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Is Inhibitory Control Related to Conflict in Reasoning: A Preliminary Study

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The purpose of this study was to test a belief-bias effect on reasoning in relation to inhibitory control functions and to determine whether inhibition is activated in conflict syllogisms. A total of 85 university students (78% women, M_{age} = 20.51, *SD* = 2.90) participated in the study. We measured three types of inhibition – proactive interference resistance (the Brown-Peterson task and the Cued Recall task), distractor interference control (the Eriksen flanker letters and arrows tasks), and prepotent response inhibition (the Spatial and Numerical Stroop tasks). We administered a syllogistic reasoning task containing no-conflict and conflict syllogisms saturated by socially relevant content. We replicated the typical belief-bias effect on reasoning in invalid/believable conflict syllogisms. All three types of inhibition accounted for reasoning performance only on valid/unbelievable conflict syllogisms, where belief-bias was not registered, indicating an inverse relation of bias and inhibition.

Key words: inhibitory control, syllogistic reasoning, belief-bias

Introduction

Belief-bias is a cognitive distortion in reasoning, which manifests itself when conclusions are evaluated based on their believability rather than their validity, and which has been corroborated in a significant body of research (e.g., Evans, Barston, & Pollard, 1983; Markovits & Nantel, 1989). Contrary to the broadly accepted assumption of syllogistic reasoning as a formal, content-independent process (Revlin, Leirer, Yopp, & Yopp, 1980), numerous studies show that reasoning is not content-in-

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dependent. For example, in a syllogism that reads "All mammals can walk. Whales are mammals. Therefore, whales can walk", the formally valid solution would be to accept the conclusion (as correct), though walking whales contradict common knowledge. Similarly, in the 'roses' syllogism: "All flowers have petals. Roses have petals. Therefore, roses are flowers." (Stanovich & West, 2008, p. 152), common knowledge suggests that roses are indeed flowers; however, accepting this conclusion is not a logically valid response. As demonstrated, in the belief-bias paradigm the content of the reasoning task is at odds with the logically correct response. A great number of belief-bias studies converge to a consistent finding (Evans, 2008) that people tend to accept believable syllogisms more often than unbelievable ones and valid conclusions more often than invalid ones. In addition, a logic-by-belief interaction is also present, i.e. people are more prone to rely on syllogism believability for invalid conclusions than for valid ones.

However, some people seem to be able to resist belief-bias in reasoning. Cognitive reflection and analytic style (Trippas, Pennycook, Verde, & Handley, 2015), successful performance on several versions of the Cognitive Reflection Test (Toplak, West, & Stanovich 2013, 2014), response slowing on reasoning problems (Pennycook, Cheyne, Koehler, & Flugelsang, 2013), working memory capacity, but even more the ability to generate alternatives to premises, or use a counterexample strategy (de Chantal, Newman, Thompson, & Markovits, 2020) were all found to be predictors of less belief-bias.

Belief-bias Effect and Inhibition

But why are some people better at reaching the correct solution regardless of the truthfulness of either the premises or the conclusion? As stated in De Neys and Bonnefon (2013), reasoning biases can be the consequence of a) a storage failure, or a lack of formal logic knowledge, b) a monitoring failure, i.e. the inability to recognize the conflict in reasoning or c) an inhibition failure, or the failure to inhibit first intuitive responses. Therefore, inhibition is one possible mechanism that could explain the differences in belief-bias. Inhibition or inhibitory control is the ability to actively inhibit or delay a dominant response in order to achieve a goal (Morasch & Bell, 2011). According to the dual process framework (De Neys, 2006; Stanovich & West, 2008), and in line with the classic default-interventionist model (Evans & Stanovich, 2013), an implicit, belief-based response governed by the automatic System 1 is the first to emerge in a given situation. In order to reach the correct conclusion, one needs to override this System 1 response by the analytic processing of the deliberate System 2 (Denes-Raj & Epstein, 1994). System 2 manages the reasoning process by decontextualization, i.e. the separation of logic from prior knowledge (De Neys & Van Gelder, 2009). Thus, according to the default-interventionist model, to come to a logically valid conclusion, it would be necessary to exert inhibitory control over what we believe to be generally true (Stollstorff, Vartanian, & Goel, 2012). However, more recent parallel processing models propose that first intuitive responses need not be necessarily overridden, because they are already correct in the intuitive stage. Accordingly, concurrent dual-process models, such as the parallel model (e.g., Sloman, 1996) or the hybrid model (De Neys, 2018), assume that System 2 can be activated immediately (i.e., parallel processing), or that the normative response can be cued by intuitive, logical knowledge-based System 1 (i.e., the hybrid model) in which case inhibitory control is not necessary. For example, using the two-response paradigm (Thompson, Prowse Turner, & Pennycook, 2011) in a series of 12 experiments with nearly 1000 participants, Bago and De Neys (2017) recently found that some participants generated an initial correct response and then confirmed it as their final response after delay. This pattern corresponded to 15% – 42% of trials and demonstrated that some participants are capable of generating System 1 correct responses without having to engage inhibition. However, in most trials (48% – 76% of trials) participants did not manage to correct the initial erroneous response and in few trials (7% – 10% of trials) they overrode the intuitive response, which implies that inhibition was activated.

The findings of Bago and De Neys (2017) are also relevant in the context of our study, since the distribution of inhibition activation patterns they obtained could be an indication of consistent individual differences in inhibitory control. Exploring individual differences in inhibitory control could shed further light on the inhibitory mechanisms in reasoning on no-conflict syllogisms where, theoretically, inhibition is not necessary and on conflict syllogisms where inhibition should be activated. Even though De Neys and Bonnefon (2013) presume individual differences in thinking biases to be less profound than what was previously believed, they still consider inhibition failure the most important domain of reasoning differences. In other words, they believe that reasoners start to diverge not in the formal rules application or the conflict recognition, but in the failure to inhibit their intuitive response.

Inhibition has proven important in numerous studies on reasoning tasks (Frederick, 2005; West, Toplak, & Stanovich, 2008). For example, inhibitory control negatively predicted false belief understanding, i.e. a phenomenon where one acts on beliefs that are false (Blair & Razza, 2007); and positively predicted analogy development (Richland & Burchinal, 2013) and counterfactual thinking in conditionals and syllogisms (Beck, Riggs, & Gorniak, 2009). Inhibition was also moderately associated with performance on incongruent belief-bias syllogisms in a sample of children (Toplak, West, & Stanovich, 2014).

In addition to correlational studies, experimental evidence for inhibition in reasoning was also found demonstrating inhibition failure in a negative priming paradigm in children (Moutier, Plagne-Cayeux, Melot, & Houdé, 2006). Namely, when "common" knowledge was inhibited by priming (making it less accessible) in order to reason correctly on conflict syllogisms, subjects subsequently performed poorer on no-conflict syllogisms where application of previously inhibited knowledge was required. Similarly, De Neys and Franssens (2009) found a significantly prolonged response time on a subsequent lexical decision task for the target words that comprised conflict syllogisms compared with the target words on no-conflict syllogisms, independent of the reasoning skill or reasoning correctness. The authors concluded that all participants tried to inhibit the content of incongruent problems and that inhibition failure does not seem to occur because of a lack of inhibition initiation, which supports the hybrid-model processing, but more so due to a failure to complete the process.

But why are reasoners prevented from completing inhibition? In spite of prior evidence of associations between executive functions and reasoning, the relationship between inhibition and syllogistic reasoning specifically (i.e., the suppression of syllogistic content as a prepotent response when making correctness judgements) remains uninvestigated. The fact that inhibition is activated says nothing about the process of stimulus suppression, i.e. is the syllogistic content perceived only as a distractor, or is it a fast association to past experience that should be disregarded in a task? Testing individual differences in inhibitory control may elucidate the processes at work in reasoning.

According to the Friedman and Miyake (2004) model, there are three mutually related inhibitory control functions: prepotent response inhibition, distractor interference control, and proactive interference resistance. Of the three functions, *prepotent response inhibition* is most related to the intentional suppression of a dominant, automatic response. One would use this inhibitory control function to exert task required goals by stopping an already initiated behavioral response or suspending well acquired habitual reactions like saccadic eye movements, reading, color naming, spatial location coding, etc. The most frequently used paradigms to tap prepotent response inhibition are the *Stroop task* (Stroop, 1935) and the *Stop-signal task* (Logan, 1994). *Distractor interference control* can be defined as the ability to overcome interference from irrelevant stimuli in the external environment. Typical experimental tasks that measure this function require participants to selectively attend only to the stimuli which are relevant to the task at hand (targets) and to suppress attention to all other, irrelevant stimuli (distractors). The most frequently used tasks to measure distractor interference control are the *Eriksen Flanker task* (Eriksen & Eriksen, 1974) and the *Shape Matching task* (DeSchepper & Treisman, 1996). *Resistance to proactive interference* is the ability to resist memory intrusions. It involves suppressing previously acquired information that was once relevant, but subsequently became interfering with the task at hand. The typical resistance to proactive interference experimental paradigm is a memory recall task, structured in several blocks, so that formerly presented stimuli recall interferes with the latter recall. The most commonly used tasks to assess this function are the *Brown-Peterson task* (Kane & Engle, 2000) and the *Cued recall task* (Tolan & Tehan, 1999). Unlike prepotent response inhibition, distractor interference control and proactive interference resistance do not (necessarily) involve an active suppression of a response. On the other hand, these two types of interference differ in that proactive resistance pertains to the information relevant prior to the task, whereas distractor control involves resolving simultaneously presented distractors.

Therefore, in terms of inhibition, the content of syllogistic reasoning could be understood as either an instant distractor, previously acquired experience (e.g., proactive interference or dominant response), or a combination of both.

The Current Study

Considering the lack of previous findings, our aim was to investigate the relationship between syllogistic reasoning performance and different types of inhibitory control. Since we expected to replicate the belief-bias effect, we were interested whether inhibition would be differentially related to conflict and no-conflict syllogisms. Namely, in no-conflict (bias-free) syllogisms, accepting or rejecting the conclusion based solely on its believability is in concurrence with the normatively correct response. Therefore, no inhibition is required in order to provide the correct response, for which reason we expected null correlations between no-conflict syllogism performance and inhibition. Conversely, in conflict syllogisms one needs to inhibit belief-based responding in order to reach the correct conclusion. Thus, we expected to register positive correlations between inhibition and conflict syllogism accuracy. We did not have specific hypotheses regarding the magnitude of correlations with different types of inhibition, since all inhibition aspects could theoretically be expected to be related to performance on conflict syllogisms.

A common problem in the field of executive function assessment is the so-called task impurity problem (Miyake, Freedman, Emerson, Witzki, Howerter, & Wager, 2000). It refers to the fact that executive functions (including inhibition) by definition incorporate other cognitive processes, making it difficult to avoid interference of these independent cognitive processes with task performance. Thus, for a better generalizability of our results, we employed a total of six inhibition tasks – two per each inhibition function.

As far as we are aware, this is the first study to explore the relationship between different types of inhibitory control and no-conflict/conflict syllogistic reasoning.

Method

Sample and Procedure

Eighty-five university students (65 females, mean age M = 20.51, SD = 2.90) participated in the study in exchange for course credit. An a priori power analysis was conducted using G*Power3 (Faul, Erdfelder, Lang, & Buchner, 2007). To test the difference in reasoning performance on two syllogism validity and believability conditions in a repeated measures ANOVA, a total sample of 80 participants is sufficient to detect a medium effect size f = 0.25 with an alpha of .05 and a power of .95. To detect an effect size of 0.30 in a multiple regression with 6 predictors, with alpha = .05 and power = .95 a total sample of 77 participants is required. Thus, our sample was sufficiently large to register moderately small effects.

All participants signed informed consent and were allowed to withdraw from further participation at any point. All tasks were administered in a laboratory or a classroom setting. With the exception of the Brown-Peterson task and Cued recall task, which were administered individually, participants were tested in groups of 20 to 25. Participants completed the tasks in several testing sessions, the majority in the following order: Syllogistic reasoning task (session 1), Numerical Stroop task, Spatial Stroop task (session 2), Eriksen flanker letters task, Eriksen flanker arrows task (session 3), Brown-Peterson task, Cued recall task (session 4). Participants who missed a session could complete the remaining tasks in an additional testing session. Single sessions lasted from 10 to 30 minutes, with a total testing time of about 80 minutes.

Measures

Syllogistic reasoning task (Teovanović, Knežević, & Stankov, 2015). Participants are presented with eight syllogisms and required to verify whether the given conclusion logically follows from the premises and accept the conclusion, if and only if, it can necessarily be derived from the premises. Participants are instructed to only take into account the information given in the premises and assume all the information to be true. The task has four conditions: believable/valid, believable/invalid, unbelievable/valid and unbelievable/invalid, with two syllogisms per condition. The examples of the tasks are given in Table 1.

This task was administered in two paper-and-pencil parallel forms, where, due to the physical proximity of the participants, half the students reasoned on form A and the second half on form B of the task. There were no differences in performance on the two parallel forms $t(81) = -1.18$, $p = .24$. In this study we calculated separate scores for each of the four syllogism types, with scores ranging from 0 to 2. A total reasoning score can also be calculated (with a maximum of 8), as well as scores for no-conflict (valid/believable and

Table 1 *Examples of syllogistic tasks used in the study*

no-conflict syllogisms	
valid/believable	invalid/unbelievable
Premise 1: All birds have feathers.	Premise 1: All vegetables are edible.
Premise 2: Woodpecker is a bird.	Premise 2: Banana is not a vegetable.
Conclusion: Therefore, woodpeckers have feathers.	Conclusion: Therefore, bananas are not edible.
conflict syllogisms	
valid/unbelievable	invalid/believable
Premise 1: All mammals can walk.	Premise 1: All fish have scales.
Premise 2: Whale is a mammal.	Premise 2: Catfish has scales.
Conclusion: Therefore, whales can walk.	Therefore: Catfish is a fish.

invalid/unbelievable) and conflict (valid/unbelievable and invalid/believable) syllogisms (with a maximum of 4). For easier comparison, all scores were expressed as proportions ranging from 0 to 1. Cronbach's alpha reliability for the total score was α = .57.

Proactive interference resistance. We measured proactive interference resistance with the Brown-Peterson task (Kane & Engle, 2000) and the Cued recall task (Tolan & Tehan, 1999). Both tasks comprise multiple lists of words that participants need to memorize, presented in such a way that the words on the previous lists interfere with recall of the words on the current list. The Brown-Peterson task requires free recall of whole lists of words belonging to the same category, while the Cued recall task requires recall of a single word, cued by demanded category. The final measure of proactive interference resistance for each task is a residual score from linear regression where performance on subsequent lists (interference lists) is predicted by performance on the first list (no interference list). This scoring method is used to capture the proactive interference resistance variance, while removing the variance of general memory ability. Reliabilities for conditions (no-interference/interference lists) ranged from α = .33 to .57 (with three to eight items per list).

Distractor interference control. To tap distractor resistance, we used the Eriksen flanker letters task (Eriksen & Eriksen, 1974) and the Eriksen flanker arrows task (Kopp, Mattler, & Rist, 1994). In both tasks, participants are requested to react to a target stimulus (letter or arrow, respectively) appearing at the center of the screen in three different conditions: without distractors – only the target is present, congruent – the target and the distractor stimulus share the same response key and incongruent – the target and the distractor stimulus have the opposite response keys. In all conditions with a distractor, the target is embedded in the distracting stimuli. The difference in reaction times between the condition without distractors and the incongruent condition is considered a measure of distractor interference. Reliabilities for conditions ranged from α = .87 to .91.

Prepotent response inhibition. We assessed inhibition of a prepotent response with the Spatial Stroop Task (Wühr, 2007) and the Numerical Stroop Task (Shilling, Chetwynd, & Rabbitt, 2002). Participants are presented with stimuli (words referring to a spatial direction or a number, respectively) in three conditions: neutral (unrelated stimulus or a stimulus that is not at odds with the prepotent response), congruent (stimulus consistent with the prepotent response) and incongruent (stimulus opposite to the prepotent response). The difference in reaction times between congruent and incongruent conditions is taken as a measure of inhibition. Reliabilities for conditions ranged from α = .82 to .95.

For a detailed description of all inhibitory control tasks, see Supplement 1 (https://osf.io/fze4b/).

Results

Table 2 shows descriptive statistics for all variables registered in the study. Inhibition task distributions were normal, while reasoning distributions showed mostly moderate deviations from normality. Thus, we conducted our further analyses using parametric procedures[1].

[1] We also conducted analyses after applying lg10 transformations to original distributions. The results were almost identical on transformed variables, so we kept the analyses conducted on original data for easier interpretability. The data and syntax for analyses of transformed data are also provided on the research OSF page.

Belief-bias in Reasoning

First, to check for the existence of the belief-bias effect, we conducted a 2 (validity: valid/invalid) x 2 (believability: believable/unbelievable) repeated measures ANOVA. As expected, the analysis revealed a main effect of validity $F(1, 84) = 9.27$, $p = .003$, $\eta^2 = .10$, a main effect of believability $F(1, 84) = 19.15$, $p < .001$, $\eta^2 = .19$, and a validity x believability interaction $F(1, 84) = 15.22$, $p < .001$, $\eta^2 = .15$. The reasoning performance was better on valid (*M* = 0.87, *SD* = 0.02) than invalid (*M* = 0.76, *SD* = 0.03) syllogisms, and unbelievable (*M* = 0.86, *SD* = 0.03) compared to believable syllogisms (*M* = 0.77, *SD* = 0.03).

A simple effects analysis of the validity x believability interaction (Figure 1) showed that participants scored better on valid/believable (*M* = 0.87, *SE* = 0.03) and invalid/unbelievable (*M* = 0.87, *SE* = 0.03) than invalid/believable syllogisms (*M* = 0.66, *SE* = 0.04). There was no difference between valid/believable (*M* = 0.87, *SE* = 0.03) and valid/unbelievable (*M* = 0.86, *SE* = 0.03), *p* = .71, or valid/unbelievable (*M* = 0.86, *SE* = 0.03) and invalid/unbelievable (*M* = 0.87, *SE* = 0.03) syllogisms *p* = .87. Thus, the performance was better on no-conflict than on (one of the forms of) conflict syllogisms, which is in line with general belief-bias expectations. In other words, our results replicated the belief-bias effect usually more pronounced on invalid/believable conflict syllogisms.

The Relationship Between Inhibitory Control and Syllogistic Reasoning

Table 2 shows the intercorrelations between all variables. The correlations among reasoning variables were mostly moderate, while the correlations among inhibition scores were all small to moderate and significant only for

Table 2 *Descriptive statistics and correlations between inhibitory control and reasoning variables*

	M	*SD*	1	2	3	4	5	6	7	8	9
Proactive interference resistance											
1. BP residual score	-0.05	2.59									
2. CR residual score	0.00	1.67	.34**								
Distractor interference control											
3. EF letters differential score	-86.70	41.09	-.10	.01							
4. EF arrows differential score	-90.49	33.33	.05	-.03	.31**						
Prepotent response inhibition											
5. SS differential score	-49.59	47.18	.10	.21†	.11	-.02					
6. NS differential score	-67.33	33.24	-.06	.02	.22*	.03	.26*				
No-conflict syllogisms											
7. valid/believable syllogisms	0.87	0.25	.05	-.12	.01	.08	.06	-.21†			
8. invalid/unbelievable syllogisms	0.87	0.28	.03	-.07	.07	.23*	-.05	-.10	.17		
Conflict syllogisms											
9. valid/unbelievable syllogisms	0.87	0.27	.28**	.02	.18	.03	.02	-.21*	.42**	.32**	
10. invalid/believable syllogisms	0.66	0.41	.07	.00	.09	.18	-.01	-.04	.06	.50**	.37**

Note. BP – Brown-Peterson; CR – Cued Recall; EF – Eriksen flanker; SS – Spatial Stroop, NS – Numerical Stroop

†$p = .06$; *$p < .05$; **$p < .01$

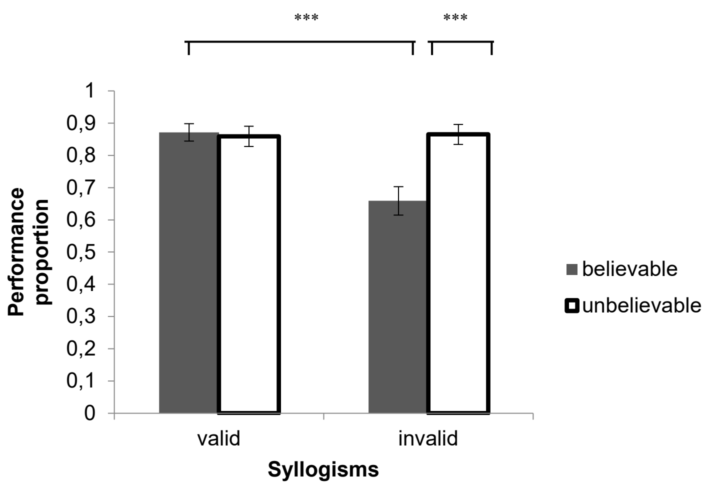

Figure 1 Reasoning performance (proportion). Error bars display 95% CI.

the two tasks tapping the same inhibitory function, save for a significant positive correlation between Eriksen flanker letters and Numerical Stroop task scores.

The correlations between inhibitory control functions and reasoning performance were moderate. No-conflict syllogisms were unrelated to inhibition scores, except for a negative correlation of valid/believable syllogisms and Numerical Stroop, and a positive correlation of invalid/unbelievable syllogisms and the Eriksen flanker arrows task score. The correlations between inhibition and conflict syllogisms were mixed. The correlation was positive for the Brown-Peterson task score and valid/unbelievable syllogisms, which was in line with our hypothesis, but some were also negative (e.g., between valid/unbelievable syllogisms and Numerical Stroop), while the majority of them were insignificant, disconfirming our initial expectations. The correlations on total no-conflict and conflict syllogisms scores followed a similar pattern (see Table S2.1. in Supplement 2, https://osf.io/3df4b/).

To better understand the relationship between reasoning and inhibition, we conducted several multiple regression analyses with inhibitory control scores as predictors and reasoning performance scores as criteria as shown in Table 3 and Table 4. A bias corrected and accelerated bootstrap (BCa) method was applied with 1000 sample generated iterations.

Inhibition did not account for any of the no-conflict reasoning performances, so these results were in line with expectations. However, of the remaining two models that we expected to explain conflict reasoning, only the model predicting valid/unbelievable syllogisms was significant, so that Brown-Peterson residual score and Eriksen flanker letters task were positively, and Numerical Stroop marginally (p = .07) negatively related to reasoning score. Inhibition was not a significant predictor of performance on complementary invalid/believable conflict syllogisms.

Considering the small number of items per type of syllogism, we repeated the analysis on no-conflict and conflict syllogism scores

Table 3 *Summary of regression analyses of inhibitory control on no-conflict syllogisms*

	no-conflict syllogisms											
Variables	valid/believable						invalid/unbelievable					
	B	*SE*(B)[a]	95 % CI	*β*	*t*	*p*[a]	B	*SE*(B)[a]	95 % CI	*β*	*t*	*p*[a]
Constant	0.88	.10	[0.69, 1.06]		9.10	< .01	0.98	.11	[0.73, 1.19]		8.71	< .01
Proactive interference												
BP res	0.01	.01	[-0.02, 0.04]	.10	0.86	.51	0.01	.01	[-0.02, 0.03]	.08	0.64	.58
CR res	-0.03	.02	[-0.07, 0.01]	-.18	-1.54	.15	-0.01	.02	[-0.06, 0.02]	-.08	-0.71	.47
Distractor interference												
EFletters	0.00	.00	[0.00, 0.00]	.06	0.51	.65	0.00	.00	[0.00, 0.00]	-.01	-0.04	.96
EFarrows	0.00	.00	[0.00, 0.00]	.12	1.01	.27	0.00	.00	[0.00, 0.00]	.25	2.14	.02
Response inhibition												
S Stroop	0.00	.00	[0.00, 0.00]	.14	1.25	.24	0.00	.00	[0.00, 0.00]	-.02	-0.18	.85
N Stroop	0.00	.00	[0.00, 0.00]	-.28	-2.46	.04	0.00	.00	[0.00, 0.00]	-.14	-1.20	.23
	$F(6, 75) = 1.65$ $p = .14$ $R^2 = .12$						$F(6, 75) = 1.23$ $p = .30$ $R^2 = .09$					

Note. BP res – Brown-Peterson residual score, CR res – Cued recall residual score, EFletters – Eriksen flanker letters differential score, EFarrows – Eriksen flanker arrows differential score, S Stroop – Spatial Stroop differential score, N Stroop – Numerical Stroop differential score

[a] Table contains bootstrap generated standard errors and *p*-values ($N = 1000$)

Table 4 *Summary of regression analyses of inhibitory control on conflict syllogisms*

	conflict syllogisms											
Variables	valid/unbelievable						invalid/believable					
	B	*SE*(B)[a]	95 % CI	*β*	*t*	*p*[a]	B	*SE*(B)[a]	95 % CI	*β*	*t*	*p*[a]
Constant	0.87	.12	[0.63, 1.07]		8.41	< .01	0.88	.17	[0.51, 1.18]		5.21	< .01
Proactive interference												
BP res	0.04	.01	[0.01, 0.06]	*.33*	*2.96*	*.02*	0.01	.02	[-0.02, 0.04]	.07	0.55	.57
CR res	-0.02	.02	[-0.05, 0.02]	-.10	-0.90	.38	-0.01	.03	[-0.06, 0.06]	-.02	-0.17	.85
Distractor interference												
EFletters	0.00	.00	[0.00, 0.00]	*.27*	*2.43*	*.02*	0.00	.00	[0.00, 0.00]	.07	0.60	.57
EFarrows	0.00	.00	[0.00, 0.00]	-.06	-0.51	.56	0.00	.00	[0.00, 0.01]	.17	1.43	.20
Response inhibition												
S Stroop	0.00	.00	[0.00, 0.00]	.04	0.37	.71	0.00	.00	[0.00, 0.00]	.00	0.04	.98
N Stroop	0.00	.00	[0.00, 0.00]	*-.24*	*-2.15*	*.07*	0.00	.00	[0.00, 0.00]	-.04	-0.37	.68
	$F(6, 75) = 2.78$ $p = .02$ $R^2 = .18$						$F(6, 75) = .60$ $p = .73$ $R^2 = .05$					

Note. BP res – Brown-Peterson residual score, CR res – Cued recall residual score, EFletters – Eriksen flanker letters differential score, EFarrows – Eriksen flanker arrows differential score, S Stroop – Spatial Stroop differential score, N Stroop – Numerical Stroop differential score

[a] Table contains bootstrap generated standard errors and *p*-values ($N = 1000$)

(which have four items each) and the results were mostly in line with what was obtained for syllogism type scores (see Table S2.2. in Supplement 2, https://osf.io/3df4b/).

Discussion

In everyday situations, it is commonplace to take our intuitive experience, such as 'roses are flowers', for granted. For the most part, our mundane reason will suffice; however, in certain situations our intuition is at odds with common sense which requires us to inhibit our mundane knowledge. In this study, we explored the relationship between syllogistic reasoning and the executive function of inhibition. As part of examining the relationship between inhibitory control and reasoning, we first tested for the existence of the widely-replicated belief-bias effect (Evans et al., 1983), and indeed, we confirmed its presence in our study as well.

With respect to our main aim – to investigate the relationship between inhibitory control and syllogistic reasoning – our hypotheses were only partially confirmed. Namely, we hypothesized no correlation between inhibitory control and reasoning on no-conflict syllogisms and a positive correlation between inhibitory control and conflict syllogism reasoning. There were practically no correlations between inhibition and no-conflict reasoning, as hypothesized, while correlations for conflict syllogisms were positive, negative and null, which was not entirely in line with our expectations.

We observed moderate intercorrelations between almost all syllogistic reasoning tasks, indicating that the same cognitive mechanism may be responsible for syllogistic reasoning, likely based on common propositional rules, regardless of syllogistic validity or content (e.g., Braine & O'Brien, 1998). On the other hand, inhibition task correlations were surprisingly low – we only obtained significant correlations for the tasks assessing the same inhibition type. This pattern of correlations might be explained by the task impurity problem (Miyake et al., 2000), which in turn could reduce the reliability of inhibition task scores. Additionally, since we only administered two inhibition tasks per function, more reliable latent variables could not be extracted.

All types of inhibition predicted reasoning only on conflict valid/unbelievable syllogisms, but, for all three inhibition functions, only one of the two administered tasks was significant. Therefore, the obtained findings should be interpreted cautiously before they are replicated in future studies. Still, it should be noted that the Brown-Peterson task assessing proactive interference resistance seemed to be the most relevant for this reasoning, while the Numerical Stroop task was only marginally significant (p = .07).

Even though De Neys and Bonnefon (2013) considered individual differences in inhibitory control crucial in explaining differences in performance on reasoning tasks, the relationships obtained in our study were fairly weak. This may at least partly be due to the low reliabilities of some measures, which may have attenuated the true correlations. Moreover, the sample we used was a preselected sample of psychology students, which may have additionally restricted the range of measured variables, since performance on all types of syllogisms (except the invalid/believable) was very high.

On the other hand, weak correlations could imply that other factors, such as cognitive ability and thinking dispositions, may play an important role in reasoning. For example, highly intelligent individuals performed better on incongruent problems under the validity vs. believability instruction and also had an overall better performance on congruent problems (Thompson, Pennycook, Trippas, & Evans, 2018; Trippas, Thompson, & Handley, 2017), even at the initial stage of reasoning (Thompson & Johnson, 2014; Thompson et al., 2018). Future studies could shed light on the relative importance of these various factors, ideally by simultaneously examining a wider range of individual differences variables.

Even though our initial hypotheses were not entirely confirmed, the correlations did show some form of regularity, thus potentially indicating a differential relationship between inhibition and various syllogistic forms used in our study. A consistent, yet unusual finding is the negative correlation of Numerical Stroop with valid/believable (no-conflict) syllogisms and the positive correlation of the Eriksen flanker arrows task score with invalid/unbelievable (no-conflict) syllogisms. Theoretically, inhibition should not be related to reasoning performance on no-conflict syllogisms, which is also confirmed by previous findings (De Neys & Van Gelder, 2009). However, these correlations should not be interpreted solely in the context of the presence or absence of conflict in a syllogism. Namely, both the Numerical Stroop (negatively) and the Eriksen flanker arrows task (positively) were also correlated with valid/unbelievable, i.e. conflict syllogisms. Taken together, it would appear that the Numerical Stroop and the Eriksen flanker arrows task are related to syllogism validity and believability, respectively, independent of other task features.

If this is the case, then the “conflict-ness” of a syllogism may not be the only task feature activating inhibition, at least to a certain degree. Interestingly, on very simple syllogistic forms (modus ponens), in a procedure analogous to the Stroop task (Thompson & Newman, 2018), where participants are instructed to reason based only on one dimension of the problem (for example, believability) and to ignore other dimensions (i.e., validity), validity interfered more with believability of the conclusions than vice versa (Handley, Newstead, & Trippas, 2011). If we presume that solving easy syllogisms is an almost automatic response (e.g., as fast responses were found to be rule-informed; Newman, Gibb, & Thompson, 2017), this could indicate a minimal logic “intuition” postulated by the hybrid model (De Neys, 2018).

Similarly, the positive association of the Eriksen flanker arrows task with both types of unbelievable syllogisms might indicate a “distractive” nature of unbelievable content demanding the activation of distractor control. Such reasoning could be explained within the mental model theory (e.g., Johnson-Laird & Byrne, 1991), assuming more sensitivity to unbelievable conclusions which triggers a search for counterexamples. Importantly, this would coincide with findings that distrust facilitates analytical processing (e.g., Mayo, Alfasi, & Schwartz, 2014).

Although our finding that inhibition is associated with reasoning is not new per se, how this process works is still a matter of debate. The finding that better inhibitory control contributes to a better performance on at least one form of conflict reasoning is in line with the presumed activation of System 2 postulated by the default-interventionist and the parallel model and does not contradict the hybrid-model assumptions. The research on the influence of different types of inhibitory control could shed further light on what activates the inhibition process in terms of syllogistic validity, syllogistic content or their interaction. Since this study is the first to explore the relationship between individual differences in various types of inhibitory control and reasoning performance, our findings could initiate further inquiries of this matter.

Study Limitations

First, since we used a brief instrument to assess reasoning, there were only two syllogisms per condition, limiting both the variability and reliability of participant scores. Coupled with low reliabilities of inhibition tasks, this may have led to an attenuation in observed correlations. Future studies using longer and more reliable instruments could presumably obtain higher correlations than those found in our study.

Second, the correlations between tasks pertaining to measure the same inhibitory function were lower than expected, and there were practically no correlations between tasks measuring different inhibitory functions. Moreover, correlations between inhibitory control functions and syllogistic reasoning were mostly obtained for only one of the two tasks used to assess the same function, limiting the generalizability of our results.

Finally, since syllogistic tasks were administered in a paper-and-pencil form, we were only able to register individual differences in participants' response accuracy. However, it is possible that larger differences would emerge if reaction times were registered, and these differences might also be related to inhibition in more meaningful ways.

Future Directions

This study is one of the few attempts to explore how different types of inhibitory control are related to syllogistic reasoning. Our results demonstrated that some correlations between inhibitory control and syllogistic reasoning were obtained, but their pattern indicates that rather than the distinction between conflict and no-conflict syllogisms, syllogistic validity seems more relevant for inhibition activation. An important preliminary finding is that different inhibitory functions tap validity, believability and their interaction in different ways. Prepotent response inhibition seems to be related to validity, distractor control to believability, and proactive interference resistance might be especially important for their interaction, i.e. conflict reasoning. However, since this is a preliminary finding, further research on this topic is needed. A general inverse relation between inhibition and belief-bias was confirmed in our research, given that belief-bias was registered on invalid/believable syllogisms where inhibition was not activated. Considering the small effect size of our regression model, it would be interesting to explore the effects of inhibitory control in concert with other cognitive functions in future research.

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