Why are some inhibitory tasks easy for preschool children when most are difficult? Testing two hypotheses

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Why are some inhibitory tasks easy for preschool children, when most are difficult?

Testing two hypotheses.

Abstract

Understanding the processes that create inhibitory demands is central to understanding the role of inhibitory control in all aspects of development. The processes that create inhibitory demands on most developmental tasks seem clear and well understood. However, there is one inhibitory task that appears substantially easier than the others: the Reverse Categorisation task, in which children are asked to "reverse sort" items (e.g., put large items in a small box, and small items in a large box). This finding is both surprising and problematic, as it cannot be explained by any existing account of inhibitory development. Four experiments with 3- and 4-year-olds sought to explain why the Reverse Categorisation task is easy. Two experiments (n=64) investigated the hypothesis that children conceptualise the task in a way that reduces its inhibitory demands; and two experiments (n=56) tested the hypothesis that the task is easier because children sort items slowly. The data indicate that children spontaneously respond more slowly in the Reverse Categorisation task than on other inhibitory tasks, and that this slowing reduces the task's cognitive demands. The way that slowed responding works, and its relation to other inhibition-reducing interventions, is discussed.

Keywords: Inhibitory control, Preschoolers, Task conceptualisation, Response delay, Reverse Catergorisation task

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Introduction

Inhibitory Control (IC) is the ability to suppress responses that are incompatible with an individual's goals. There is robust evidence that preschool children have weak inhibitory control (Petersen *et al.*, 2016), although over development, effective inhibitory control is ultimately linked to a range of positive outcomes. These include improvements in a variety of reasoning abilities (Beck *et al.*, 2011; Carlson & Moses, 2001), category formation (Rabi & Minda, 2014), figurative drawing (Riggs *et al.*, 2013), self-control (Kochanska *et al.*, 2001), behavioral adjustment (Kim *et al.*, 2013), and academic abilities in both childhood (Bull *et al.*, 2008) and adolescence (Duckworth & Seligman, 2005).

While performance on inhibitory tasks clearly improves across development, there is less clarity regarding which cognitive processes underpin this change. Broadly speaking, two different mechanisms have been proposed to explain improvements in inhibitory performances (Simpson & Carroll, 2019). First, inhibitory *capacity* may improve: essentially children's "inhibitory muscles" may get stronger. For example, inhibitory control could improve through changes in the fronto-basal-ganglia network, which is proposed to facilitate the cognitive act of inhibition (Aron et al., 2014; Smith et al., 2017). Second, children may develop *strategies* that reduce their need to apply inhibitory control in a task or situation. One proposal is that children are sometimes able to reconceptualise a task in an "IC-avoiding" way, which enables them to reduce its inhibitory demands (Simpson & Carroll, 2018).

Despite these uncertainties about how inhibitory control develops, we do have a good understanding of where inhibitory demands come from – that is, we know why inhibitory tasks require inhibitory control. Much of what we understand about the development of inhibitory control comes from studying the most widely used category of inhibitory task, known as Stimulus-Response Compatibility (SRC) tasks. Briefly, we know that a task requires inhibitory control if it (i) uses two pairs of matched stimuli and responses, and (ii) requires the child to produce response A when they see stimulus *b*, and response B when they see stimulus *a*. For example, in the Black/White SRC task, the child is shown either a *black* prompt card, and must say "white"; or they are shown a *white* prompt card, and must say "black". On every trial, the child knows they will say either "white" or "black", so these two responses are primed – that is, partially activated so that they can be made quickly. When the *black* prompt card is shown, the matched (but incorrect) response of saying "black" is triggered – and inhibitory control is needed to suppress this response, in order to then make the task-appropriate response of saying "white" instead (see Simpson & Carroll, 2019, for a fuller account). The key feature of SRC tasks is that they share this same basic Ab/Ba task structure: their stimuli and responses are paired according to "if-A-then-*b*/if-B-then-*a*" rules. If a task has these features, young children will find it challenging, due to their poor inhibitory control.

This account of why SRC tasks require inhibitory control is supported by a meta-analysis of almost two hundred studies of children's inhibitory control (Petersen *et al.*, 2016). The meta-analysis included data from a wide range of SRC tasks, which used a variety of stimuli and responses – including making manual responses to hand gestures (the Hand Game; the Knock/Tap task), pointing to pictures in response to verbal cues (the Grass/Snow task), and making verbal responses to pictures (the Day/Night task). All of these tasks share the same Ab/Ba task structure. Petersen and colleagues found that these tasks were difficult, and posed real challenges for preschoolers.

However, there was one surprising exception: a single task that shared the Ab/Ba structure, but which children appeared to find much easier: the Reverse Categorization task. In this SRC task, children sort either objects or cards according to Ab/Ba rules. For example, when they see a card with a picture of a *horse*, they must put it in a tray marked with an apple;

and when they see a picture of an *apple*, they must put it in a tray marked with a horse. Despite sharing the same Ab/Ba structure as other SRC tasks, Petersen and colleagues' analysis (Figure 2) suggested that the Reverse Categorization task was substantially easier than other SRC tasks (based on data from: Baker *et al.*, 2011; Bellagamba *et al.*, 2013; Bibok, 2007; Carlson *et al.*, 2004; Di Norcia *et al.*, 2015; Duvall, 2012; Evans & Lee, 2103; Gandolfi *et al.*, 2014; Kloo *et al.*, 2010; Muller *et al.*, 2012; Poulin-Dubois *et al.*, 2011; Wyss, 2013). Carlson (2005, Figure 2) had previously produced a similar analysis, when reviewing her own published and unpublished data, with the Reverse Categorization task being easier than other SRC tasks.

This discrepant finding is hard to explain, and poses a puzzling question: why is the Reverse Categorization task easy, when preschoolers' inhibitory control is so poor? According to the prevailing account of where inhibitory demands come from, we would expect that the presence of the Ab/Ba rules would make any task require inhibitory control; and because young children have poor inhibitory control, they should do poorly (Simpson & Carroll, 2019). Nevertheless, the data from Petersen and colleagues' (2016) meta-analysis would appear to suggest that this view is wrong. The Reverse Categorization task shares the same challenging rule structure as other SRC tasks, and yet preschoolers find it easy. Clearly, these data present a problem. Either we need to revise our fundamental account of why inhibitory tasks are difficult, or we need to explain why children perform well on a task that current views of inhibitory control would suggest should be difficult. In the present article, we aimed to explain this surprising finding.

Experiment 1

One potential explanation for good performance on the Reverse Categorization task is that children are able to think about the task in a way that allows them to circumvent its inhibitory demands. This phenomenon has been referred to as "task reconceptualization" (Simpson & Carroll, 2018). There is evidence that under certain circumstances, preschoolers are able to *avoid* the inhibitory demands of SRC tasks. They do this by thinking about the task in a way that allows them to produce the correct response, without needing to first inhibit a prepotent response – in other words, they conceptualize the task in a *Inhibitory Control (IC)-avoiding* way.

To illustrate with an example: the Grass/Snow task requires children to make pointing responses to a verbal cue (e.g., when they hear the word "grass", they should point to a *white* card; when they hear the word "snow", they should point to a *green* card). This task has high inhibitory demands, and is difficult for preschoolers (Simpson & Riggs, 2009). However, when the task is adapted slightly, so that the cue changes from the experimenter saying "grass" to the experimenter placing a marker on the *green* card, the task becomes trivially easy (Simpson & Carroll, 2018). This improvement occurs because the change of cue (from word to marker) allows children to think about the task in a different way. On the "Marker" version of the Grass/Snow task, instead of having to engage with challenging Ab/Ba rules, children can get to the correct response just by *pointing to the card without the marker* (e.g., if the marker is on the green card, they can just point to the white card) – since doing that will always give the correct answer. This simple change in how children conceptualize the task means that the prepotent response (that is, the response that first comes to mind) is also the *correct* response. Thus, there is no need to inhibit it, and children's poor inhibitory control is therefore not a problem. This contrasts with the standard way of thinking about the task –

conceptualizing the task in an IC-*requiring* way – where the response that first comes to mind is incorrect (the experimenter says “grass”, so the child is initially inclined to point to the *green* card). Inhibitory control is therefore required to suppress that initial response, so that a task-appropriate response can be made instead.

It is possible that the Reverse Categorization task is easy because children conceptualize it in an IC-avoiding way. The Reverse Categorization task has quite different superficial characteristics to the Marker task (notably, it has no marker). So, if children *are* using an IC-avoiding conceptualization on the Reverse Categorization task, it must be different to that reported by Simpson and Carroll (2018). One hypothesis is that children conceptualize the Reverse Categorization task in terms of *making pairs* of cards. On each trial their aim is to form a pair comprising one *horse* card and one *apple* card. According to this “make a pair” conceptualization, children could arrive at the correct answer by combining each cue card (that they are given by the experimenter) with the complementary target card (that label the trays), to make the same pair of cards on every trial. So when given a *horse* card, they put it with the apple tray, and when given an *apple* card, they put it with the horse tray. Using a “make a pair” conceptualization would eliminate the need to follow the IC-requiring “Ab/Ba” rules, and thus eliminate the need to use inhibitory control in the Reverse Categorization task.

The suggestion that the Reverse Categorization task is easy because children conceptualize it in an IC-avoiding way would be a parsimonious explanation for a surprising finding. It would also be consistent with previous research showing that young children are able to spontaneously use an IC-avoiding conceptualization (Simpson & Carroll, 2018). However, testing this hypothesis directly is difficult. We cannot usefully ask preschool children to describe to us how they conceptualize a task – we can only infer how they conceptualize the task from their performance. Nevertheless, one test of this hypothesis would be to compare performance on the Reverse Categorization task with performance on a different SRC task that we know children can conceptualize in an IC-avoiding way (i.e., the Marker task). This approach would give two points of comparison: standard (i.e. poor) performance on the Grass/Snow task, and improved, ceiling-level performance (i.e. greater than 90% accuracy) on the Marker task. If good performance on the Reverse Categorization task came about because children were using an IC-avoiding conceptualization, then their performance levels should be similar to that on the Marker task, since children would be using an IC-avoiding conceptualization on both tasks. Further, performance on the Reverse Categorization task should be substantially better than performance on the Grass/Snow task, since the latter task would require inhibitory control, while the former would not.

Of course, just because children's performance is the same on two tasks, it does not necessarily follow that the cognitive mechanisms which underpin that performance are also the same. However, a clear strength of SRC tasks is that there is evidence that it is *specifically* the inhibitory demands of these tasks that principally determines children's performance on them. Thus, ceiling performance on an SRC task is entirely consistent with a mechanism that eliminates the task's inhibitory demands. If children perform at ceiling on the Marker task and Reverse Categorization task, it is reasonable – and parsimonious – to propose that they are using an IC-avoiding conceptualisation in both tasks (even if the conceptualisations differ).

An alternative possibility is that *some but not all* children may be using an IC-avoiding conceptualization on the Reverse Categorization task (perhaps because coming up with this conceptualization is itself quite challenging). This speculation would also be consistent with research investigating task conceptualization on the Grass/Snow task, in which some, but not all, children were able to come up with an IC-avoiding conceptualization in a further version of the task (Experiment 3, Simpson & Carroll, 2018). If this were the case for the Reverse Categorization task, then we would predict two things. First, performance on the Reverse Categorization task would be *worse* than the ceiling performance observed on the Marker task, but *better* than performance on a Grass/Snow task. Second, a task manipulation that encouraged children to use the IC-avoiding conceptualization (i.e., explicitly instructing children to “make a pair”) would improve performance on the Reverse Categorization task.

These hypotheses were tested in Experiment 1. To summarise, we speculated that the Reverse Categorization task is easy because children conceptualize the task in an IC-avoiding way. We tested this by comparing performance on the Reverse Categorization task with performance on the Grass/Snow task (expected to be poor) and on the Marker task (expected to be at ceiling). We also included a second version of the Reverse Categorization task, presented in such a way as to make it more likely that children would adopt an IC-avoiding conceptualization. In this version, referred to as the Single-Rule Reverse Categorization task, children were shown cards depicting images of *an apple* and *a horse*. They were told that because horses like eating apples, the aim of the task is to put a horse with an apple, on every trial. If *all* children use an IC-avoiding conceptualization on the standard Reverse Categorization task, then performance should be at ceiling, like the Marker task. If only *some* children use an IC-avoiding conceptualization, then performance on the Reverse Categorization task should fall *between* the Grass/Snow task and the Marker task.

To remove differences that might reduce comparability across the four tasks, Experiment 1 used closely matched versions of the Reverse Categorization and Grass/Snow task. Several different variations of the Reverse Categorization task have been used previously (Petersen et al., 2016). Nevertheless, two principal ways in which this task often differs from other SRC tasks are: the Reverse Categorization task typically has a congruent sorting phase before the main incongruent testing phase; and it features rule reminders on every trial. The Grass/Snow task has no congruent phase, and no trial-by-trial rule reminders. To remove such differences, the Reverse Categorization task was matched to the Grass/Snow task. This gave us four matched tasks: Standard Reverse Categorization, Single-Rule Reverse Categorization, Grass/Snow, and Marker.

Method

Participants

An *a priori* power analysis using G*Power (Faul *et al*., 2007) indicated that 32 participants were required to have 90% power for detecting a medium-sized effect (0.25) with an alpha value of .05. Thirty-two children participated (mean age: 43 months; range: 36-51 months; 20 females). In all experiments described here, the age range tested was determined using Petersen and colleagues' (2016) meta-analysis of the Grass/Snow task. In line with Petersen et al's analysis, the aim was to obtain mean accuracy on the Grass/Snow task of between 20% and 80% (that is, performance that avoided both floor and ceiling effects). All experiments produced a mean accuracy in this range. Children were recruited from nursery schools in a mid-sized town in a semi-rural county of the UK. All spoke English as their first language, and none had any behavioral or educational problems. The group was predominantly white, and was of mixed social class.

Design

A repeated-measures design was used, with Task (Standard Reverse Categorization, Single-Rule Reverse Categorization, Grass/Snow, Marker) as the independent variable. The dependent variable for each task was the number of correct responses (out of 16).

Materials

For the two Reverse Categorization tasks, 20 laminated picture cards were used (measuring 10cm by 7cm), ten with a black and white drawing of a horse, and ten with a black and white drawing of an apple. Two sorting trays were used, with a *horse* picture or an *apple* picture attached to the back of each. For the Grass/Snow and Marker tasks, two black and white line drawings of a horse and an apple were used (each measuring 14cm by 10cm). For the Marker task, a wooden star (5cm diameter) was used as a marker.

Procedure

Testing was conducted across two sessions, each lasting approximately 10 minutes, and administered between one and ten days apart. Task order was counterbalanced, constrained so that the two Reverse Categorization tasks were in different sessions. For each session, the experimenter and child sat next to each other at a table.

For the two Reverse Categorization tasks, children were shown the horse and apple cards, and the two sorting trays with the attached picture cards. For the *Standard Reverse Categorization* task, the experimenter said that in the game, when he gave them an apple, they should put it with the horse; and he when he gave them a horse, they should put it with the apple. On each trial the experiment held up the card, named it, and then passed it to the child. For the *Single-Rule Reverse Categorization* task, the experimenter said that in the game they should put a horse and apple together, because horses like eating apples. So, when they got an apple, they should give it to the horse; and when they got a horse, they should put it with the apple.

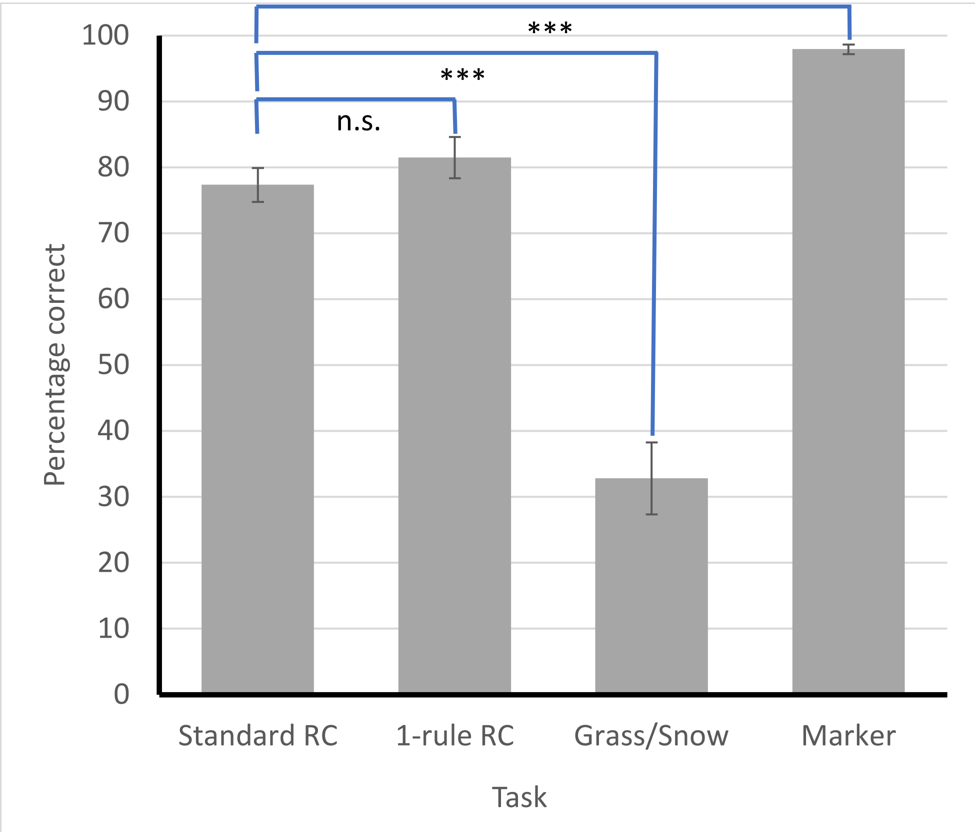
For the Grass/Snow and Marker tasks, children were first introduced to the horse and apple cards. The experimenter picked up each picture in turn, and asked the child to name it. The two pictures were then placed on the table in front of the child, and the rules of the task were explained. For the *Grass/Snow* task, the experimenter explained that when he said "apple", the child should point at the horse card; and when he said "horse", the child should point at the apple card. For the *Marker* task, the experimenter explained that when he put the star on the apple card, they should point to the horse card; and when he put the star on the horse card, they should point to the apple card.

The practice and testing procedure was the same for all four tasks. All tasks comprised four practice trials with feedback (order ABAB), followed by 16 test trials without feedback or reminders of the rules, presented in a fixed pseudorandom order (ABBABAABBABAABAB). During practice trials children were provided with feedback; the experimenter confirmed correct responses (e.g. "Yes, that's right – I said 'apple', so you had to point to the horse"), and corrected errors (e.g. "No, remember when I say 'apple', you have to point to the horse").

Results and Discussion

Accuracy on the four tasks is shown in Figure 1. No order effects were observed (main effect of order: $F(3,28)=0.938$, $p=.435$; interaction with task: $F(9,84)=0.444$, $p=.907$). To look at performance across tasks, a repeated-measures ANOVA with Task (Standard Reverse Categorization, Single-Rule Reverse Categorization, Grass/Snow, Marker) as the independent variable, and Accuracy as the dependent variable, was conducted. There was a main effect of Task, $F(3,93)=73.4$, $p<.001$, $\eta^2 = .703$. Standard Reverse Categorization task accuracy was significantly higher than the Grass/Snow task, $t(31)=8.67$, $p<.001$, 95% CI 28.8 to 46.7%; but lower than the Marker task, $t(31)=6.54$, $p<.001$, 95% CI 12.6 to 40.9%. There was no significant difference in performance between the Standard Reverse Categorization task and the Single-Rule Reverse Categorization task, $t(31)=1.46$, $p=.155$.

Figure 1. Accuracy on the four conditions in Experiment 1. Error bars show standard error of the means. The statistical significance of contrasts, described in the text, are shown in the figure (n.s. non-significant, *** p<.001).



As predicted, these results replicate previous findings: performance on the Standard Reverse Categorization task was significantly better than on the Grass/Snow task, consistent with the findings of Petersen and colleagues' (2016) meta-analysis. This confirms that preschoolers perform well on the Reverse Categorization task, despite their weak inhibitory control, and despite the task's Ab/Ba task structure. Importantly, the Reverse Categorization task is still found to be easier than the Grass/Snow task when incidental differences between the tasks are removed. However, these data offer no support for our prediction that children perform well *because* they conceptualize the Reverse Categorization task in an IC-avoiding way. Accuracy on the Reverse Categorization task was significantly lower than on the Marker task, contrary to what we would expect if *all* children used an IC-avoiding conceptualization on the Reverse Categorization task. Nor was children's performance on the Reverse Categorization task improved when children were encouraged to think of it in an IC-avoiding way. These findings offer no evidence to suggest that children are using an IC-avoiding conceptualization on the Reverse Categorization task.

So there is little evidence from Experiment 1 that the way that children conceptualize the Reverse Categorization task explains their good performance. Nevertheless, investigating children's conceptualization of a task is not straightforward, and it is possible that our efforts to get children to think about the task in a different way failed. If so, it would be premature to reject task conceptualization as a possible explanation. For example, while the "make a pair" wording in Experiment 1 failed to get *all* children to think about the task in an IC-avoiding way, it is possible that a proportion of children may nevertheless have *spontaneously* come up with a similar IC-avoiding conceptualization for themselves. If so, then task conceptualization could still explain good performance on the Reverse Categorization task (since if *some* children avoided the need to use inhibitory control, then performance in the group as a whole would be improved). One test of this hypothesis would be to alter the Reverse Categorization task in such a way as to make it *harder* for children to think about it in an IC-avoiding way. If this change led to poorer performance, that would support the hypothesis that task conceptualization can explain good performance on the Reverse Categorization task. Conversely, if performance remained good despite making it harder for children to use an IC-avoiding conceptualization, then this would be further evidence that task conceptualization does not explain good task performance. This possibility was tested in Experiment 2.

Experiment 2

To provide a further test of the hypothesis that the Reverse Categorization task is easy because children use an IC-avoiding conceptualization, Experiment 2 compared children's performance on the Standard Reverse Categorization task with a new version of the task, designed to make it harder for children to use such a conceptualization. We refer to this new version as the *Face-down Reverse Categorization* task. On the Standard Reverse Categorization task, on every trial, children can see *both* the card to be sorted, *and* the cards attached to the sorting trays. It may be that as children carry out the task, on every trial they *see* that they are making a pair of cards, comprising one horse and one apple. This repeated visual conjunction may lead them to conceptualize the task as one in which two types of card are placed together in a pair. Conceptualizing the task as one where you make a horse-and-apple pair would allow children to ignore the Ab/Ba task structure, and thus to bypass the need for inhibitory control. However, if the to-be-sorted cards were given to the child face down, the repeated pairing of one horse and one apple would be much less visually salient, making it less likely that children would conceptualize the task in an IC-avoiding way.

In the Face-down Reverse Categorization task, therefore, the experimenter told children the identity of the card before handing it to them face-down, so that the picture could not be seen. In this way children were discouraged from using a "make a pair" conceptualization, since they could not *see* that they were combining the same two pictures on every trial. If some preschoolers spontaneously use an IC-avoiding "make a pair" conceptualization on the Reverse Categorization task, then discouraging such an approach – as in the Face-down Reverse Categorization task – would lead to poorer performance than in the Standard Reverse Categorization task. To provide reference points for the different levels of performance, Experiment 2 also included the Grass/Snow, Standard Reverse Categorization and Marker task, administered as in Experiment 1.

Method

Participants

The sample size was set at 32 based on the power analysis conducted for Experiment 1. Thirty-two children participated (mean age: 43 months; range: 36 - 51 months; 17 females). Sample demographics were similar to Experiment 1.

Design

A repeated-measures design was used. Task (Standard Reverse Categorization, Face-down Reverse Categorization, Grass/Snow, Marker) was the independent variable. The dependent variable for each task was the number of correct responses (out of 16).

Materials and Procedure

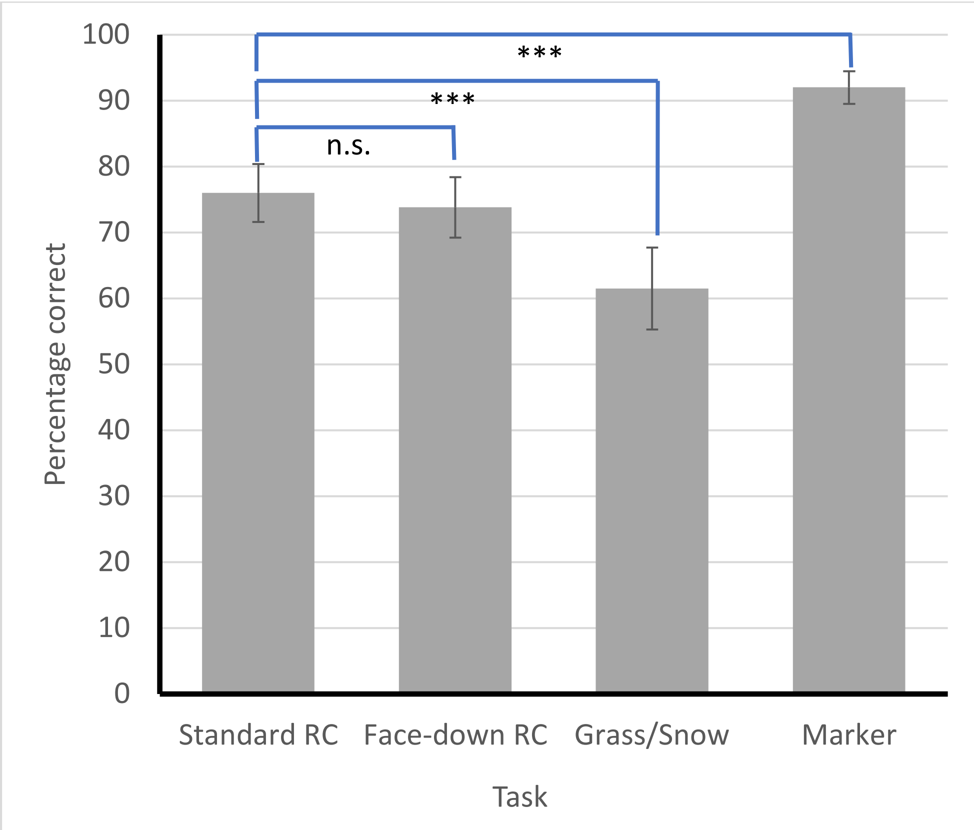
Materials and Procedure were similar to Experiment 1. The only difference concerned the Face-down Reverse Categorization task: children were not shown each picture card. Instead the experimenter looked at the card, named it, and then handed it to the child face down. Children were told not to look at the picture cards, and rarely attempted to do so.

Results and Discussion

Accuracy on the four tasks is shown in Figure 2. No order effects were observed (main effect of order: $F(3,28)=0.702$, $p=.559$; interaction with task: $F(9,84)=0.862$, $p=.562$). Accuracy was analysed in a repeated-measures ANOVA, with Task (Standard Reverse Categorization, Face-down Reverse Categorization, Grass/Snow, Marker) as the independent variable. There was a main effect of Task, $F(3,93)=12.3$, $p<.001$, $\eta^2=.288$. Accuracy on the Standard Reverse Categorization task was significantly higher than on the Grass/Snow task, $t(31)=2.44$, $p=.021$, 95% CI 2.38 to 26.5%; but lower than on the Marker task, $t(31)=4.16$, $p<.001$, 95% CI 8.17 to

23.9%. However, there was no difference in performance between the Standard Reverse Categorization task and Face-down Reverse Categorization task, t(31)=0.847, p=.403.

Figure 2. Accuracy on the four conditions in Experiment 2. Error bars show standard error of the means. The statistical significance of contrasts, described in the text, are shown in the figure (n.s. non-significant, *** p<.001).



As in Experiment 1, performance on the Reverse Categorization task was significantly higher than the Grass/Snow task, and easier than the Marker task. This suggests that the inhibitory demands of the Reverse Categorization task are significantly lower than other SRC tasks, but are still nevertheless not completely absent, since children's performance was not at ceiling. However, there was once again no support for the suggestion that the inhibitory demands of the Reverse Categorization task are reduced by the use of an IC-avoiding conceptualization. We had predicted that if children used an IC-avoiding "make a pair" conceptualization when performing the Reverse Categorization task, then their ability to do so would be impaired in the Face-down Reverse Categorization task, since children would be unable to see the cue card and so make a pair with the target card. However, performance on the Face-down Reverse Categorization task was not significantly different to that on the standard version of the Reverse Categorization task.

Thus, across two experiments, there was no support for the proposal that the Reverse Categorization task is easy because preschoolers are using an IC-avoiding conceptualization. One should always be cautious when interpreting null findings, and as Simpson and Carroll (2018) noted, studying IC-avoiding conceptualizations is challenging because the experimenter cannot be certain how preschoolers are conceptualizing a task. So strictly speaking, it remains possible that preschoolers are using an IC-avoiding conceptualization on the Reverse Categorization task – but just not the one we proposed. However, it is difficult to see what alternative IC-avoiding conceptualization children could use that would remain unaffected by either of the task manipulations reported in Experiments 1 and 2. So it is unlikely that task conceptualization can explain good Reverse Categorization performance – a conclusion that suggests we must look elsewhere for an explanation of why preschoolers find the task easy.

Experiment 3

An alternative explanation for why children find the Reverse Categorization task easy relates to the way that children respond on this task (e.g., being given a card by the experimenter and putting it into a tray). It may be that this response *takes longer* than the responses used in other SRC tasks (e.g., pointing in the Grass/Snow task). As such, children have longer to respond, and that additional time may make the task easier – perhaps because children have longer to work out the correct response (see Diamond *et al.*, 2002), or because the extra time allows incorrect responses to fade (see Simpson *et al.*, 2012), or both (Simpson & Carroll, 2019). There is evidence that interventions which slow preschoolers' responses can boost performance on some inhibitory tasks (Beck *et al.*, 2011; Carroll *et al.*, in press; Diamond *et al.*, 2002; Ling *et al.*, 2016; Montgomery & Fosco, 2012; Simpson *et al.*, 2012; Simpson & Riggs, 2007), but not all (Barker & Munakata, 2015). For example, accuracy on the Day/Night task improves when the experimenter inserts a delay between the presentation of a stimulus and the child's response (Diamond *et al.*, 2002). It is possible that on the Reverse Categorization task, the act of passing the cue card from the experimenter to the child delays their responding enough to reduce the task's inhibitory demands. If so, then performance would be better on the Reverse Categorization task than the Grass/Snow task *because* preschoolers sort cards more slowly than they point to cards.

If this were the case, then we would expect children to take longer to respond on the Reverse Categorization task than on the Grass/Snow task. To test this prediction, Experiment 3 measured children's reaction times to determine how quickly they respond on the Reverse Categorization task and the Grass/Snow task. To remove incidental differences, both tasks used an image of a sun and an image of a moon as stimuli. On the Reverse Categorization task, children were told "If I give you a *sun* card, then put it with the *moon* card. If I give you a *moon* card, then put it with the *sun* card". On the Grass/Snow task, children were told "If I say *sun,* then you point to the *moon* card. If I say *moon*, then you point to the *sun* card". If the Reverse Categorization task is easier than the Grass/Snow task because children respond more slowly when sorting cards, we would expect a clear difference in reaction times on the two tasks. Thus, the Reverse Categorization task should yield responses that are slower and more accurate, and the Grass/Snow task should yield responses that are faster and less accurate.

Method

Participants

Pilot data suggested that the effect size for this experiment would be large, with most children responding slower on the Reverse Categorization task than the Grass/Snow task. An *a priori* power analysis using G*Power (Faul et al., 2007) indicated that 19 participants were required to have 90% power for detecting a large-sized effect (0.80) with an alpha value of .05. Twenty-four preschool children participated (mean age: 49 months: range: 41-54 months; 11 females). Sample demographics were similar to Experiment 1.

Design

A repeated-measures design was used. The independent variable was Task (Reverse Categorization, Grass/Snow). There were two dependent variables: mean accuracy, and mean reaction time (on correct responses), across 16 test trials.

Materials and Procedure

The two tasks were tested in a single session and the order of presentation was counterbalanced. The Materials and Procedure for the Reverse Categorization task and Grass/Snow task were identical to Experiment 1, except that the stimulus/response pair for both tasks was “sun” and “moon” (instead of “horse” and “apple”). In addition, a video camera and tripod were used to film the experiment and to determine reaction times for each trial. Video editing software (MPEG Streamclip) was used to determine reaction times to the nearest one hundredth of a second. For the Reverse Categorization task, reaction time measurement began when the sun or moon picture was made visible to the child, and ended when the cue card first touched the sorting tray. For the Grass/Snow task, reaction time measurement began when the experimenter had finished saying the word "sun" or "moon", and ended when the child's hand touched the sun or moon picture. Children were asked to touch the card, rather than just point to it, so that reaction times could be measured more reliably. Only correct responses were coded, and reaction times of less than 300ms, or more than two standard deviations above the mean, were excluded.

Results and Discussion

Mean accuracy and reaction time for both tasks are shown in Table 1. No order effects were observed (main effect of order: $F(1,22)=0.241$, $p=.236$; interaction with task: $F(1,22)= 1.485$, $p=.236$). A t-test comparing accuracy across tasks found that children performed better on the Reverse Categorization task than on the Grass/Snow task, $t(23)=-3.62$, $p=.001$, 95% CI 12.0 to 44.2%. Mean reaction times, for correct trials only, were computed for each task. Again, no order effects were observed (main effect of order: $F(1,22)=0.154$, $p=.699$; interaction with task: $F(1,22)= 0.419$, $p=.524$). A t-test comparing reaction time for each task found a significant difference, $t(22)=8.68$, $p<.001$, 95% CI 1.34 to 2.18s, with children responding faster on the Grass/Snow task than on the Reverse Categorization task.

Table 1: Mean reaction time and accuracy by task in Experiment 3 (standard error of the mean).

	RT (in seconds)	Accuracy (%)
Standard Reverse Categorization task	3.03 (0.21)	89.1 (2.7)
Standard Grass/Snow task	1.18 (0.09)	60.9 (7.6)

Once again, children's performance on the Reverse Categorization task was better than the Grass/Snow task. This is consistent with Experiments 1 and 2, as well as with the findings from Petersen and colleagues' (2016) meta-analysis. More importantly, reaction time analysis showed that children took significantly longer to respond on the Reverse Categorization task than on the Grass/Snow task. Thus, the speculation that children might be responding more slowly on the Reverse Categorization task was supported: receiving a card and placing it in a tray takes longer than pointing to a card. This reduced speed of responding is a plausible mechanism to explain the good performance on the Reverse Categorization task (either because the additional time allows children to work out how to respond, or because the delay allows the activation of the incorrect response to fade). Experiment 3 thus offered evidence *consistent with* the suggestion that the Reverse Categorization task is easy because children respond more slowly than on other SRC tasks. However, this evidence was correlational, rather than causal. We would have greater confidence in this suggestion if it could be demonstrated that changes in the speed of responding *led to* changes in task performance. It was this aim that motivated the final experiment.

Experiment 4

Experiment 4 aimed to provide a causal test of the hypothesis that the Reverse Categorization task is easy because children respond more slowly than on other SRC tasks. To do this, children's performance was compared across the standard Reverse Categorization and Grass/Snow tasks, as well as on two new versions of these tasks: a variant of the Reverse Categorization task where children responded more *quickly*, and a variant of the Grass/Snow task where children responded more *slowly*. In the *Speeded Reverse Categorization* task, the to-be-sorted cards were placed in a pile next to the sorting trays (rather than being handed to the child one at a time by the experimenter). Children could therefore respond more quickly, as they did not have to wait to be given a card on each trial. In the *Slowed Grass/Snow* task, the experimenter kept the two response cards away from the child. On each trial, the experimenter said the cue word (either "sun" or "moon") and then waited for two seconds, before moving the response cards in front of the child, for the child to point to. This therefore introduced a delay before the child could respond. If the difficulty of SRC tasks is directly determined by the speed at which children respond, then performance on the Standard Reverse Categorization task should be better than on the Speeded Reverse Categorization task, and performance on the Standard Grass/Snow task should be poorer than on the Slowed Grass/Snow task.

Method

Participants

The sample size was set at 32 based on the power analysis conducted for Experiment 1. Thirty-two children participated (mean age: 48 months; range: 39 - 54 months; 16 females). Sample demographics were similar to Experiment 1.

Design

A repeated-measures design was used. The independent variable was Task (Standard Reverse Categorization, Speeded Reverse Categorization, Standard Grass/Snow, Slowed Grass/Snow). The dependent variable was the number of correct responses (out of 16).

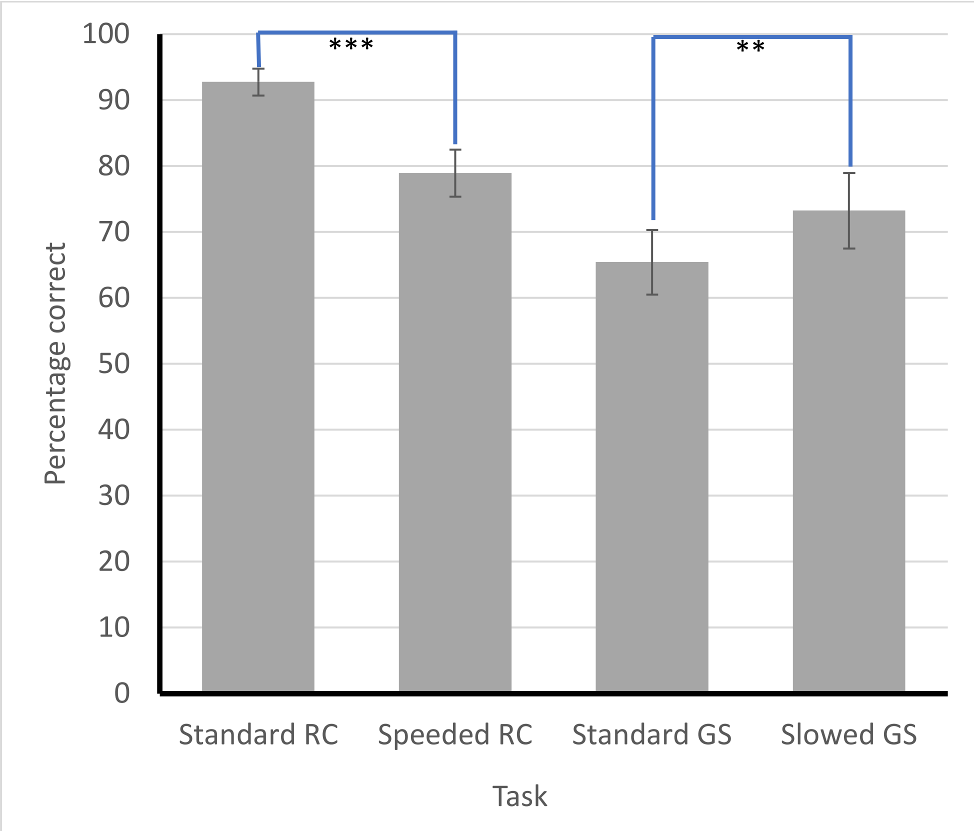
Materials and Procedure

Task order was counterbalanced, constrained so that the two Reverse Categorization tasks were in different sessions. The Materials and Procedure for the Standard Reverse Categorization task and Standard Grass/Snow task were identical to Experiment 3. In the Speeded Reverse Categorization task, the experimenter did not pass picture cards to the child. Instead, the picture cards were placed face-up in a pile between the two trays. This meant that the child could respond more quickly, simply picking up each card in turn and placing it in one of the two trays. In the Slowed Grass/Snow task, the experimenter sat opposite the child at a table. The experimenter had the two picture cards on their side of the table. On each trial, the experimenter said the cue word for that trial (either "sun" or "moon") and then waited two seconds before pushing the picture cards across the table so that the child could point to one of them. For all tasks, there were 4 practice trials with feedback, followed by 16 test trials without feedback.

Results and Discussion

Accuracy on the four tasks is shown in Figure 3. No order effects were observed (main effect of order: $F(3,28)=0.647$, $p=.591$; interaction with task: $F(9,84)=0.694$, $p=.713$). Accuracy was analysed in a repeated-measures ANOVA, with Task (Standard Reverse Categorization, Speeded Reverse Categorization, Standard Grass/Snow, Slowed Grass/Snow) as the independent variable. There was a main effect of Task, $F(3,93)=11.70$, $p<.001$, $\eta^2 =.274$. As in the three previous experiments, accuracy on the Standard Reverse Categorization task was significantly higher than on the Standard Grass/Snow task, $t(31)=5.91$, $p<.001$, 95% CI 17.9 to 37.8%. As predicted, accuracy was lower on the Speeded Reverse Categorization task than on the Standard Reverse Categorization task, $t(31)=4.01$, $p<.001$, 95% CI 6.82 to 20.9%. Also as predicted, accuracy was higher on the Slowed Grass/Snow task than on the Standard Grass/Snow task, $t(31)=2.90$, $p=.007$, 95% CI 2.30 to 13.3%.

Figure 3. Accuracy on the four conditions in Experiment 4. Error bars show standard error of the means. The statistical significance of contrasts, described in the text, are shown in the figure (** p<.01, *** p<.001).



Experiment 3 showed that children respond more slowly on the Reverse Categorization task than on the Grass/Snow task. As predicted, Experiment 4 further showed that if this speed of responding is changed, children's performance changes with it – in other words, the speed with which children respond causally affects the difficulty of SRC tasks. Performance was significantly worse on the Reverse Categorization task when responding was slowed, and better on the Grass/Snow task when responding was speeded. These data provide strong support for the hypothesis that the Reverse Categorization task is easy because children respond slowly, and that this slowing reduces the task's inhibitory demands.

General Discussion

The present article investigated why the Reverse Categorization task is easy for preschool children, despite it using Ab/Ba rules, which are typically very challenging. Two hypotheses were tested across four experiments. Across all four experiments, the Reverse Categorization task was repeatedly found to be easier than the standard Grass/Snow task (even when incidental differences between the two tasks were removed), confirming the robustness of this finding. In Experiments 1 and 2, no support was found for the hypothesis that preschoolers conceptualize the Reverse Categorization task in a way that reduces the need for inhibitory control. In contrast, Experiments 3 and 4 provided strong support for the hypothesis that the time taken to pass a cue card from experimenter to child *slowed* children's responding in the Reverse Categorization task, which reduced the task's inhibitory demands. Experiment 3 showed that children do indeed respond more slowly on the Reverse Categorization task than on the Grass/Snow task. Experiment 4 confirmed that making children respond more quickly on the Reverse Categorization task impaired their performance, whereas making children respond more slowly on the Grass/Snow task improved it. We can therefore now provide an answer to the question of why children find the Reverse Categorization task easier than the Grass/Snow task (and indeed other SRC tasks). Children take longer to respond when they sort cards than when they point, or name, or imitate – and this slowing down of responding leads to better performance.

These results pose an obvious question: if the Reverse Categorization task has only modest inhibitory demands, then is it a good measure of inhibitory control? If you want a task to measure a specific cognitive capacity, shouldn't you choose a task which taxes that capacity as much as possible? Actually, we assert that the Reverse Categorization task is a good measure of inhibitory control – it is just that, as always in developmental research, its use must be age-appropriate. The inhibitory demands on the Reverse Categorization task are reduced by children's slow responding on the task, but they are not eliminated (as they are in the Marker task – Simpson & Carroll, 2018). The Reverse Categorization task has *moderate* inhibitory demands, and is therefore ideal for testing younger preschool children who have particularly weak inhibitory control (Carlson, 2005, Figure 2).

The current results are consistent with research showing that introducing a delay before responding improves performance on a range of tasks, including on the Day/Night task (Diamond *et al.*, 2002; Ling *et al.*, 2016; Montgomery & Fosco, 2012), on counterfactual reasoning tasks (Beck *et al.*, 2011), and on tests of strategic reasoning (Carroll *et al.*, 2021). The present study, however, is importantly different from this previous research. In the Reverse Categorization task, delay is not artificially imposed, but rather is a natural consequence of the sorting behavior used in the task. Whereas previous studies used externally imposed delays to slow responding, the Reverse Categorization task simply requires the child to make their *normal* response, albeit via a means that takes a little longer to produce. Delay is a natural consequence of children's normal behavior, rather than being the product of an intervention imposed by the experimenter.

At present, it is not clear what length of delay provides the greatest boost to preschoolers' inhibitory performance. One reason for this lack of clarity is that previous studies have generally described *how* the delay was imposed, but not *how long* the delay lasted. In the current study, we know that children were taking about two seconds longer to sort in the Reverse Categorisation task than to point in the Grass/Snow task (Experiment 3). This suggests that a delay of a couple of seconds can be sufficient to improve children's inhibitory performance. Future research should investigate the dynamics of this process, and also the role of other executive functions. One possibility is that while delay reduces the inhibitory demands of SRC tasks, it also increases their working memory demands. A Dynamic Systems Framework could be applied here to unpick this potential interaction, as the framework has previously been used effectively to explore how speed of responding interacts with different executive functions during development (Spencer et al., 2001).

These results still leave open the question of which specific mechanism it is that causes slowed responding to enhance children's inhibitory performance. Two accounts that have been offered to explain this are the Passive Dissipation account (Simpson *et al.*, 2012) and the Active Computation account (Diamond *et al.*, 2002). According to the Passive Dissipation account, on SRC tasks the two possible task responses a child could make are both primed (e.g. saying "sun", or saying "moon"). At that point, the presentation of the cue stimulus creates a strong, but temporary, boost in activation to the *incorrect* response (e.g. presenting a *sun* picture boosts activation of the response of saying "sun"). If no response is made and time passes, this activation is thought to fade, and with it, the prepotency of the incorrect response. Thus, the prepotency of this response is at its strongest immediately following the presentation of the cue. When children's responding is slowed – as in the Reverse Categorization task – the prepotency of incorrect responses fades, meaning that by the time the child responds, the to-be-inhibited response is less prepotent. Conversely, the Active Computation account suggests that young children sometimes do not take the time they need to work out the correct response, and so prematurely produce the incorrect, prepotent response (Diamond *et al.*, 2002). According to this account, slowing children's responding gives them more time to work out the correct response.

The Passive Dissipation and Active Computation accounts are not mutually exclusive (Simpson & Carroll, 2019). It may be that the Reverse Categorization task is easier than other

SRC tasks both because its slowed responding allows activation of the incorrect response to fade, and also because it gives children more time to work out the correct response.

These results are also consistent with other research showing that slight changes in how children respond can significantly improve young children's inhibitory performance. Performance improves when children are asked to replace a standard response – for example, pointing with their finger – with a less familiar method of responding – such as pointing with a rotating arrow (e.g., Carlson, Moses & Hix, 1998). Such interventions have been shown to improve performance on some tasks with inhibitory demands (e.g., counterfactual reasoning tasks, Beck *et al.*, 2011; strategic reasoning tasks, Hala & Russell, 2001) but not on others (e.g., False Belief tasks, Carroll *et al.*, 2012; Grass/Snow tasks, Simpson & Riggs, 2009). One explanation for why alternative methods of responding boost inhibitory performance is that these methods slow down children's responding, in the same way that having to place the cards slows responding in the Reserve Sort task. This hypothesis might also account for the inconsistency in findings across tasks: it may be that alternative methods of responding only enhance performance when they substantially slow children's responding (Carroll *et al.*, 2021).

However, these accounts cannot explain all the circumstances in which interventions boost young children's performance on inhibitory tasks. Barker and Munakata (2015) report that performance on developmental Go/No-Go tasks improves when children are provided with reminders of the task rules, and not when responding is slowed. This finding suggests that rule maintenance can be an important aspect of successful inhibitory performance. However, the current results cannot be explained by rule reminders, since there were no additional rule reminders provided with the Reverse Categorization tasks in the four studies presented here. Rather, changes in the speed of responding offer a parsimonious account of the current data. It appears, therefore, that there is more than one way in which children's inhibitory performance can be boosted – by reminders of the task rules, and by a slowing of responding. It is for future research to elucidate the contexts in which each of these kinds of intervention are most useful.

A strength of the current study is that two alternative hypotheses were tested to address the question of why the Reverse Categorization task is easier for children than other SRC tasks. Clear evidence was obtained to support one hypothesis, and not the other. Thus we conclude that *one reason* the Reverse Categorization task is easier than other SRC tasks is because children sort more slowly than they make other responses (such as pointing, or naming objects), and this slowed responding improves inhibitory performance. However, a limitation of the current study is that it does not explore or exclude the possibility that other factors may *also* affect children's performance on these tasks. In order to test our specific hypotheses, it was necessary to remove some of the differences between the Reverse Categorization task and other SRC tasks (e.g., the congruent sorting phase was removed from the Reverse Categorization task). It is quite possible that some of the differences removed in order to match the tasks, might themselves affect task performance if re-introduced. This possibility may be a fruitful direction for future research. The present study offers strong evidence that children's slow responding in the Reverse Categorization task is one factor that affects their performance. Whether this is the single factor driving the difference in inhibitory performance, or whether it is one of several, remains to be determined.

In conclusion, the kind of analysis presented here, investigating how exactly inhibitory demands are created and eliminated in specific tasks, will help us understand what determines the need for inhibitory control *more generally* in children's everyday lives (Simpson *et al.*, 2012). There is still a lot to discover about precisely when and how delay improves performance on inhibitory tasks. It is possible that this understanding could help to create simple interventions which reduce the inhibitory demands children experience. Helping children to overcome their inhibitory weakness has the potential to aid their development across a wide range of domains.

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