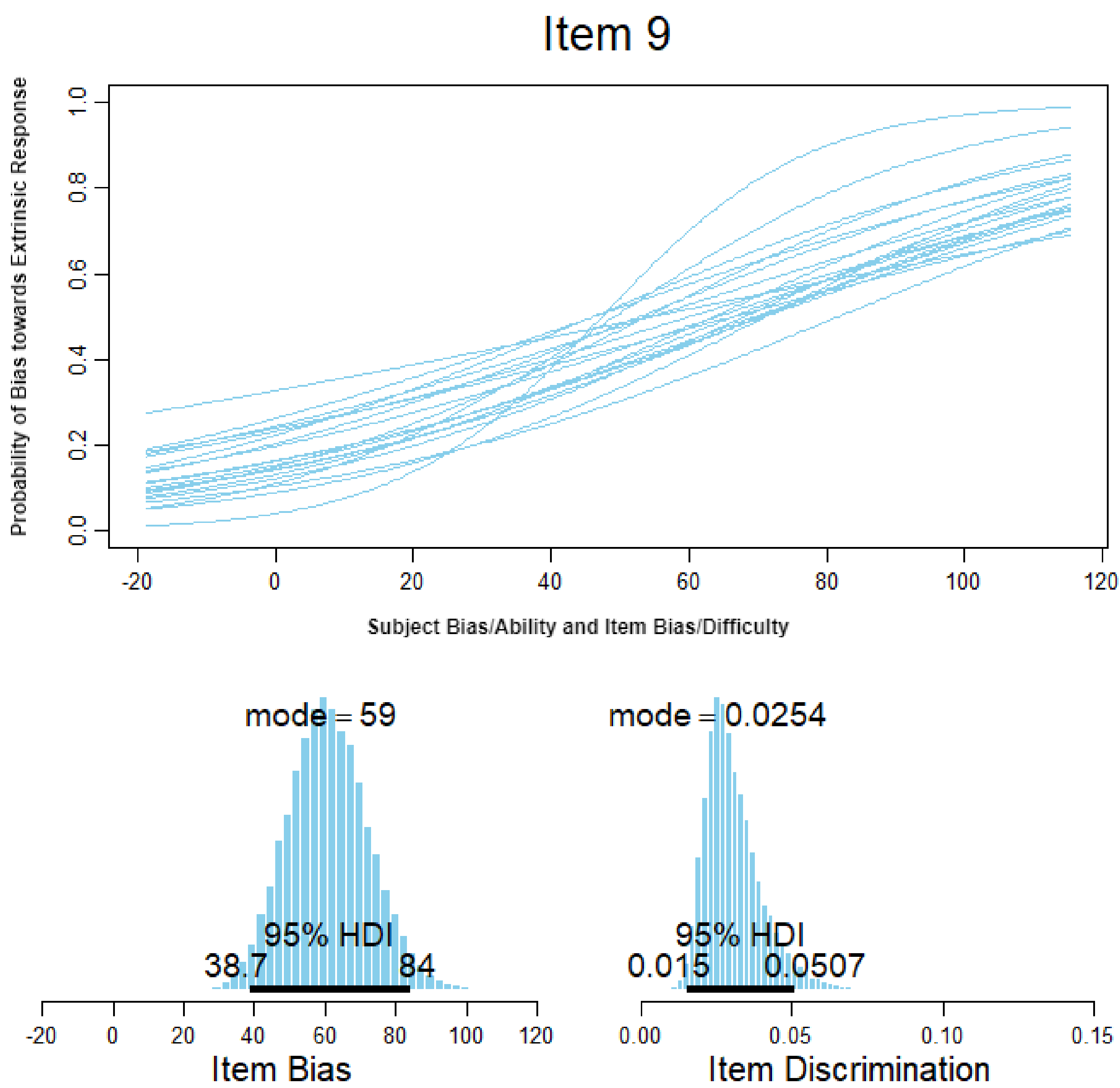


Figure 10. Bias and discrimination in Item 10.

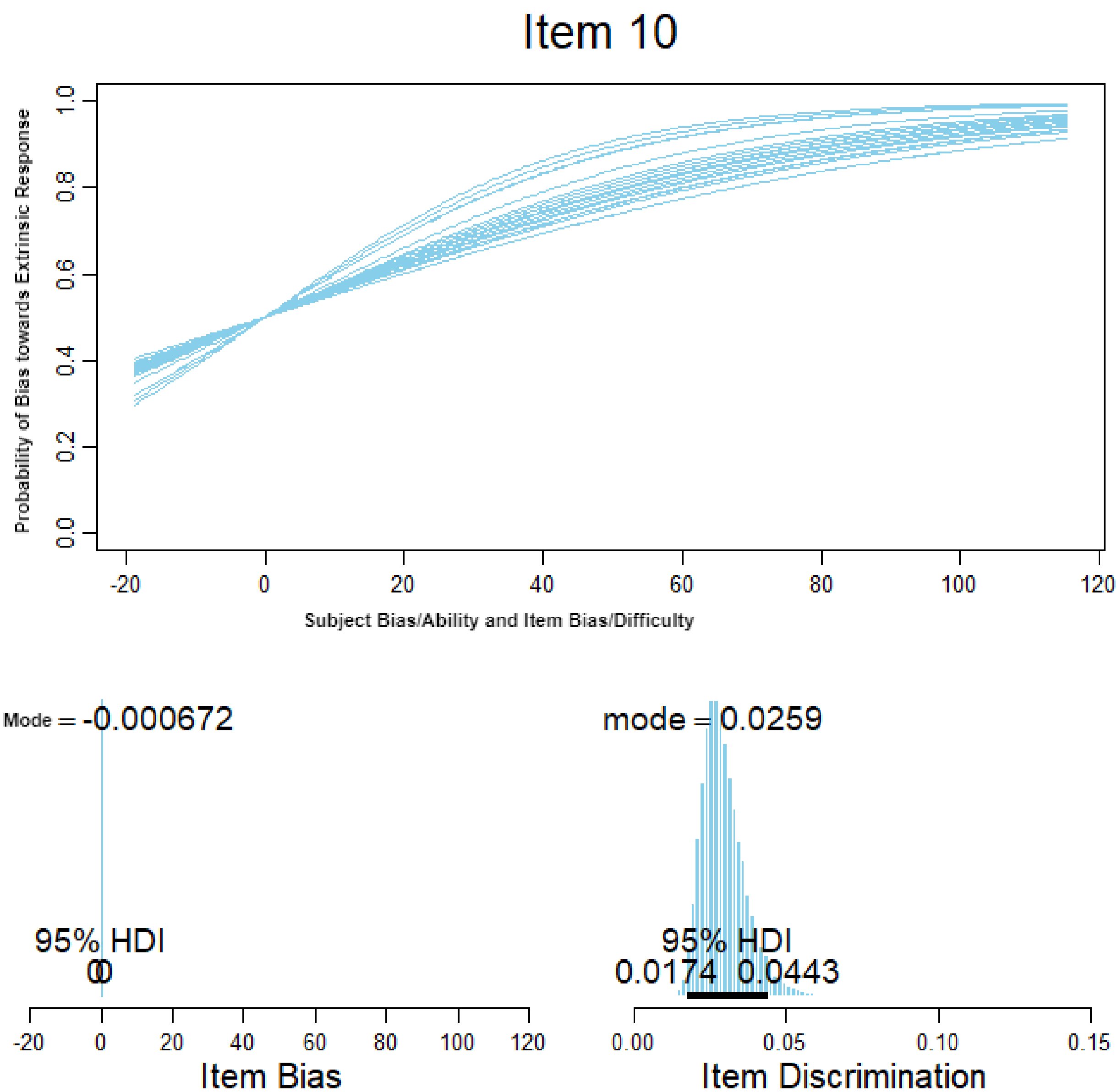


Figure 11. Bias and discrimination in Item 11.

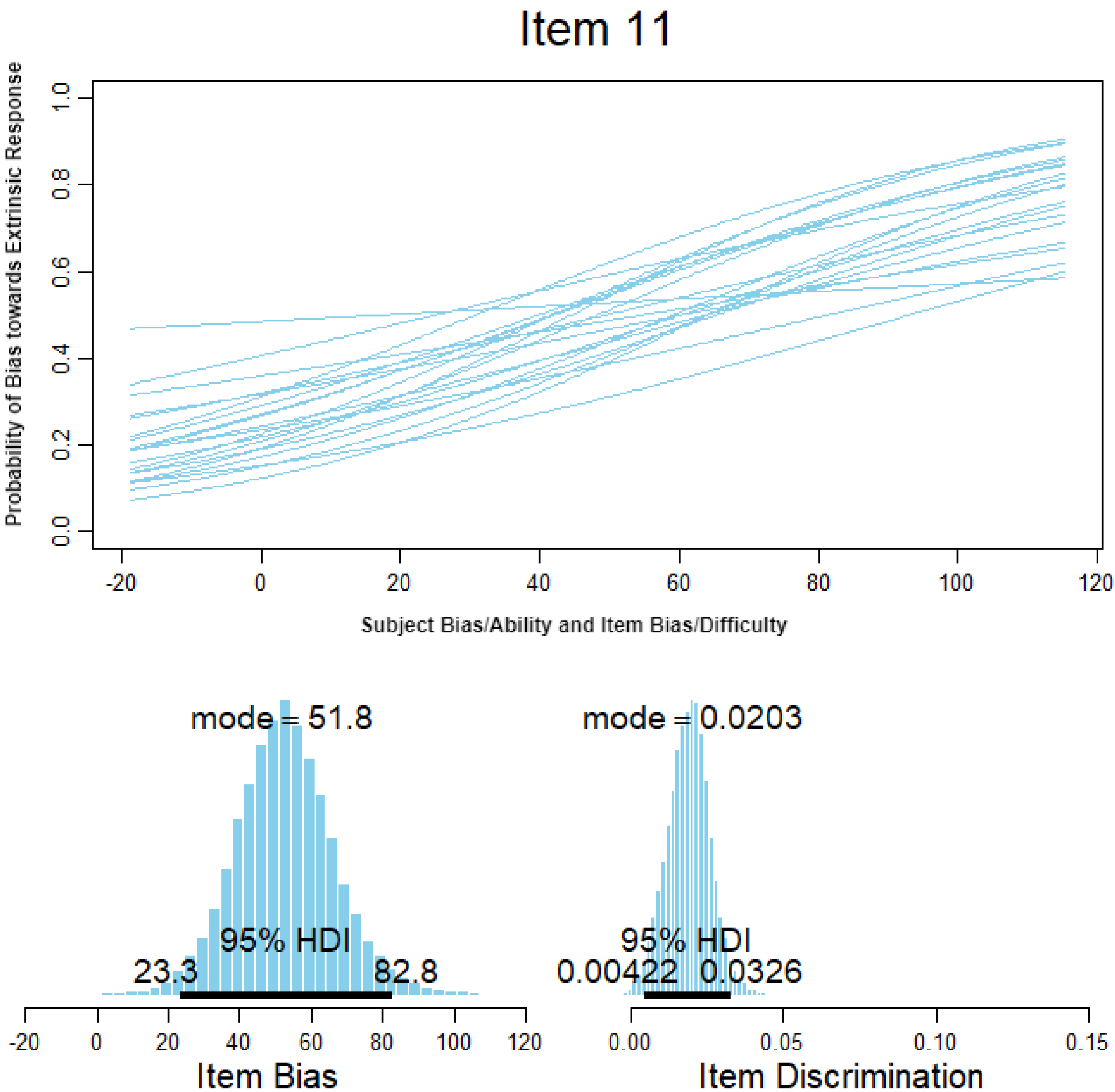
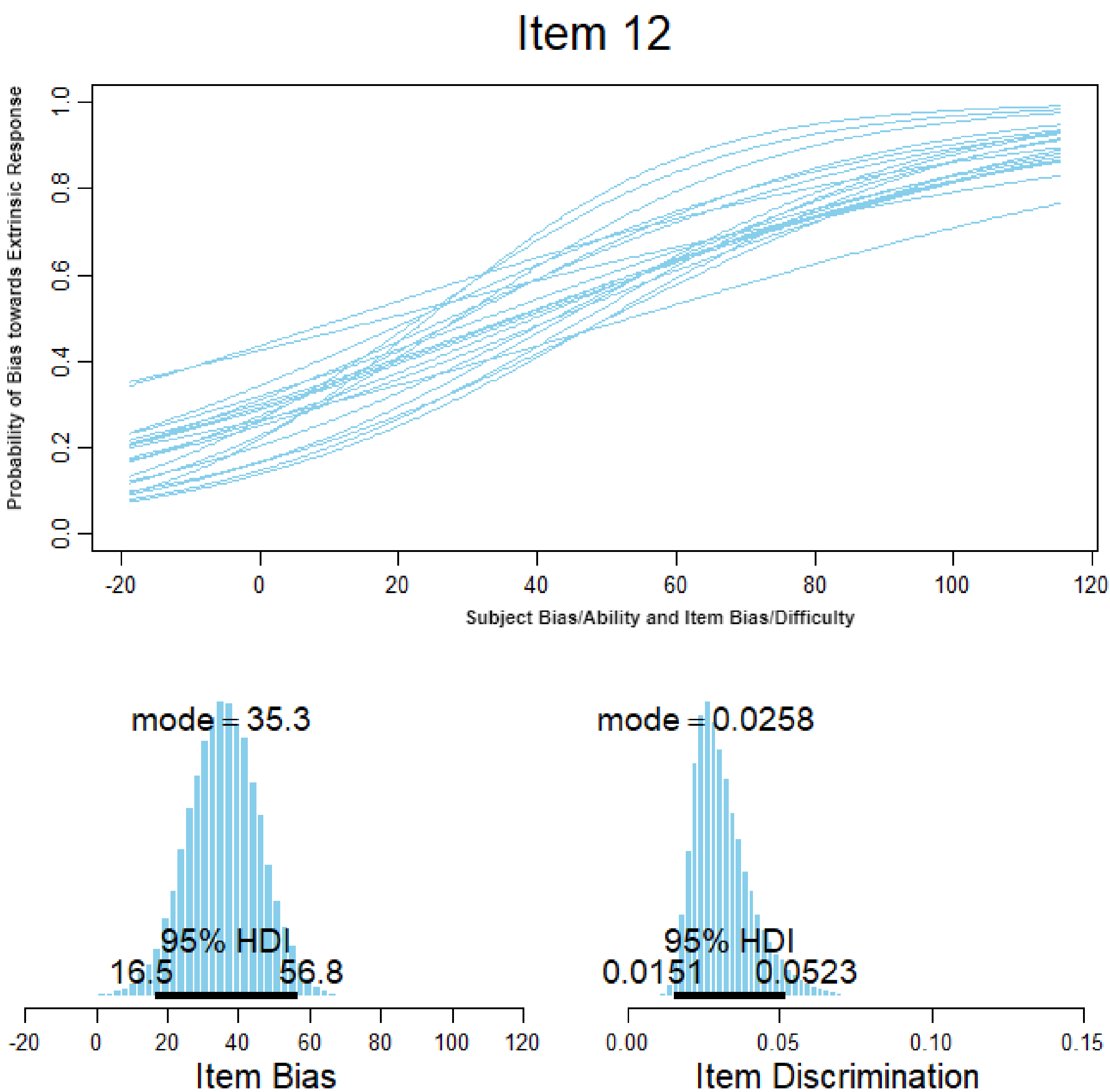


Figure 12. Bias and discrimination in Item 12.



Appendix B

Item 1:

Chemists working in the humid jungle of Cambodia were looking to develop a new pain reliever using extracts from local plants -- Globba graminifolia and Gardenia godefroyana. In a strange turn of events, these chemists found that when they attempted to develop a pain reliever using these extracts, it led to a result that completely defied their expectations. Instead of creating a low-cost pain reliever the extracts gave rise to a chemical that produces muscle spasms. This is despite the fact that these scientists had more than 40 years of experience between them.

Item 2:

Chemists in a lab high in the Colorado Rockies were investigating the possibility of storing hydrogen atoms in lithium nitride crystals. In a strange turn of events, these chemists found that when they attempted to store the hydrogen atoms in the lithium nitrides crystalline structures, it led to a result that completely defied their expectations. Instead of the lithium nitride structure storing 15% of hydrogen atoms, the crystaline structures stored 0% of hydrogen atoms. This is despite the fact that these scientists had more than 40 years of experience between them working with lithium nitride.

Item 3:

Biologists in a lab high in the Colorado Rockies were investigating the possibility of developing a new drug for lowering acetylcholine levels. In a strange turn of events, these biologists found that when they attempted to lower acetylcholine levels in the brain of the Wistar rat with the drug they developed, it led to a result that defied their expectations. Instead of the drug reducing acetylcholine levels in the rat by 85% as they predicted, the drug reduced the Wistar rats' acetylcholine levels by 60%. This is despite the fact that these scientists had more than 40 years of experience between them developing drugs.

Item 4:

A group of experienced biologists wanted to observe the rare *Nyctereutes* dogs' mating behavior. These biologists were working in the forests of Siberia, the *Nyctereutes* dogs' habitat. Typically, dogs have multiple mates over the course of their lives. Surprisingly, these biologists observed that the *Nyctereutes* dogs maintained one life-long mate for most of their lives.

Item 5:

A biologist conducted the following study: The biologist compared the amount of carbon in a *Viridiplantae's* leaves under two circumstances -- when the plant was inside an empty sealed vessel and when the plant was placed in a planter. The biologist noted that the leaves of a *Viridiplantae* contained more carbon when the plant was placed in the planter. This result was quite striking to the biologist.

Item 6:

Physicists working in an underground lab in Colorado were testing how graphene holds liquids. In a strange turn of events, these physicists found that when they fully submerged a cup made of graphene into water, and flipped the cup upside down, it led to an outcome that defied their expectations. When the cup was lifted out of the water upside down, the water remained suspended in the cup instead of falling out. This is despite the fact that these physicists had more than 40 years of experience working with graphene.

Item 7:

Physicists working in a lab in Norway were testing the effects of magnetic fields on transistors. In a strange turn of events, these physicists found that when a magnet was positioned near a transistor, it led to an outcome that completely defied their expectations. Instead of the transistor malfunctioning, it continued to function properly. This is despite the fact that these scientists had more than 40 years of experience working with transistors.

Item 8:

A physicist performed the following experiment: They fired a cannonball at a target 1000 meters to the north. The physicist noticed that the cannonball curved right of the target repeatedly even though there was no wind that day and the cannon was perfectly straight. This result was quite striking to the physicist.

Item 9:

A group of experienced physicists were looking to create thermal solar panels for use in urban environments. These physicists were conducting field measurements of experimental solar panels in a densely populated square of Beijing, China. Typically, their panels can convert 75% of the energy they absorb into usable power. Surprisingly, when they measured the conversion of energy into usable power, they noticed that the experimental solar panels were converting nearly 90% of the power they received into usable energy.

Item 10:

Chemists have discovered something astonishing about nitrogen triiodide, a substance that can only be experimented with under tightly controlled conditions. Chemists observed nitrogen triiodide turn into a iodine solid when coming into contact with other objects. A solid form of nitrogen triiodide puzzled chemists because they initially theorized that this chemical would combust before solidifying.

Item 11:

A chemist conducted the following experiment: They applied heat to a piece of manganese and then weighed it, noting that the manganese had gained mass. This result was quite striking to the chemist.

Item 12:

Physicists have discovered something astonishing about molybdenite, which can be experimented with most easily in water. Physicists observed molybdenite clumping together when placed in water. This puzzled physicists because they theorized that molybdenite would remain separated.

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Curriculum Vitae

Education

- **M.S., Psychology**, Syracuse University (SU).

(Fall 2022)

- **B.Sc., Cellular & Molecular Biology** (2016), Ferdowsi University of Mashhad (FUM), Mashhad, Iran, Overall GPA: 3.36/4 or 16.16/20 with 137 credits, CGPA: 3.66/4.33 with 104 credits (excluding general subjects)
- **Pre-university Certificate, Mathematics & Physics** (2008), Imam-Reza Pre-university, Mashhad, Iran, Final GPA: 3.8/4
- **High School Diploma, Mathematics & Physics** (2007), Imam-Reza High School, Mashhad, Iran, Final GPA: 3.95/4

Research Interests

. Philosophy of Information

. Cognitive Science

. Philosophy & Methodology of Psychology

Academic Activities

- **Master's Thesis:** "Does working memory predict preference to use inherent explanations in scientific observations?

A Bayesian Item Response Theory Approach", under the supervision of Dr. Michael Kalish (Fall 2022).

- **Research Assistant**: "The Relationship between Cognitive Aging and the Tendency to Create and Evaluate Explanations," under the supervision of Dr. Jefferey Zemla, (Summer 2021).
- **First-Year Research Project**: "A Retrospective Evaluation of Past Hedonic Experiences: How the Rate of Change in Valence and Intensity Predicts Future Response to a Previously Experienced Episode," under the supervision of Dr. Lael J. Schooler (Fall 2020).
- **Research Assistant**, "The Role of Cognitive Processing on Dieter's Success or Fail," under the supervision of Dr. Javad S. Fadardi. Published in the *Journal of Cognitive Psychology*, Iran, (2016-2017).

- **Bachelor Thesis**: “A Review of Cognitive Processes of Forgetting with a Focus on Defense Mechanisms,” under the supervision of Dr. Masoud Fereidoni, FUM, (2015-2016).
- **Working and Research**: “The Effect of Everolimus on Glutamate-induced Cytotoxicity in PC12 Neurons,” under the supervision of Dr. Hamid Reza Sadeghnia, Mashhad University of Medical Science, department of neuropharmacology. Mashhad, Iran (Fall 2015).
- **Cooperation in Research**: “The Effect of Arsenic on the Chromosome Health in Blood Cells,” under the supervision of Dr. Farhang Haddad and Dr. Zahra Ghasemzadeh, FUM (Winter 2012).

Conference Proceedings

- “A Higher Purpose: Towards a Social Justice Informatics Research Framework” Zhasmina Tacheva, Syracuse University; Sepideh Namvarrad, Syracuse University; Najla Almissalati, Syracuse University

Skills

- **Computer Skills**: MS Word, MS Excel, MS Power Point, MS Access
- **Programming Languages**: R, Python, SPSS, JavaScript (JSPsych Library).
- **Cell & Molecular Biology and Genetics Techniques**: PCR, DNA Extraction, Mouse handling

Work Experience

- **Main Instructor,** Cognitive Psychology (PSY322), Syracuse University, (Summer 2022), Responsibilities: Developing and delivering lectures, leading class discussions, and grading student assignments.
- **Teaching Assistant**, Foundations of Human Behavior (PSY205), Syracuse University, (Spring 2020, Fall 2021, Spring 2022, Fall 2022), Responsibilities: Teaching 3 to 4 Recitation sections, including developing and delivering lectures, facilitating class discussions, and grading student assignments.
- **Teaching Assistant and Guest Lecturer**, Cognitive Psychology (PSY322), Syracuse University (Fall 2020 – Spring 2021), Responsibilities: Teaching 3 to 4 Recitation sections, including developing and delivering lectures and grading student assignments.
- **Member of Zamime Business Development and Software Design Center;** Responsibilities: Research, Translation, and Content Creation for Websites and Applications in the fields of Psychology, Economics, and General Health (2018 June-2018 December)

- **Freelance English Teacher** (2009-2019).
- **Freelance Math & Biology Teacher**: Preparing students for Iran's University Entrance Exam, (2009-2014).
- **Member of the Student Scientific Committee (Biology, Faculty of Sciences, FUM):** Responsibilities: Leading problem-solving sessions and discussions.
- **Member of the Student Organization, Academic Center Education Culture & Research of Mashhad, FUM:**

Responsibilities: Holding undergraduate workshops and discussions in social science and the humanities (2014-2016).

Course Work

- **PSY655: Statistics and Research Design I**
- **PSY756: Statistics and research Design II**
- **PSY854: Bayesian Statistics**
- **PSY612: Advanced Experimental Psychology**
- **PSY736: Advanced Introduction to Cognitive Psychology**
- **PSY777: Advanced Cognitive Neuroscience**
- **IST707: Applied Machine Learning**
- **PSY605: Teaching of Psychology**

Non-Profit and Social Work

- **Member of the Editorial Board and Author**, *Baztab:* A Cultural and Political Student Magazine, FUM (2014-2016)
- **Member of the Editorial Board and Author**, *Arghanoon*: An Art and Music Student Magazine, FUM (2016)
- **Member of *Imam-Ali* Popular Students Relief Society (IAPSRS)**, Mashhad, Iran (2015- present)

Main responsibility: Mathematics, English, and Art Instructor

Honors and Awards

- Ranked among 0.1% in Iran's Public Graduate Universities Entrance Exam in Psychology (2016)
- Ranked among 0.5% Iran's Public Undergraduate Universities Entrance Exam (2011)

Language Skills

. **Persian**: Native

. **English**: Fluent