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PAPER

Logic and belief across the lifespan: the rise and fall of belief inhibition during syllogistic reasoning

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Abstract

Popular reasoning theories postulate that the ability to inhibit inappropriate beliefs lies at the heart of the human reasoning engine. Given that people's inhibitory capacities are known to rise and fall across the lifespan we predicted that people's deductive reasoning performance would show similar curvilinear age trends. A group of children (12-year-olds), young adults (20-year-olds), and older adults (65+-year-olds) were presented with a classic syllogistic reasoning task and a decision-making questionnaire. Results indicated that on syllogisms where beliefs and logic conflicted, reasoning performance showed the expected curvilinear age trend: Reasoning performance initially increased from childhood to early adulthood but declined again in later life. On syllogisms where beliefs and logic were consistent and sound reasoning did not require belief inhibition, however, age did not affect performance. Furthermore, across the lifespan we observed that the better people were at resisting intuitive temptations in the decision-making task, the less they were biased by their beliefs on the conflict syllogisms. As with the effect of age, one's ability to override intuitions in the decision-making task did not mediate reasoning performance on the no-conflict syllogisms. Results lend credence to the postulated central role of inhibitory processing in those situations where beliefs and logic conflict.

Introduction

Human thinking often relies on prior knowledge and intuitive beliefs. Sometimes these intuitions can provide us with valid problem solutions but they can also bias our judgment. For example, negative stereotypical beliefs about Africans or Muslims can easily disturb an employer's evaluation of an applicant's job performance. Likewise, when asked whether taking the plane is safer than taking the car many people overestimate the risks of flying because of the dreadful images of crashing planes and terrorist attacks they intuitively think of. Hence, the problem is that belief-based reasoning will often cue erroneous responses that conflict with the logically appropriate response. Popular dual process theories (e.g. Evans, 2003, 2007; Sloman, 1996; Stanovich & West, 2000) have postulated that a demanding logical reasoning process will need to override the intuitive response and inhibit people's belief-based reasoning in these cases. Hence, it is claimed that sound reasoning in the case of a belief–logic conflict requires that people temporarily discard their beliefs and refrain from taking them into account (e.g. De Neys, Schaeken & d'Ydewalle, 2005; Handley, Capon, Beveridge, Dennis & Evans, 2004; Houdé, 1997; Markovits & Doyon, 2004; Moutier, Plagne-Cayeux, Melot & Houdé, 2006). Such a belief inhibition or decontextualization process is considered one of the cornerstones of the human reasoning ability (e.g. Stanovich & West, 2000).

In the developmental literature, models that feature the key role of inhibitory processing capacities have become increasingly popular (e.g. Harnishfeger & Bjorklund, 1994; Houdé, 2000; Dempster & Brainerd, 1995; Dempster & Corkill, 1999). People's general ability to effectively suppress salient stimuli or associations that are not appropriate to the task at hand is believed to be a major factor in the development and decline of cognitive abilities. Developmental studies clearly indicate that this capacity for inhibition shows a curvilinear age trend: Basic inhibition tests where people have to resist prepotent, habituated responses established that after an initial improvement from childhood to late adolescence, inhibitory performance declines again in later life (e.g. Bedart, Nichols, Barbosa, Schachar Logan & Tannock, 2002; Christ, White, Mandernach & Keys, 2001; Dempster, 1992). This lifespan pattern has been linked to specific neurological maturation and involution of the frontal lobes (e.g. see Aron, Robbins & Poldrack, 2004; Casey, Tottenham, Liston & Durston, 2005).

The curvilinear age trend in the development of inhibitory capacities points to an interesting test for the postulated role of the belief inhibition process in reasoning. If the ability to inhibit the belief-based system is indeed crucial for sound reasoning then the development of people's reasoning performance should also show a similar age trend. The increased inhibitory capacities should help to boost logical reasoning performance over the childhood years to early adulthood. Because of the declined inhibitory

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efficiency in later adulthood, the reasoning performance of older adults should start to decrease again.

Deductive reasoning studies on belief bias in syllogistic reasoning have presented some partial evidence for this claim. Consider, for example, the following syllogism: 'All mammals can walk. Whales are mammals. Therefore, whales can walk.' The conclusion is valid but unbelievable. Although standard logic tells us to accept the conclusion, many people will be biased by their beliefs and tend to reject it simply because it is unbelievable. Sound reasoning thus requires that this prepotent belief-based response is inhibited. Consistent with the predictions based on the development of inhibitory capacities, Kokis, Macpherson, Toplak, West and Stanovich (2002) showed that when 10- and 13-year-olds solved these problems, the older children were less biased by their beliefs. In a related study, Gilinsky and Judd (1994) also showed that older adults were more biased than younger ones when solving similar problems.

When taken together, the Kokis *et al.* (2002) and Gilinsky and Judd (1994) findings fit with the expected curvilinear age trend in reasoning performance. However, developmental psychologists have raised serious objections against the practice of inferring general lifespan trends by simply combing partial data from different studies (e.g. Christ *et al.*, 2001). The present study sidesteps these complications by directly comparing the reasoning performance of the different age groups in a single study. A group of children (12-year-olds), young adults (20-year-olds), and older adults (65+-year-olds) were presented with a syllogistic reasoning task. For half of the problems, referred to as *conflict* syllogisms, the logical status of the conclusion conflicted with its believability as in the above example. For the other half of the problems, referred to as *no-conflict* syllogisms, the logical status of the conclusion was consistent with its believability.

The inclusion of the no-conflict items allows a crucial validation of the belief inhibition claim. Dual process theories do not postulate that belief-based thinking needs to be prevented all the time. Belief-based reasoning is not always wrong. In the no-conflict syllogisms, for example, our beliefs are not inappropriate. Consider the following example: 'All mammals can walk. Apes are mammals. Therefore, apes can walk.' The logical structure of this argument is the same as in the first example. However, now the conclusion is also believable. Hence, in this case beliefs and logic do not conflict. Responses can be based on mere intuitive thinking without any need to engage in more demanding processing and inhibit the belief-based system. This implies that inhibitory capacities should not always mediate reasoning performance. More specifically, the belief inhibition hypothesis entails that the effects of age and problem type will interact. Young adults' superior inhibition capacity should allow them to outperform other age groups on those reasoning problems where beliefs need to be inhibited (i.e. on conflict syllogisms). However, on no-conflict problems all age groups should benefit from the non-demanding belief-based reasoning to solve the problem. Hence, if the age trends on the conflict problems specifically result from developmental changes in inhibitory processing capacity, age should not affect the reasoning performance on the no-conflict problems.

Together with the syllogistic reasoning task, participants were also presented with a set of classic judgment problems from the decision-making literature (e.g. covariation detection, gambler's fallacy, and class-inclusion problems). In all these tasks sound decision-making required that a salient but inappropriate intuitive response was inhibited. The deductive reasoning and decision-making fields remain somewhat disparate (Evans, 2002, 2003). Reasons for the sharp division are not very clear, but they may in part have to do with the different normative theories the two domains draw upon; formal logic for deductive reasoning and probability theory for decision-making. We nevertheless hypothesized that the performance on the decision-making task might give us a general indication of an individual's capacity to resist tempting but erroneous intuitions in a reasoning context. This implies that the performance on the decision-making task would allow us to predict an individual's performance on the deductive reasoning task. Moreover, if the decision-making index can serve as a distant but specific proxy of inhibitory efficiency, the predictive power should be restricted to syllogisms with belief–logic conflict. Indeed, on the no-conflict problems, inhibition is not required and individual differences in inhibitory capacity should not mediate performance.

A final prediction concerns the predictive power of the decision-making index in different age groups. Overall, deductive reasoning performance on the conflict syllogisms should show a curvilinear age trend. However, if the deductive reasoning performance across the lifespan is determined by the outcome of the belief inhibition process, inhibitory capacity should mediate performance in all age groups. Bluntly put, although children should reason more poorly than young adults, children with high inhibitory capacities should still outperform children with lower capacities.

Experiment

Method

Participants

A total of 88 individuals from three age groups were recruited: 35 children (M = 12.5 years, SD = .51, 63% female), 28 young adults (M = 19.04, SD = 1.89, 67% female), and 25 older adults (M = 66.46, SD = 7.38, 52% female). The children were drawn from the seventh grade of a public high school that serves families from the lower-middle to middle socioeconomic classes. Young adults were undergraduate psychology students at the University of Leuven. Older adults were retired citizens who were enrolled in a program at the University of Leuven that gives senior citizens the opportunity to attend a number of university courses. Mean years of education in the consecutive age groups was 6.97 (.32), 13.43 (1.35), and 14.07 (2.17), respectively.

Material

Deductive reasoning task. The syllogistic reasoning task was based on Sá, West and Stanovich (1999) and De Neys (2006a). Participants evaluated eight conditional syllogisms. Four of the problems had conclusions in which logic was in conflict with believability (i.e. *conflict items*, two items with an unbelievable-valid conclusion, and two items with a believable-invalid conclusion). For the other four problems, the believability of the conclusion was consistent with its logical status (i.e. *no-conflict items*, two items with an unbelievable-invalid conclusion, and two items with a believable-valid conclusion[1]). Hence, believability and validity of the conclusions were fully crossed. The following item format was adopted:

Premises: All fruits can be eaten.
Hamburgers can be eaten.
Conclusion: Hamburgers are fruits.

1. The conclusion follows logically from the premises.
2. The conclusion does not follow logically from the premises.

Care was taken to select material that all age groups would be familiar with. As in the above example, the conclusions always concerned cases where a well-known instance matched or mismatched a well-known category (see Appendix A for a complete overview of the adopted material). Instructions, which showed an example item, emphasized that the premises should be assumed to be true and that a conclusion should be accepted only if it followed logically from the premises.

Decision-making questionnaire. Participants solved three classic decision-making problems (see Appendix B for an overview). In all problems correct decision-making required that a salient but inappropriate intuitive response was inhibited. The first item in the questionnaire was a covariation detection problem based on the work of Wasserman, Dorner and Kao (1990). The simulated problem for the participants was to determine whether a new therapy improved the condition of depression. The covariation information concerned the number of patients who received the new and old therapies and the number of patients who showed improvement. In this task, correct responding depends on comparing ratios and resisting the intuitive tendency to simply focus on absolute numbers. Participants entered their response on a 5-point scale. Following Stanovich and West (1998) and Klaczynski (2001), ratings of 4 or 5 (i.e. 'the old therapy is slightly or much better than the new one') were deemed correct.

The second item was a gambler's fallacy problem based on Kahneman, Slovic and Tversky (1982). Participants were given information about the likelihood of an event (i.e. 50% of the babies that are born in a hospital are boys) and information about a recent series of outcomes (e.g. the last three babies that were born in the hospital were boys). They were asked how likely it was that the next baby would be a boy. Correct decision-making on the gambler's fallacy problem requires that people override the impression that after a 'run of boys' the equilibrium will be repaired and the next baby will be a girl. Participants were given a range of response options from 0 to 100%. The correct response was to select the alternative that matched the objective probability (i.e. 50%).

The last item was a class-inclusion problem that was based on De Neys' (2006b) adaptation of Reeves and Lockhart's (1993) 'Job' problem. In this problem participants have to rank-order the probability of two individual events and the conjunction of the events.[2] The probability of a conjunction of two events cannot exceed that of either of its constituents. Nevertheless, many people report having the strong feeling that the conjunction is most likely. Responses were scored as correct if participants managed to refrain from this intuitive impression and ranked the conjunction as less likely than either of its components.

Procedure

Participants were tested in small groups of 2–12 participants. All participants started with the deductive reasoning task. Problems were printed one to a page in a booklet. The first page of the booklet stated the instructions. After completing the deductive reasoning task, participants had a short break and then were presented with the decision-making questionnaire. All problems were presented in the same, randomly determined order to minimize any measurement error due to a possible participant by order interaction.

Results

Deductive reasoning performance

For each participant we calculated the average number of logically correct responses on the four conflict and four no-conflict syllogisms. The averages were entered in a 3 (age group, between-subjects) × 2 (conflict, within-subjects) analysis of variance. Figure 1 presents an overview of the findings.

There were main effects of age, $F(2, 85) = 3.26$, $p < .05$, $\eta_p^2 = .07$, and conflict, $F(1, 85) = 78.52$, $p < .001$, $\eta_p^2 = .48$,

[1] Valid problems were *Modus Ponens* (MP) and *Modus Tollens* (MT) inferences. Invalid problems were Affirmation of the Consequent (AC) and Denial of the Antecedent (DA) inferences.

[2] A nice illustration of the somewhat artificial boundaries between reasoning and decision-making is the fact that class-inclusion problems were originally introduced in the developmental field by Piaget as deductive reasoning tasks (Inhelder & Piaget, 1964).

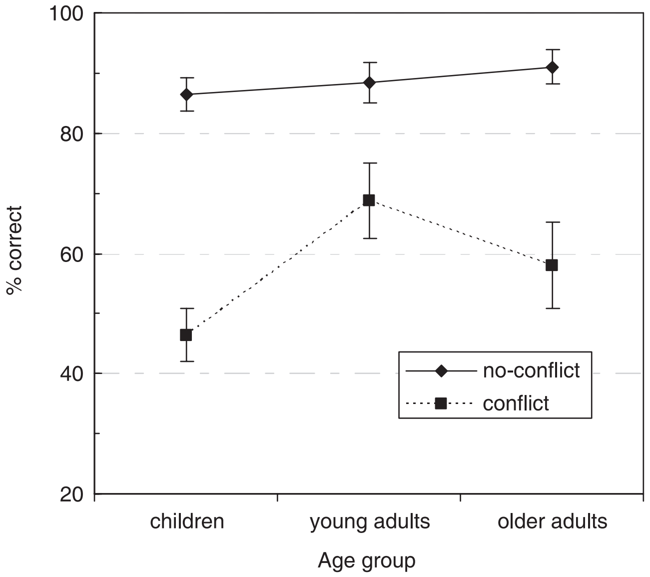

Figure 1 *Syllogistic reasoning performance on conflict and no-conflict syllogisms across the lifespan. Error bars are standard errors.*

and the two factors also interacted, $F(2, 85) = 3.11$, $p < .05$, $\eta_p^2 = .07$. As expected, on the no-conflict syllogisms where beliefs and logic did not conflict participants had little trouble in reasoning correctly and age did not affect performance, $F(2, 85) < 1$. However, as Figure 1 shows, there was a clear age effect on the conflict syllogisms, $F(2, 85) = 3.87$, $p < .03$, $\eta_p^2 = .08$. As expected, a trend analysis showed that the effect had a curvilinear, quadratic nature, $F(1, 85) = 5.14$, $p < .03$, $\eta_p^2 = .06$.

Decision-making questionnaire

Participants' performance on each of the three problems was combined into a single decision-making index score. For each correct response participants received 1 point. This resulted in a decision-making index score ranging from 0 to 3. As Table 1 indicates, the index score (and the performance on the individual problems) showed a curvilinear age trend. Young adults were doing a better job in overcoming the tempting but erroneous intuitive beliefs on the decision-making problems than younger children and older adults, $F(1, 85) = 4.5$, $p < .05$, $\eta_p^2 = .05$. However, the crucial question is whether the capacity to resist inappropriate intuitions and solve the decision-making problems allows us to predict participants' ability to overcome belief bias during deductive reasoning. To address this question we compared the syllogistic reasoning performance for two capacity groups based on a median split of the decision-making index score in each age group. This capacity factor was entered in the 2 (capacity group) × 3 (age group) analysis of variance on the syllogistic reasoning scores. Figure 2 shows the results.

Table 1 *Performance on the decision-making questionnaire across the lifespan*

	Age group					
	Children		Young adults		Older adults	
Tasks	Mean	*SD*	Mean	*SD*	Mean	*SD*
Covariation detection	.69	.47	.71	.46	.56	.51
Gambler's fallacy	.54	.51	.68	.47	.56	.51
Class-inclusion	.63	.42	.79	.42	.48	.51
Decision-making index	1.86	.91	2.18	.86	1.6	1

As Figure 2 indicates, performance on the no-conflict syllogisms did not depend on the capacity factor. Indeed, on the no-conflict syllogisms neither the main effect of capacity nor its interaction with age reached significance, all *F*s < 1. However, on the conflict syllogisms there was a clear main effect of capacity, $F(1, 82) = 4.28$, $p < .05$, $\eta_p^2 = .05$, and this effect was not qualified by an interaction with age group, $F(2, 82) < 1$. As Figure 2 shows, across the lifespan, being better at resisting tempting intuitive thinking during decision-making also resulted in a better logical reasoning performance when beliefs and logic conflicted.

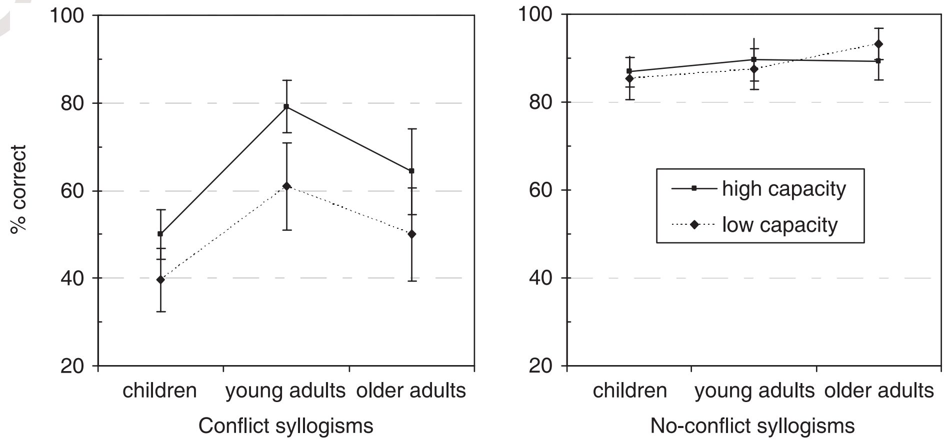

Figure 2 *Syllogistic reasoning performance across the lifespan as a function of one's capacity to resist intuitive thinking in the decision-making tasks. Error bars are standard errors.*

General discussion

The present study showed that when sound reasoning required that people refrained from taking salient beliefs into account, syllogistic reasoning performance rose and fell across the lifespan. Consistent with the development of inhibitory capacities, older adults' reasoning performance declined after it initially increased from childhood to early adulthood. On the no-conflict problems where beliefs and logic were consistent and sound reasoning did not require belief inhibition, age did not affect the reasoning performance. As expected, the decision-making questionnaire further indicated that the better people were at resisting intuitive temptations in the decision-making tasks, the less they were biased by their beliefs on the conflict syllogisms. This relation held for all age groups. As with the effect of age, one's ability to override intuitions in the decision-making task did not mediate reasoning performance on the no-conflict syllogisms. Taken together, these results lend credence to the postulated central role of a belief inhibition process during reasoning.

Although the present findings fit with the inhibition framework, it might be tempting to suggest alternative accounts. For example, one could try to attribute the age trends to the development and decline of a general, formal reasoning ability rather than to a more specific belief inhibition factor. Likewise, one might suggest that the predictive power of the decision-making index simply results from the fact that it taps such a general reasoning ability: The better one is at reasoning in a decision-making context, the better one will be at reasoning in a deductive reasoning task without any need to postulate an additional belief inhibition process. In theory, such a general reasoning ability explanation would be more parsimonious than the inhibition hypothesis. However, the crucial point is that age and performance in the decision-making tasks did not always mediate reasoning performance. The crucial effects depended on the presence of a belief–logic conflict. Consistent with the predictions from the dual process framework, age and the capacity factor only mattered when solving conflict syllogisms where sound reasoning required overriding inappropriate beliefs. This interaction is hard to reconcile with any model that neglects the specific role of inhibitory processing in reasoning.

It will be clear that in order to initiate an inhibition process people need to be able to detect a conflict between the logically appropriate response and the belief-based response (De Neys & Glumicic, 2008). This requires that people be familiar with the logical principles and beliefs that are triggered in the task in question (e.g. Brainerd & Reyna, 2001; Reyna, Lloyd & Brainerd, 2003). If these conditions are not met, findings will be affected. For example, in the developmental literature it has sometimes been reported that children behave more logically than young adults on a number of reasoning tasks (e.g. Jacobs & Potenza, 1991; Klaczynski, 2001). Jacobs and Potenza, for example, studied children's performance on the notorious base-rate neglect problem (e.g. the lawyer–engineer problem; Kahneman & Tversky, 1973). In this task, salient, stereotypical information is pitted against more reliable statistical base-rate information. When a person is described as a stereotypical engineer, adults will erroneously conclude that it is an engineer although they were told that the person was drawn from a sample where there were twice as many lawyers as engineers. Adults' stereotypical beliefs thus bias sound decision-making. Jacobs and Potenza observed that 6-year-old children easily outperformed adults on this task despite their less developed inhibitory capacities. As Kokis *et al.* (2002) argued, the finding that younger children err less frequently on these problems is not problematic or surprising because stereotype knowledge is typically also less developed for children. Since children lack knowledge of many social stereotypes, they will be less biased by the beliefs that are impeding adults' reasoning. In other words, what is a conflict problem for adults will be a no-conflict problem for children where inhibitory processing is simply not required. In the present study, such complications were avoided by using material that was familiar to all ages groups. This is a crucial control when adopting a developmental perspective to examine the role of inhibitory processing. Nevertheless, it should be clear that the present focus on inhibition does not downplay the role of other developmental factors. As indicated above, at any single point in time reasoning performance can be characterized as an interplay between beliefs, logical knowledge, and inhibitory capacities. It is evident that the development of children's semantic knowledge base, for example, will have a crucial impact on their ability to rely on belief-based reasoning.[3] The crucial point, however, is that whenever these same beliefs start to conflict with logical considerations, one's reasoning performance will be determined by the capacity to inhibit belief-based reasoning.

In the introduction we noted that the development of inhibitory capacities has been linked to specific neurological maturation and involution of the frontal lobes. In particular, the activation of the lateral prefrontal cortex is believed to be crucial for successful inhibition (Aron *et al.*, 2004). It is interesting to note that recent brain imaging studies with young adults indicate that dealing with belief–logic conflict during reasoning and decision-making recruits this very same brain area (e.g. De Neys, Vartanian & Goel, 2008; Goel & Dolan, 2003; Houdé, 2007; Houdé & Tzourio-Mazoyer, 2003). A speculative idea for future research is to examine the lateral prefrontal cortex activation during reasoning with different age groups. Given the results and available imaging findings one might speculate that not only the reasoning performance *per se* but the very involvement of the lateral prefrontal 'inhibition' region shows a curvilinear age pattern.

[3] This issue underscores the point that belief bias is essentially semantic in nature. As one reviewer noted, one interesting line for future research is to test whether the present findings extend towards biases in other reasoning tasks that are, for example, more perceptual in nature (e.g. matching bias; see Houdé, Zago, Mellet, Moutier, Pineau, Mazoyer & Tzourio-Mazoyer, 2000).

Finally, we want to point out that the present findings present interesting evidence against the popular (but mistaken) characterization of cognitive aging as a simplistic general decline of cognitive abilities. Although performance on the conflict problems decreased in later life, older adults performed on a par with the 45-year-old younger adults on the no-conflict problems. On the no-conflict syllogisms, belief-based reasoning cued the correct response. This suggests that the latter type of reasoning is more resistant to decline in later life than pure logical reasoning. Consequently, it should be clear that the message of the present paper is not simply that older adults reason more poorly than younger adults. The point is that older adults (and younger children) will specifically run into trouble in those situations where beliefs and logic conflict and sound reasoning calls for an inhibition of one's beliefs. Thereby the study helps establish the crucial mediating role of the belief inhibition process in human reasoning and decision-making.

Appendix A

Syllogistic reasoning problems (translated from Dutch)

Conflict syllogisms

All things that have a motor need oil.
Cars need oil.
Cars have a motor. (Invalid-Believable)

All unemployed people are poor.
Kim Clijsters is not unemployed.
Kim Clijsters is not poor. (Invalid-Believable)

All mammals can walk.
Whales are mammals.
Whales can walk. (Valid-Unbelievable)

All animals like water.
Cats do not like water.
Cats are not animals. (Valid-Unbelievable)

No-conflict syllogisms

All guns are dangerous.
Swords are dangerous.
Swords are guns. (Invalid-Unbelievable)

All things made out of wood can be used as fuel.
Gasoline is not made out of wood.
Gasoline cannot be used as fuel. (Invalid-Unbelievable)

All birds have feathers.
Eagles are birds.
Eagles have feathers. (Valid-Believable)

All cows have four legs.
Snakes do not have four legs.
Snakes are not cows. (Valid-Believable)

Appendix B

Decision-making questionnaire (translated from Dutch)

Covariation detection task

A doctor developed a new depression therapy. The doctor wants to test the new therapy. In an experiment, 16 patients received the new therapy. A control group of eight patients were treated with the traditional therapy. After 6 months the therapies were evaluated by checking how many patients' condition improved in each group. These are the results

	Improvement	No improvement
New therapy	10	6
Traditional therapy	6	2

Evaluate the new therapy on the basis of these findings. Circle your response:

1. The new therapy is much better than the traditional one
2. The new therapy is slightly better than the old one
3. Both therapies are equally good
4. The traditional therapy is slightly better than the new one
5. The traditional therapy is much better than the new one

Gambler's fallacy task

In a hospital 50% of the babies that are born are girls. One specific day eight babies have been born so far. The gender of the eight consecutive babies was:

1. Girl 2. Boy 3. Girl 4. Girl 5. Boy 6. Boy 7. Boy 8. Boy

How likely is it that the next baby born will be a boy? Circle your response.

1. 100%
2. 88%
3. 60%
4. 50%
5. 40%
6. 12%
7. 0%

Class-inclusion task

Lisa is in her twenties and jobless. She applied for three different part-time jobs. For the dress shop job, there are seven other applicants; for the bookstore job, there are five other applicants; and for the job in the shoe-store, there is only one other applicant.

Please rank the following statements by their probability:

A. Lisa will be offered the job in the shoe-store
B. Lisa will be offered the dress shop job and the job in the shoe-store
C. Lisa will be offered the dress shop job

The most probable statement is: _
The second most probable statement is: _
The least probable statement is: _

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