An Investigation on How Inhibition in Cognitive Processing Contributes to Fluid Reasoning

Tengfei Wang[1], Chenyu Li[1], Wei Wei[1], Karl Schweizer[2]

[1] Department of Psychology and Behavioral Sciences, Zhejiang University, Hangzhou, China

[2] Department of Psychology, Goethe University Frankfurt, Frankfurt am Main, Germany

ABSTRACT

This article reports an investigation of how inhibition contributes to fluid reasoning when it is decomposed into the reasoning ability, item-position, and speed components to control for possible method effects. Working memory was also taken into consideration. A sample of 223 university students completed a fluid reasoning scale, two tasks tapping prepotent response inhibition, and two working memory tasks. Fixed-links modeling was used to separate the effect of reasoning ability from the effects of item-position and speed. The goodness-of-fit results confirmed the necessity to consider the reasoning ability, item-position, and speed components simultaneously. Prepotent response inhibition was only associated with reasoning ability. This association disappeared when working memory served as a mediator. Taken together, these results reflect the inhomogeneity of what is tapped by the fluid reasoning scale on one hand and, on the other, suggest inhibition as an important component of working memory.

KEYWORDS

fluid reasoning
prepotent response inhibition
working memory
fixed-links modeling

INTRODUCTION

Fluid reasoning—also referred to as fluid intelligence—has been conceptualized as the ability to solve novel and complex problems by means of mental operations such as identifying relations, concept formation, drawing inferences, classification, and so forth (Cattell, 1963). Compared with crystallized intelligence, fluid intelligence is relatively less influenced by educational and cultural factors. During the last decades, there has been an increasing interest in exploring the cognitive basis underlying fluid reasoning. A number of cognitive resources, such as working memory (e.g., Ackerman et al., 2005; Kane et al., 2005), processing speed (Fry & Hale, 1996), and executive functions (Friedman et al., 2006), have been identified. Among those cognitive functions, inhibition is a controversial one since it has been assumed to be a key component of executive functioning (Miyake et al., 2000) that is essential for both working memory (WM) and fluid reasoning (Engle, 2002). However, the available evidence regarding the relationship between inhibition and fluid reasoning is not unequivocal. Some recent studies provide supporting evidence (e.g., Shipstead et al., 2014; Unsworth et al., 2014), while others fail to do so (e.g., Friedman et al., 2006; Rey-Mermet et al., 2019). A possible reason for these inconsistent results are the method effects, such as the effect of latent processing speed (Chuderski, 2013, 2015) and the effect of item-position (Lozano,

Corresponding author: Wei Wei, Department of Psychology and Behavioral Sciences, Zhejiang University, Hangzhou, China
E-mail: weiwei820@zju.edu.cn

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2015; Ren et al., 2017), which may impair the quality of fluid reasoning measurement. In order to rule out impairment due to such method effects, we investigated the relationships between inhibition, WM, and fluid reasoning using a refined representation of fluid reasoning.

Inhibition and Fluid Reasoning

Inhibition, together with updating and shifting, have been identified as three major components of executive functioning (Miyake et al., 2000). Since inhibition plays a role in suppressing irrelevant impulses or stimuli that potentially distract attention from the task-relevant goals (Nigg, 2000), it is considered essential for human thinking (Garavan et al., 1999). Despite the large amount of research into inhibition, there are still some inconsistencies that may obscure the communication in this field. On one hand, different terms, for example, "executive control" or "attentional control" have been used interchangeably; on the other hand, different researchers who use the same term may refer to different types of inhibition. According to Friedman and Miyake (2004), there are three main types of inhibition: prepotent response inhibition, resistance to distractor, and resistance to proactive interference (PI). In the current study, we mainly focused on the prepotent response inhibition, which has been described as the ability to deliberately suppress dominant, automatic, or prepotent responses (Miyake et al., 2000). We chose to focus on this type of inhibition since it represents a key dimension of inhibition in actively suppressing distractions (Friedman & Miyake, 2004). In addition, overriding habitual responses is a primary function of the supervisory attentional system (Norman & Shallice, 1986), which has been suggested to be significantly involved in fluid reasoning tasks (Engle, 2002).

Inhibition is considered important for completing the items of fluid reasoning measures (e.g., Dempster, 1991; Ren et al., 2017; Shipstead et al., 2014; Unsworth et al., 2014). This does not depend on the availability of specific knowledge, but requires the identification and subsequent application of abstract rules. During such complex cognitive processing, the prevention of interruptions is an important precondition for arriving at correct solutions since there are irrelevant rules or alternatives that may divert one's attention to a wrong answer. However, the expectation of a relationship between inhibition and fluid intelligence is not unanimously supported by recent studies (e.g., Chuderski et al., 2012; Friedman et al., 2006; Rey-Mermet et al., 2019). For example, Friedman et al. (2006) examined the relationships between executive functions (i.e., updating, shifting, and prepotent response inhibition) and fluid intelligence. Whereas their results provided evidence for the assumed relationship between updating and fluid intelligence, the correlations for inhibition and shifting were of negligible size only.

The other issue of importance concerns the relationship between inhibition and WM. Inhibition has proved to be important for holding information temporarily in WM (e.g., Engle, 2002; Vogel et al., 2005). Engle (2002) describes WM as the ability to hold information in the face of possible interference. That is, individuals with high WM capacity are suggested to outperform their low-WM capacity counterparts especially when interference makes it difficult to hold information. According to Vogel et al. (2005), individual differences in WM capacity are partly due to variation in the active suppression of irrelevant information entering into WM. Low-WM capacity individuals are more likely to encode irrelevant information into WM than their high-WM capacity counterparts. Therefore, individuals showing stronger resistance to interference can maintain more relevant and useful information and thus perform better during fluid reasoning tests (Chuderski et al., 2012; Unsworth, 2010).

However, inhibition can be triggered either consciously or unconsciously (Chiu & Aron, 2014). On one hand, controlled processes may undergo automatization due to frequent practice (Nordgren et al., 2011). For example, Chiu and Aron (2014) found that automatic inhibition emerges in an executive setting when the inhibition task undergoes multiple training. On the other hand, WM is considered to be essentially controlled processing and includes interference control. Therefore, after frequent practice inhibition may operate outside the framework of WM. In this case, inhibition may still, to some degree, be a unique source of individual differences in fluid reasoning. This line of reasoning suggests that inhibition might also contribute to fluid reasoning without mediation by WM.

Considerations Regarding the Measurement of Fluid Reasoning: The Speed Effect

As indicated above, one reason for the observed differences in the relationships between inhibition, WM, and fluid intelligence can be varying influence of processing speed. Processing speed may lead to an overestimation of these relationships. According to Chuderski (2013, 2015), fluid intelligence and WM are virtually indistinguishable if fluid intelligence is measured by highly speeded measures. Such measures have to be completed within an insufficient time span. Prolonging the time span for measurement decreases the correlation between fluid intelligence and WM. Furthermore, a similar effect has also been observed in correlations between inhibition and fluid reasoning. Since inhibition tasks are usually reaction time (RT) measures and likely to be confounded with general processing speed, Rey-Mermet et al. (2019) assessed inhibition through accuracy and found that none of the inhibition measures were consistently related to fluid intelligence. This result suggests that the correlation observed between inhibition and fluid reasoning may be due to the influence of speed on both measures creating a commonality that boosts the correlation.

A restricted time span for completing a fluid reasoning scale usually means that some participants are able to complete all items and to achieve highest possible scores, whereas others cannot; they stay below what they could reach otherwise (Oshima, 1994). Therefore, processing speed influences the outcome of testing. A possible provision for overcoming this problem is to control for the influence of processing speed on testing in the statistical analysis. This requires the confirmatory factor model to be enlarged by including an additional latent variable representing processing speed. This latent variable is expected to capture the variation due to processing speed because of the time limit (Schweizer et al., 2018; Schweizer et al., 2019; Ren et al., 2018; Zeller et al., 2018). In a previous study, Ren et al. (2018) investigated a reasoning test with a time limit by means of a confirmatory factor model that separated the processing speed component from the ability component. The results showed that there was a substantial correlation between the speed component of the reasoning test and measures of processing speed. This confirmed the nature of the speed component and its suspected influence on the estimation of the correlations between fluid reasoning and the other cognitive constructs.

Since latent processing speed can be assumed to show a normal distribution, the effect of latent processing speed on responding is likely to follow the cumulative normal distribution. This course of the effect of latent processing speed can be employed for decomposing the observed variation into components, one of which represents latent processing speed. The decomposition requires the constraint of the loadings on the corresponding factor according to how the effect of latent processing speed is assumed to unfold. The loadings on the speed factor are constrained using numbers obtained by the logistic function that approximates the cumulative normal distribution function (cf., Schweizer et al., 2019; Zeller et al., 2018).

The Effect of the Item-Position on Fluid Reasoning

Another effect frequently observed in scales of fluid reasoning is referred to as item-position effect since its size depends on the item position (e.g., Birney et al., 2017; Debeer & Janssen, 2013; Zeller et al., 2017). This effect contributes to the systematic variation of an item so that the response to an item is not only due to an individual's ability but also to the position of the item within the test (Schweizer et al., 2011). This effect, observed in reasoning items, has been ascribed to learning (Carlstedt et al., 2000; Embretson, 1991; Verguts & De Boeck, 2002). This assumption can be explained, for example, by the low number of rules that underlie all reasoning test items so that the detection of a rule in one item may facilitate performance on others. Ren et al. (2014) have shown that the latent variable capturing this effect correlates with the latent variable derived from learning tasks.

This effect of item position can also be separated from reasoning ability by means of a latent variable added to the measurement model (Ren et al., 2014). That is, the item-position effect can be captured by decomposing the observed variation into parts. For this purpose, numbers have to be selected as factor loadings that reflect the unfolding of the effect. Since the item-position effect is assumed to show a monotonic increase, numbers achieved by components of the polynomial, as, for example, by a linear or quadratic function have so far served for this purpose (Zeller et al., 2017).

The Current Study

To sum up, the main objective of the current study was to achieve an estimate of the relationship between inhibition and fluid reasoning after eliminating the influences of latent processing speed and item-position. Theory-guided variance decomposition by means of fixed-links models (Schweizer, 2008) served as the control of the influences of processing speed and item-position on the investigated relationship. We included two measures of inhibition so that either separated representations of inhibition or a unified hierarchical one could be linked to fluid reasoning. According to the executive attention theory (Engle, 2002), inhibition is assumed to predict reasoning ability even after the item-position and speed effects are statistically controlled for (Hypothesis 1).

A second objective was to examine the relationship of inhibition and WM in predicting fluid reasoning. Considering inhibition as part of WM suggests full mediation. Since inhibition may be triggered either consciously or unconsciously, there is the possibility of a partial instead of a full mediation by WM (Hypothesis 2).

METHOD

A total of 223 university students (100 males) aged between 16 and 27 years (M = 19.87, SD = 1.74) participated in the study. Participants were recruited from Zhejiang University. The structural investigation of fluid reasoning was based on the whole sample; since the data of 17 participants were incomplete, they were excluded from the further investigations. Participants received course credits or a financial reward (30 RMB) for participation.

Measures

ABSTRACT REASONING SCALE (ARS)

This scale is selected from an intelligence test battery and frequently used to assess fluid reasoning (Horn, 1983). It consists of 40 items presented in an ascending order of difficulty. Each item is composed of a series of nine numbers or letters. The arrangement of eight numbers or letters follows a rule but one does not. Participants had to infer the rule and cross out the number or letter that did not follow the rule. The time limit for completing all items was 8 min. Responses to each item were recorded as binary data. Only the last 15 items of the ARS were used for modeling since the first 25 items were too easy for university students so that there was no or virtually no variance. These 15 items showed good reliability (Cronbach' α = .79) and a virtually perfect correlation (r = 0.96, p < .001) with the total ARS score.

LETTER SPAN TASK (LST)

This task was used to tap verbal WM (Wang et al., 2017). Participants were asked to memorize a series of unrelated consonants while performing verbal judgement subtasks. Each trial started with a fixation point displayed on the computer screen for 750 ms, followed by a blank screen of 250 ms and then a series of letters interleaved with distraction subtasks. Each letter was presented on the screen for 750 ms, followed by another 250-ms delay before a couple of word judgments were required. Each trial comprised three, five, or seven letters. Two words were successively presented after each letter, and each word appeared for 900 ms followed by a 25 ms delay. The participants had to determine whether the presented word was an animal noun or not by pressing either the "F" or "J" key. The task comprised 12 trials. The percentage of correctly completed trials served as the performance indicator.

SYMMETRY SPAN TASK (SST)

This task tapped visuospatial WM (Unsworth et al., 2014). Participants had to memorize the locations of a series of red squares in a 4 × 4 matrix while performing symmetry-judgement tasks. Three practice sessions preceded the start of the main task. First, participants had to recall a sequence of successively presented red squares in the same order as they appeared by clicking the corresponding locations in a blank matrix. Second, participants had to judge whether black squares were distributed symmetrically along the central vertical axis of an 8 × 8 matrix. There was a total of 15 trials in this session, during which each participant's mean (*SD*) processing time was calculated. Thereafter, the two types of tasks were combined by alternatively asking participants to decide whether a matrix was symmetric and to memorize the location of a red square that appeared for 650 ms. The time limit for each symmetry judgment task was set to the individual participant's mean time plus 2.5 *SD*. The number of the red squares varied from 3 to 5. Each set size included four trials. The order of trials with different set sizes was arranged randomly. The performance indicator was the percentage of trials in which all of the locations were correctly recalled.

ANTISACCADE TASK (AT)

This task tapped the ability to resist the interference of prepotent responses (Friedman & Miyake, 2004; Unsworth et al., 2014). Each trial started with the presentation of a fixation point for a varying amount of time (200-1800 ms). Then, a "=" sign was flashed twice to the left or right of the fixation point (at 11.33" of visual angle) for 100 ms with a 50 ms interval inbetween. After another 50 ms of a blank screen, the target stimulus (a "B", "P", or "R") was presented on the opposite side of the flashing cue for 100 ms, followed by an "H" for 50 ms and an "8" that remained on the screen until a response was given. Participants had to identify the letter by pressing the "1", "2", or "3" key for "B", "P", or "R" respectively. There were 15 practice trials preceding 40 experimental trials. The proportions of correct responses were computed for every set of 10 trials for the statistical modeling.

FLOWER-HEART TASK (FHT)

This task was used to tap the ability of inhibiting prepotent responses (Brocki & Tillman, 2014; Davidson et al., 2006). The task combined the Simon task and the task switching paradigm. There were three treatment levels (i.e., congruent, incongruent, and mixed). In the congruent level, participants were asked to press the key ("F" on the left or "J" on the right) on the same side as the stimulus (a red heart). In the incongruent level, participants had to press the key on the opposite side of the stimulus (a red flower). In the mixed level, red hearts and flowers were presented randomly and participants had to respond according to corresponding rules. According to Davidson et al. (2006), completing the incongruent trials requires subjects to resist the habitual tendency to press the key on the same side as the stimuli. The mixed trials also require inhibition since incongruent trials are included. In addition, participants have to resist their tendency to continue using the same rule in trials that require a switch.

Each trial started with the presentation of a fixation point for 500 ms, followed by a visual stimulus (a red heart or flower) for 1500 ms. Participants had to respond as quickly and as accurately as possible. There were four practice trials preceding 30 experimental trials in both the congruent and incongruent blocks and 60 experimental trials in the mixed block. The averaged RT of correct trials for each block were computed. Since only the incongruent and mixed blocks required prepotent response inhibition, the scores of these two blocks were used to represent inhibition. The average score of the trials in the incongruent block was labeled as FHT1. The trials in the mixed block were separated into non-switch and switch trials. The scores of the non-switch and switch trials were labeled as FHT2 and FHT3, respectively.

Procedure

Participants were tested individually in a laboratory. The WM and inhibition tasks were programmed with E-prime 2.0 (Psychology Software Tools, Pittsburgh, PA) and presented on a 19 in. monitor. The fluid reasoning scale was a paper-and-pencil test. The measures were administered in the following order: the ARS, the LST, the AT, the SST, and the FHT. The entire procedure took approximately 50 minutes, and participants could take a short break between tasks.

Models

Several confirmatory factor models were designed for investigating the reasoning scale. First, there were one-factor models with free factor loadings (Jöreskog, 1971) or with equal-sized factor loadings. The ARS items served as manifest variables of the model. In the case of free factor loadings, the variance parameter was fixed to one, and in other cases, it was estimated. Second, there were 2 two-factor models including latent variables for capturing the reasoning ability and the item-position effect. In the first case, the factor loadings were constrained to show equal sizes and in the second case, to correspond to either linearly or quadratically increasing numbers. These latent variables were referred to as reasoning ability and item-position latent variables, respectively. Furthermore, there were 2 three-factor models that additionally included a latent variable representing processing speed. This speed latent variable had factor loadings according to the logistic function.

Structural equation models were used for investigating the relationships between the reasoning scale on one hand and the inhibition and WM measures on the other hand. The measurement part of the model regarding inhibition was composed of two separate models of measurement since each inhibition task yielded more than one score. The AT model included one latent variable and four manifest variables that were the four AT scores. The model of FHT comprised one latent variable and three manifest variables that were the scores of the incongruent and mixed blocks. In order to have one inhibition score, the inhibition models were combined and a second-order latent variable was added. In the case of WM, the measurement model included one latent variable and two manifest variables that were the scores of the two WM tasks.

Modeling Analyses

The parameters were estimated by means of the maximum likelihood method using LISREL 8.8. The fit statistics were evaluated using the criteria recommended by DiStefano (2016). The model fit was considered good (or acceptable) if normed χ^2 (=χ^2/df) ≤ 2 (3), RMSEA ≤ .05 (.08), SRMR ≤ .05 (.10), and CFI ≥ .95 (.90). Furthermore, the difference in CFI results was considered for model comparisons. A difference of .01 or larger was considered a substantial difference (Cheung & Rensvold, 2002).

RESULTS

Descriptive Statistics

Table 1 presents the descriptive results for the LST, the SST, the AT, the three treatment levels of the FHT, the ARS, and the intercorrelations among them. Cronbach's α was calculated for the LST, the SST, the AT, and the ARS. Permutation-based split-half reliability estimates were computed for the subscores of the FHT (Parsons et al., 2019). As shown in Table 1, the reliability estimates of all variables were good, ranging from .79 to 89. Scores of the AT and the FHT were significantly correlated, indicating convergent validity. Both the WM and the prepotent response inhibition tasks showed correlations of small to moderate size with the ARS.

The Structural Investigation of the Abstract Reasoning Scale

At first, the ARS was investigated using different models of measurement in order to check whether the representation of item-position and speed effects was necessary and whether the preferred model showed a sufficient degree of model fit. The fit results observed for the ARS models are reported in Table 2. The one-factor model with free factor loadings yielded acceptable fit according to normed χ^2, RMSEA, and SRMR (except for CFI), while the other one-factor model did not. Second, 2 two-factor models with linear and quadratic representations of the item-position effect were tested. Both models showed model misfit. Therefore, it was concluded that both the one- and two-factor models were insufficient for representing ARS data.

Next, the three-factor models additionally including a representation of processing speed were investigated. According to the fit results, both three-factor models showed better degrees of model fit than the two-factor models. However, only the model with a linear representation of the item-position effect showed acceptable model fit. It also showed a better degree of model fit according to the CFI difference (ΔCFI = 0.025). Furthermore, the variance estimates of the three latent variables of the model reached significance (reasoning ability: t = 5.45, p < .001; item-position: t = 4.80, p < .001; speed: t = 2.90, p = .003). These results were a further indication that all three latent variables were necessary.

The Relationship of Prepotent Response Inhibition with Fluid Reasoning

Next, we examined the correlations of inhibition with the ability, item-position, and speed components of the ARS. For this purpose, the measurement models of reasoning and inhibition were integrated into comprehensive models. First, we explored the relations of prepotent response inhibition represented by the AT and the FHT with components of the ARS (see Figure 1). Scores of the FHT were reversed so that higher scores in both measures meant higher levels of performance in the models. The fit statistics of this model indicated good fit, χ^2(214) = 307.93, χ^2/df = 1.44, RMSEA = .046, SRMR = .076, CFI = .958, AIC = 385.93. Prepotent response inhibition represented by the AT showed a significant correlation with inhibition represented by the FHT (r = .44, t = 4.42, p < .001), suggesting convergent validity of the two inhibition tasks. Inhibition represented by the AT showed a medium correlation with reasoning ability (r = .49, t = 3.55, p < .001). The correlations between inhibition and item-position (r = .16, t = 1.35, p = .18) and speed (r = .18, t = 1.12, p = .26) were not significant. As for the FHT, the correlation between inhibition and reasoning ability also reached significance (r = .37, t = 2.78, p = .005), while the other correlations with item-position (r = .18, t = 1.57, p = .12) and speed (r = .12, t = .83, p = .41) were not significant.

TABLE 1.
Descriptive Statistics for all Measures and the Correlations Between Them (N = 206)

Measure	M	SD	Reliability	1	2	3	4	5	6	7
1. LST	.80	.16	.83[a]	–						
2. SST	.74	.17	.79[a]	.22	–					
3. AT	.58	.19	.87[a]	.39	.22	–				
4. FHT1	290.46	30.02	.80[b]	−.23	−.12	−.27	–			
5. FHT2	352.49	49.04	.87[b]	−.35	−.26	−.33	.52	–		
6. FHT3	561.34	93.83	.89[b]	−.43	−.32	−.40	.52	.88	–	
7. ARS	33.82	3.54	.79[a]	.37	.34	.40	−.19	−.33	−.36	–

Note. LST = the letter span task; SST = the symmetry span task; AT = the antisaccade task; FHT = the flower-heart task, FHT1 = the score of the incongruent level, FHT2 = the score of the non-switch trials in the mixed level, FHT3 = the score of the switch trials in the mixed level; ARS = the abstract reasoning scale; correlations larger than .15 are significant at the .05 level. [a] = Cronbach's Alpha, [b] = Permutation-based split-half reliability.

TABLE 2.
Fit Statistics of the Measurement Models for the Fluid Reasoning Scale (*N* = 223)

Type of model	χ^2	df	χ^2/df	RMSEA	SRMR	CFI	AIC
One-factor model							
Freely estimated loading	206.38	90	2.29	.076	.068	.894	266.38
Fixed loading	247.42	104	2.38	.079	.100	.866	279.42
Ability-position mode							
Linear increase	242.41	103	2.35	.078	.101	.869	276.41
Quadratic increase	234.00	103	2.27	.076	.103	.873	234.00
Ability-position-speed model							
Linear increase	189.78	102	1.86	.062	.087	.909	225.78
Quadratic increase	217.88	102	2.14	.072	.095	.884	253.88

Additionally, the correlations between inhibition and fluid reasoning prior to decomposition of the ARS were estimated. This model also showed a good fit, χ^2 (206) = 325.04, χ^2/df = 1.58, RMSEA = .053, SRMR = .060, CFI = .954, AIC = 419.04. The correlations between fluid reasoning and prepotent response inhibition represented by the AT (r = .52, t = 3.67, p < .001) and the FHT (r = .43, t = 3.31, p = .001) were larger than the correlations after controlling for the item-position and speed effects (see previous paragraph). The correlation with the AT was reduced by 11 % (i.e., .11 = 1–.492/.522) and the other correlation was reduced by 26 % (i.e., .26 = 1–.372/.432). After the removal of the item-position and speed effects, the relationship between the FHT (a measure based on reaction time) and fluid reasoning decreased more than that for the AT (a measure based on accuracy) although the decreases did not reach the level of significance.

Given the substantial correlation between the two prepotent response inhibition components, a second-order latent variable representing general inhibition was established and linked to the three components of the ARS (see Figure 2). The model showed acceptable model fit, χ^2 (218) = 310.12, χ^2/df = 1.88, RMSEA = .045, SRMR = .076, CFI = .959, AIC = 380.12. General inhibition significantly predicted reasoning ability (r = .61, t = 2.67, p = .008) but neither item-position (r = .13, t = 1.01, p = .31) nor speed (r = .03, t = .19, p = .85).

Finally, we investigated how the integration of WM modified the prediction of fluid reasoning. Inhibition was linked directly and indirectly via WM to reasoning ability (see Figure 3). This model also showed good fit, χ^2(260) = 348.27, χ^2/df = 1.35, RMSEA = .041, SRMR = .074, CFI = .963, AIC = 428.27. Inhibition significantly contributed to WM (r = .78, t = 4.15, p < .001), and WM substantially predicted reasoning ability (r = .83, t = 6.27, p < .001). Besides this indirect effect, the direct effect of inhibition on reasoning ability was investigated. It proved to be negligible (r = .02, t = .55, p = .58), indicating that inhibition predicted reasoning ability via WM only.

DISCUSSION

The concept of inhibition is closely related to the question of how it is possible to complete a complex task and why we can perform according to a complex plan of action even though there is always distraction. These questions and, so far, insufficient results have presumably

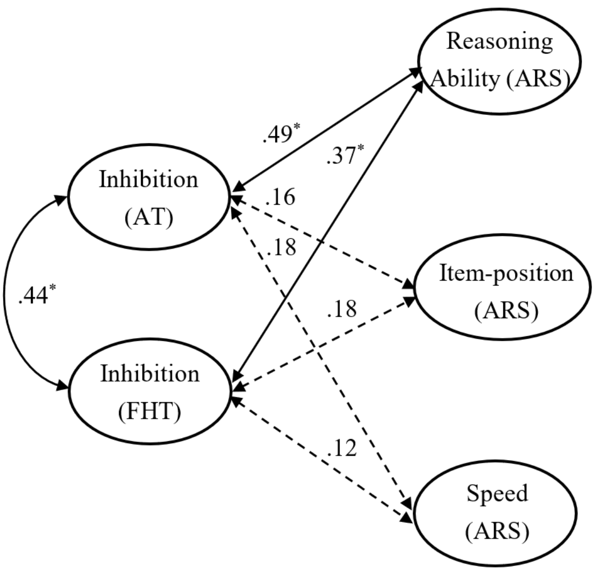

FIGURE 1.
The relationship of prepotent response inhibition represented by the antisaccade task (AT) and the flower-heart task (FHT) with components of the fluid reasoning scale (ARS) (*p < .05).

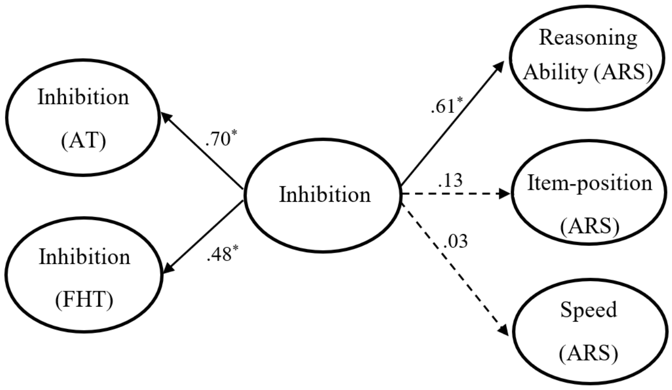

FIGURE 2.

The prediction of components of the fluid reasoning scale (ARS) by the second-order inhibition extracted from the first-order inhibition of the antisaccade (AT) and flower-heart tasks (FHT) (*$p < .05$).

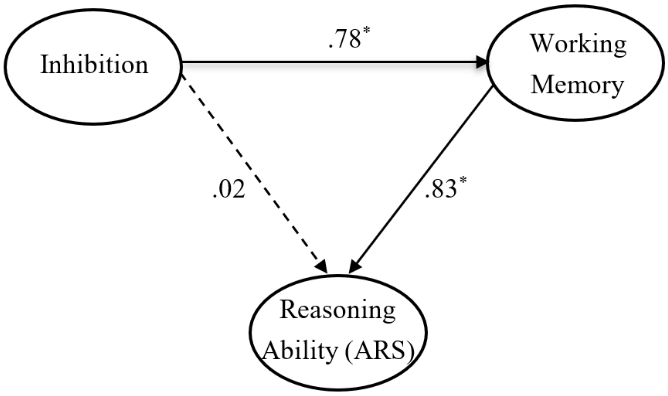

FIGURE 3.

Illustration of the mediation model in which the effect of inhibition on the reasoning ability component of the fluid reasoning scale was fully mediated by working memory (*$p < .05$).

stimulated the scientists' interest in this concept over the past decades (Dempster, 1991; Friedman et al., 2006; Rey-Mermet et al., 2019; Unsworth et al., 2014). The present study is another attempt to substantiate the expectation that inhibition is fundamentally important for higher-order processing. It takes method effects into consideration that may have diluted or modified the relationship with measures of higher-order processing in other studies so that more valid results can be obtained.

The first hypothesis required to investigate whether inhibition predicts fluid reasoning. The regression weights observed in this study were in line with this hypothesis. The scores obtained for the individual prepotent response inhibition tasks and for the combination of both tasks predict fluid reasoning. This result is consistent with the executive attention theory of working memory (Engle, 2002), which claims that the inhibition process is crucial for actively maintaining the task-relevant goal in the presence of potent distraction. While working on the reasoning problems, one has to retain the relevant rules in order to arrive at a correct answer. However, there are also irrelevant rules or alternatives that may divert one's attention to a wrong answer. Therefore, reasoning problems require the active control of attention rather than the reactive control. In addition, prepotent response inhibition involves the active suppression of dominant, automatic, and prepotent responses according to the task demands (Friedman & Miyake, 2004). Specifically, the AT required participants to suppress the reflexive saccade toward a flashed cue and instead to look in the opposite direction to identify the target. The FHT similarly required participants to actively suppress the dominant tendency to press the key on the same side of a stimulus. Both tasks demand active suppression, and therefore contribute to the performance on the ARS.

It worth pointing out that low reliability of the tasks measuring inhibition is a widespread threat to the validity of studies on this topic (e.g., Draheim et al., 2019; Hedge et al., 2018). Given the good reliabilities of the inhibition tasks (mostly larger than .80) and the convergent validity as indicated by the substantial correlation between the two inhibition tasks, our findings regarding the relationship between inhibition and fluid reasoning can be assumed to be valid. Moreover, the close relationship between inhibition and fluid reasoning may stem from a common neural basis. For example, neuroimaging studies have indicated that the frontal cortex is associated with both inhibition and fluid intelligence (see Ebisch et al., 2012; Hilger et al., 2017a, 2017b; Rubia et al., 2003; Yuan et al., 2012).

The second hypothesis additionally required the consideration of the mediating role of WM in the relation between inhibition and fluid reasoning. According to the regression weights, there is no direct effect of inhibition on reasoning ability but there is an indirect one: both the regression weights regarding the link of inhibition to WM and the link of WM to fluid reasoning showed substantial sizes. This confirms that inhibition is related to reasoning ability as well as WM despite controlling for the effects of item-position and speed. These results regarding inhibition add to the few already published studies suggesting such a relationship (Dempster, 1991; Ren et al., 2017; Shipstead et al., 2014; Unsworth et al., 2014). The finding regarding WM is also in line with the overwhelming evidence in favor of a relationship between fluid reasoning and WM (e.g., Ackerman et al., 2005; Kane et al., 2005). Another implication of the result is that WM comprises inhibition as a component (Engle, 2002; Shipstead et al., 2014). This is in line with the concept of WM as an overarching structure, as is characteristic of Baddeley's (1986) WM model. The current study also adds empirical evidence to the model proposed by Engle (2002) and Unsworth et al. (2014) suggesting the domain-general attention control as an important function of WM. As already indicated, no direct effect of inhibition on fluid reasoning was observed in the presence of WM as a possible mediator. This seems to disconfirm the expectation that inhibition may also function automatically, as we proposed as part of the second hypothesis. However, it needs to be considered that automatization tends to eliminate individual differences so that such an effect may not be identifiable.

The expectation that processing speed might influence the relationship between fluid intelligence and inhibition was not confirmed, although there was a numerical reduction of the correlations. Instead, the consideration of processing speed substantially contributes to good model fit of the fluid reasoning scale when conducting variance decomposition. Without considering processing speed, an acceptable degree of model fit would be out of reach. These results underline the necessity of including the effect due to a time limit in testing in order to achieve a more appropriate representation of fluid reasoning and its relationship with cognitive processes.

Finally, a limitation to this study is that only one type of inhibition (i.e., prepotent response inhibition) was considered. Both the AT and the FHT tap the ability to deliberately suppress dominant, automatic or prepotent responses (Friedman & Miyake, 2004), it remains an open question whether the other types of inhibition (i.e., resistance to distractor interference and resistance to proactive interference) show the same pattern of relationships with WM and fluid intelligence. Such a pattern is probably unlikely in light of the observation that it is not possible to identify a general dimension underlying a larger number of inhibition tasks (Rey-Mermet et al., 2019). Different tasks may reflect diverse types of inhibition, which are differentially related to fluid reasoning. To be specific, resistance to distractor interference refers to the ability to resist interference of irrelevant information. However, distractor interference effects in the task could be caused by processes other than active suppression (MacLeod et al., 2003). Resistance to PI is the ability to resist memory intrusions from information that was previously relevant. Similarly, as Friedman and Miyake (2004) put it, "Resistance to PI may not actually be reflecting an effortful, controlled ability; instead, the tasks used to measure Resistance to PI may tap the amount of interference that automatically accrues without any active resistance by participants" (p. 126). The extent of the relation between inhibition and higher order cognitive functioning might mainly depend on the presence of active suppression involved in the task rather than the property of the distraction (either responses, perceptual stimuli, or information in WM). This led us to focus on the prepotent response inhibition and its relationship with reasoning. The nature of relationships between resistance to distractor interference, resistance to PI, and fluid reasoning warrant more research in the future.

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