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Understanding early inhibitory development:

distinguishing two ways that children use inhibitory control

Andrew Simpson[1] and Daniel J. Carroll[2]

[1]Department of Psychology, University of Essex, Colchester, Essex CO4 3SQ, UK.

[2]Department of Psychology, University of Sheffield, Sheffield S1 2LT, UK.

Corresponding author: Dr. Andrew Simpson, Department of Psychology, University of Essex, Colchester, Essex CO4 3SQ, UK. *Email*: asimpson@essex.ac.uk.

Abstract

Inhibitory control is the capacity to suppress inappropriate responses. It is regarded as a unitary construct, central to executive function and effortful control, as well as many aspects of child development. There are, nevertheless, significant gaps in our understanding of inhibition's early development, and several robust findings that remain hard to explain. These findings are outlined, and a new perspective on inhibitory control presented, which explains them by distinguishing between two ways that inhibitory control is used. According to the 'strength/endurance account', responses which are highly prepotent tax *inhibitory strength*; whereas, those which remain active for a long time tax *inhibitory endurance*. The review considers when and how these aspects of inhibition mature, before discussing their impact on development.

Introduction

Inhibitory control is the capacity to suppress an inappropriate prepotent response as it arises. It is a domain-general process which is a component of the broader psychological constructs of executive function and effortful control. Being able to suppress inappropriate prepotent responses – that is, responses which have been triggered despite being incompatible with current goals – is central to early development. Evidence from two decades of research suggests that inhibitory control undergoes rapid development in early childhood, with floor-to-ceiling changes in performance on many inhibitory tasks over the course of a few years (Petersen, Hoyniak, Quillian, Bates & Staples, 2016). These improvements in inhibitory control underpin important and diverse aspects of development, including changes in cognitive, social and emotional domains (e.g., Carlson & Moses, 2001; Kim, Nordling, Yoon, Bolt & Kochanska, 2013; Murray & Kochanska, 2002).

While an abundance of correlational research tells us that inhibitory control is influential in early development, some fundamental questions about the nature of inhibitory control remain unresolved. In this article, we address two of these fundamental questions. First, if inhibitory control is a single ability – as is generally held to be the case – then why are seemingly similar inhibitory tasks passed by children at such different ages? And second, if inhibitory control is a single ability, then why does study after study show that inhibitory tasks cluster in *two* distinct factors, rather than one?

To consider the first question: by definition, any valid measure of inhibitory control should assess children's ability to suppress an inappropriate response. We might therefore expect that such tasks would be passed at similar ages, as children transition from weak inhibitory control (when they fail inhibitory tasks) to strong inhibitory control (when they pass inhibitory tasks). However, this is not the case. For example, some infant search tasks which tap inhibitory control are passed by around the end of a child's first year (Diamond & Gilbert, 1989). Conversely, the Spatial Conflict inhibitory task is typically passed by the child's third birthday (Gerardi-Caulton, 2000). The Day/Night task is not usually passed until around five years of age (Gerstadt, Hong & Diamond, 1994). And the Simon Says task remains challenging for many children until their seventh birthday (Strommen, 1973).

This variability is convincingly shown by a meta-analysis of 198 studies measuring children's inhibitory control (Petersen et al., 2016). This meta-analysis reported data on the difficulty of a group of seemingly similar inhibitory tasks. Petersen and colleagues established the *useful age range* of these tasks – that is, the age range at which mean group accuracy was between 20% and 80% – and found it to vary widely (see Figure 1 and Table 1). These tasks are all regarded as good measures of inhibitory control, and are frequently used. Yet together they present a paradox: how can deploying inhibitory control be both simple for most 3-year-olds (when measured using the Spatial Conflict task), and at the same time challenging for many 6-year-olds (when measured with the Simon Says task)? For tasks that supposedly measure the same thing, this diversity in performance is striking. One might implicitly assume that different tasks require different "amounts" of inhibition; but unless we can explain *how* these differences come about, then we are choosing to ignore, rather than to understand, these differences. As we will show, while it is possible to account for much of this diversity using current theory, some findings remain hard to explain.

The second question we address is that, if inhibitory control is a single construct, why do factor analyses frequently show that inhibitory tasks load onto two factors, rather than one (e.g., Carlson & Moses, 2001; Murray & Kochanska, 2002)? This finding has been replicated many times, and various proposals have been offered to explain it (e.g., Carlson & Moses, 2001; Garon, Bryson & Smith, 2008; Zelazo & Mueller, 2002). For example, one proposal distinguishes between “Simple” and “Complex” inhibitory tasks (Garon et al., 2008). Simple tasks are those that require children to withhold a *single* response (e.g., a direct reach in a search task – Diamond & Gilbert, 1989), whereas Complex tasks require children to choose between alternative ways of responding (e.g. saying “Night” or “Day” on the Day/Night task – Gerstadt, Hong & Diamond, 1994). This and other accounts have inspired extensive experimental work which has contributed greatly to our understanding of early development. Nevertheless, as we will discuss, all these accounts struggle to explain important aspects of the available data. Thus, the fundamental question of why a single construct should load onto two factors remains unresolved.

In addressing these two questions, we look closely at the ways in which different tasks tax inhibitory control, and offer an integrated view of how inhibitory control emerges. This will allow us to identify two distinct ways of taxing inhibitory control that we believe must be separated, but which have up to now been conflated. To explain why inhibitory tasks (i) vary so much in their difficulty, and (ii) load onto two factors rather than one, we first review what is currently known about inhibitory development, highlighting a number of unexplained findings. We then set out our proposal for how these findings can be explained. Finally, we discuss when and how inhibitory control develops, before considering the wider implications of the proposal for childhood development.

Question 1: Why do inhibitory tasks differ so much in their difficulty?

To understand why inhibitory tasks vary so much in their difficulty, we need to consider where the need for inhibition comes from in the first place. By definition, inhibitory tasks are difficult because they require children to suppress a prepotent response. Knowing where prepotency (that is, the need for inhibitory control) comes from is the first step towards understanding why a particular task may be more or less challenging for young children. To date, no coherent account has been proposed to explain how prepotent responses arise in developmental tasks. To address this issue, we now present a brief overview of what is known about how inhibitory demands arise, as a first step towards explaining why inhibitory task difficulty varies. As we will show, previous research allows us to explain why *some* tasks are harder than others – but there remain several important unexplained findings.

The best current answer for where prepotency comes from is that it arises through the interaction of two task factors. The majority of research on this topic comes from Stimulus-Response Compatibility (SRC) tasks, a family of inhibitory tasks including the Day/Night task (Gerstadt et al., 1994), the Grass/Snow task (Simpson & Riggs, 2009), and the Hand Game (Simpson & Riggs, 2011). SRC tasks present children with one of two different stimuli, and require them to make one of two responses, over a series of trials (e.g., saying "black" to a white card and "white" to a black card). SRC tasks are known to be difficult because of a combination of two factors: (i) the strength of the association between the stimuli and responses used on the task (e.g., Simpson & Riggs, 2005b; Simpson, Carroll & Riggs, 2014, Simpson, Upson & Carroll, 2017), and (ii) the child's intention to make specific responses on the task (e.g., Diamond, Kirkham & Amso, 2002; Simpson & Riggs, 2005a; Simpson et al., 2012).

We illustrate how these two factors give rise to a prepotent, to-be-inhibited response using the Black/White task as an example (Simpson & Riggs, 2005a; Vendetti, Kamawar, Podjarny & Astle, 2015). First, in the Black/White task, there is an obvious, association between each stimulus and the to-be-inhibited response: the *black* card is associated with the response "black", and the *white* card is associated with the response "white". Second, the child is told that they will need to make one of two responses: either to say "black", or to say "white". Because the child intends to make these two specific responses during the task, both are *primed* – that is, partially activated so that they can be made quickly. In consequence, when the *black* card is presented, its association with the primed response of saying "black" means that this incorrect response is activated further. This incorrect response of saying "black" is thus activated much more than the correct response of saying "white". In consequence, inhibitory control is required to suppress the triggered but incorrect response. The greater the gap in activation between the correct and incorrect responses, the greater the prepotency, and thus the more inhibitory control is required. Once the incorrect response has been suppressed, the child can simply make the correct response instead.

Performance varies a great deal between the easiest and hardest SRC tasks (Carlson, 2005; Petersen et al., 2016). For example, based on Petersen and colleagues' (2016) meta-analysis, ceiling performance on the Baby Stroop task (Hughes & Ensor, 2005) is typically reached by around three years. However, at the same age, performance on the Black/White task is at *floor*: ceiling performance is not reached for another two years. The best current explanation for these differences suggests that task difficulty depends principally on the *strength of association between the stimuli and responses* used in these tasks. These associations determine the relative activation of the to-be-inhibited and to-be-produced responses in each task, and thus the degree of prepotency on the task.

As an illustration, the Black/White task reflects the *maximum difficulty* of suppressing a prepotent response, we suggest, because the stimuli trigger the to-be-inhibited response as much as possible, while triggering the to-be-produced response as little as possible. On every trial, the stimulus is strongly associated with (and thus strongly activates) the to-be-inhibited response, while having very little association with the to-be-produced response.

This gap between the activation of the to-be-inhibited and to-be-produced responses means the task's inhibitory demands are maximised. Conversely, on the Baby Stroop task, the stimulus on a trial triggers the incorrect response far less. Children are told to say "mommy" to a small stimulus, and "baby" to a large stimulus. The labels "mommy" and "baby" are only moderately associated with the concepts *large* and *small*. As a consequence, because the stimuli on the Baby Stroop task are only moderately associated with the to-be-inhibited response, that response is activated less strongly. The relative gap in activation between responses is therefore reduced, so the inhibitory demands are less, and the task is easier as a result.

So, the difficulty of SRC tasks appears to depend on the difference in activation between the to-be-inhibited and to-be-produced responses. As children get older, they become able to suppress larger and larger differences in activation – starting with small differences in activation on the Baby Stroop task, and ending with much larger differences in activation on the Black/White task. We will henceforth refer to this ability to overcome increasingly large differences in activation of the to-be-inhibited and to-be-produced response as *Inhibitory Strength*. Thus, as children's inhibitory strength increases, they become able to overcome larger difference in activation of these responses.

This account of prepotency can also be applied to the widely discussed distinction between Simple and Complex inhibitory tasks (Garon et al., 2008). As previously noted, Simple tasks require children to withhold a single response. For example, in the Detour Reach task, infants sit in front of a barrier with an object behind it (Diamond, 1990; Diamond & Gilbert, 1989). In order to get the object, the infant must suppress the single response of making a direct reach towards it, and instead make a detour reach around the barrier. In contrast, Complex tasks require children to choose between alternative ways of responding – for example, on the Day/Night task, children must select between saying "night" and "day".

Complex tasks are typically harder than Simple tasks (Garon et al., 2008). This is unsurprising, since they have both greater working memory demands and greater prepotency than Simple tasks (Carlson & Moses, 2001; Garon et al., 2008). The need to maintain two alternative ways of responding, rather than just one, necessarily means that Complex tasks require two rules to be held in working memory. In contrast, Simple tasks involve just a single response, so there is no need to maintain multiple rules. Complex tasks *also* have greater prepotency than Simple tasks. In Complex tasks, the to-be-inhibited responses are highly prepotent because children intend to make them at some point in the task – this is necessarily true, since the to-be-*inhibited* response on one trial (e.g., saying "black" to a *black* card) is also the to-be-*produced* response on another trial (saying "black" to a *white* card). Suppressing the to-be-inhibited response in a Complex task taxes inhibitory strength, making these tasks difficult for preschoolers. Conversely, in Simple tasks, there is just a single response to be inhibited at all times (e.g., making a direct reach). There is no intention to make this response during the task; it is therefore not primed; and so its prepotency is low. Suppressing the to-be-inhibited responses in Simple tasks therefore requires little inhibitory strength, making them relatively easy for preschoolers.

While much of the variation in inhibitory task difficulty can be explained, there remain two important findings which cannot. Both problems relate to a specific type of Simple task. While most Simple tasks are passed during infancy or the early preschool years, one group of Simple tasks is remarkably challenging for preschoolers. This group of tasks is sometimes referred to as "Delay of Gratification" tasks (e.g., Atance & Jackson, 2009; Mischel, 2014; Steelandt, Thierry, Broihanne & Dufour, 2012). For example, the Gift Delay task (like all Simple tasks) requires children to suppress a single response – that of looking at a gift while it is being wrapped. There are no complicated rules to remember; children only need to remember not to look at the gift. Also, this single response should be suppressed for the entire duration of the task. So children do not intend to make the response at any point, reducing its prepotency. In this sense, the Gift Delay task is clearly a Simple task, and thus makes scant demands on inhibitory strength or on working memory. Yet preschool children find the task difficult, and failures to suppress the to-be-inhibited response are common. If both prepotency and working memory demands are low on this task, why is it – and other Delay of Gratification tasks – so difficult for preschool children?

It is also hard to explain why inhibitory tasks are sometimes made *easier* when children are asked to slow their responding, but are sometimes made more *difficult*. Introducing a delay boosts performance on a range of inhibitory tasks (Diamond et al., 2002; Simpson & Riggs, 2007; although see Barker & Munakata, 2015). For example, performance on the Day/Night task improves when a delay is inserted between the presentation of a stimulus and children's response (Diamond et al., 2002). However, elsewhere, introducing a delay *impairs* children's performance. In Delay of Gratification tasks, delay makes it more likely that children will fail to suppress the to-be-inhibited response. So, for example, in the Marshmallow task children are told that they can either have one treat now, or two treats later (Mischel & Metzner, 1962; see Mischel, 2014, for a review). Most children initially resist choosing the single treat. Their inhibitory strength seems sufficient to allow this choice. Nevertheless, as the delay continues, it becomes increasingly likely that children will fail to suppress the to-be-inhibited response of eating the single treat, with preschool children struggling to resist for more than about five minutes (Protzko, 2018). Thus, in the Marshmallow task, delay makes it harder to suppress the to-be-inhibited response. By definition, inhibitory tasks tap the same construct, so for this simple manipulation to have such contrasting effects is striking.

So while we can account for some of the variation in inhibitory task difficulty, these two findings remain unexplained. Even more questions are raised when considering the lack of clarity over whether inhibitory control really is one single construct, or two – highlighted by the many factor-analytic studies that have studied the development of inhibitory control. It is to these studies that we now turn.

Question 2: Why do inhibitory tasks load onto two factors, not one?

It has long been observed that preschoolers' performance on inhibitory tasks reliably differentiates into two factors (e.g., Carlson & Moses, 2001; Murray & Kochanska, 2002). The first study to show this was reported by Carlson and Moses (2001). They conducted a comprehensive battery study that included ten different measures of inhibitory control. Using confirmatory factor analysis, they reported that performance on these tasks was best explained by two factors, not one. Thus, tasks that were all supposedly measuring the same construct instead appeared to be tapping two different constructs. Subsequent research has replicated this finding, and a number of accounts have been offered to try to explain this distinction (see Garon, 2016, for a review). However, as we will show, none of these accounts can fully explain children's behaviour across these tasks.

One commonly cited account suggests that the division of inhibitory tasks into two factors reflects a distinction between "hot" and "cool" executive function (e.g., Brock, Rimm-Kaufman, Nathanson & Grimm, 2009; Kim et al., 2013; Willoughby, Kupersmidt, Voegler-Lee & Bryant, 2011). "Hot" executive function is proposed to be used in tasks which have high motivational or emotional salience, such as those involving highly desirable rewards (Zelazo

& Mueller, 2002). For example, in a "hot" Delay of Gratification task, there is a desire for immediate gratification. In contrast, "cool" executive function is said to be used with tasks without such a motivational component, such as the Day/Night task. The "hot" versus "cool" distinction was originally drawn from work with brain-injured adults, who showed atypical patterns of performance on elaborate tasks involving gains and losses of rewards (Bechara, Damasio, Damasio & Anderson, 1994). Extending this distinction in seeking to explain the development of executive functions in young children might seem a plausible idea, and is one that has been cited quite widely.

Experimental evidence has shown, however, that motivational salience alone is not sufficient to make an inhibitory task "hot". Allan and Lonigan (2011, 2014) conducted an elegant factor-analytic study where they created a series of "hot" tasks simply by adding motivational salience to "cool"' tasks (for example, a Grass/Snow task in which children received a reward for good performance). Thus, these "hot" and "cool" tasks were very well matched for incidental task demands, so that they differed only in terms of motivational salience. However, data from both kinds of task were best explained by a single factor, not two, indicating that "cool" tasks do not become "hot" simply by adding a reward. Clearly, the presence or absence of a strong motivational component does not cause inhibitory tasks to load onto two distinct factors.

An alternative proposal has suggested that what best accounts for inhibitory tasks loading onto two factors is the presence (or absence) of *motivational conflict* (Garon, 2016). This term describes the child having two simultaneous but conflicting motivations within a single task. So for example, in a Delay of Gratification task, there is conflict between the desire for short-term gratification (e.g., getting one sweet now) and the desire to have the largest reward possible (getting two sweets later). The suggestion is that tasks involving motivational conflict load onto one factor, and tasks without motivational conflict load onto a separate factor. While this account explains most data very well, it cannot explain the findings of Carlson and Moses's (2001) original factor analysis. That study reported data from ten tasks, of which only one was high in motivational conflict (the Gift Delay task). The other nine tasks involved little or no motivational conflict. Nevertheless, five tasks loaded on one factor (the Day/Night, Grass/Snow, Bear/Dragon, Dimensional Change Card Sort, and Whisper tasks) and four tasks loaded onto the other factor (the KRISP, Pinball, Tower, and Gift Delay task; the tenth task, Spatial Conflict task, loaded on both). So, the two factors must represent something other than the presence or absence of motivational conflict.

In their seminal study, Carlson and Moses (2001) suggested that these two factors were distinguished by their working memory demands, with tasks that made high working memory demands loading onto one factor, and tasks with low working memory demands loading onto a separate factor. However, this distinction provided only a partial explanation of their data. For example, the Whisper task, which required children to whisper the names of cartoon characters, had particularly low working memory demands (a single rule: "just remember to whisper"), but loaded onto the "high working memory" factor. Conversely, the KRISP task, which required children to find a precise visual match to a target picture from four similar options, had high working memory demands ("keep track of which features you have checked in which pictures, and whether those features differ across any of the other three pictures"). Nevertheless, this task loaded on the "low working memory" factor.

There is no doubt that inhibitory tasks load onto two factors. This suggests both that the status of inhibitory control as a unitary construct is in doubt, and that we lack a clear understanding of why tasks supposedly tapping the same construct appear to be measuring two different things. There remain consistent and hard-to-explain discrepancies between the patterns of data observed, and the explanations offered. In short, none of the previous explanations can fully explain children's task performance.

How can we explain these inconsistent findings? Revising our view of inhibitory control.

To explain *both* why inhibitory tasks differ so much in difficulty, *and* why inhibitory tasks load onto two factors rather than one, we suggest that what is needed is a fundamental rethink about how to-be-inhibited responses tax inhibitory control. We propose that, while inhibitory control can rightly be regarded as a single component of executive function, the tasks that tap inhibitory control can do so in *two distinct ways*. This distinction is best illustrated by considering the type of response the child needs to inhibit.

Some measures of inhibitory control require children to suppress a response that is highly prepotent (e.g., the Black/White task). Other measures of inhibitory control require children to suppress a response that remains active for a long time (several minutes or longer – such as on a Delay of Gratification task). Both types of task involve children using inhibitory control to suppress an inappropriate response. However, the aspect of inhibitory control taxed in each task is importantly different: in the former case, what's crucial is *how strong* the to-be-inhibited response is, while in the latter case, what's crucial is for *how long* the to-be-inhibited response lasts. We refer to the former category of task as taxing inhibitory *strength* (suppressing responses that are high in prepotency), and the latter category of task as taxing inhibitory *endurance* (suppressing responses that remain active for a long time). This explicit separation of inhibitory control tasks into those that tax inhibitory strength and those that tax inhibitory endurance – and the characterizing of prepotent responses according to their magnitude and their duration – can explain all the discrepant findings presented in this article.

This Strength/Endurance account of inhibitory control offers a parsimonious explanation for why some Simple tasks are easy, while others are more challenging. We know that Simple tasks are low in prepotency, and have low working memory demands, and that therefore we would expect them to be easy for most children. However, it is clear that one kind of Simple task, the Delay of Gratification task, is difficult for young children. This difficulty arises despite Delay of Gratification tasks making little demands on inhibitory strength: most preschoolers are well able to suppress the to-be-inhibited response on a Delay of Gratification task *in the short-term* (e.g., Pecora, Addessi, Schino & Bellagamba, 2014), indicating that inhibitory strength is not particularly taxed. Failures on Delay of Gratification tasks usually arise as the task continues. It is the need to *sustain* suppression of the to-be-inhibited response that makes Delay of Gratification tasks difficult. The key to this difficulty is not how prepotent the to-be-inhibited response is, but for how long it must be suppressed. Delay of Gratification tasks are difficult not because they tax inhibitory strength, but because they tax inhibitory endurance. It is this that makes Delay of Gratification tasks harder than most Simple tasks.

The Strength/Endurance account can also explain the contrasting effects of delay on inhibitory tasks. For tasks tapping inhibitory *strength*, delay makes prepotent responses easier to suppress, and so reduces task difficulty (Ling, Wong & Diamond, 2016; Montgomery & Koeltzow, 2012; Simpson et al., 2012). Two accounts have been proposed to explain how delay makes suppressing prepotent responses easier. The first, the active computation account, proposes that delay provides time for the correct response to be actively calculated (Diamond et al., 2002). Once the correct response has been worked out, the incorrect response loses its prepotency, and the need for inhibitory control is therefore eliminated (e.g., in the Black/White task, when a *black* card is shown, the introduction of a delay provides time for children to work out that the correct response for that trial is to say "white". This knowledge means that the incorrect response of saying "black" loses its prepotency.

The second account, the passive dissipation account, proposes that delay provides time for the incorrect response to passively fade, reducing the need for inhibitory control (Simpson & Riggs, 2007). In inhibitory tasks where a prepotent response is triggered by the stimulus onset (e.g., presenting a *black* card in the Black/White task), evidence suggests that when a new stimulus is presented, the activation of the associated incorrect response is transitory (Ambrosi, Servant, Blaye & Burle, 2019; Iani, Stella & Rubichi, 2014). Introducing a delay allows time for this incorrect response to pass its peak activation and fade, so that less inhibitory control is then required to suppress it. These two accounts are not mutually exclusive. But irrespective of the precise mechanism, delay reduces the activation of the to-be-inhibited response in tasks which tax inhibitory strength, and in doing so improves performance.

In contrast, on tasks that tap inhibitory *endurance*, neither of these possible mechanisms can arise. On Delay of Gratification tasks, for example, the activation of the to-be-inhibited response can't be eliminated simply by working out the appropriate response – if a child wants to eat the marshmallow, then working out that the appropriate response is to *not* eat the marshmallow does nothing to eliminate that desire. Similarly, the activation of the to-be-inhibited response does not passively fade away. A child that wants to eat the marshmallow in front of them (i.e., a child that is motivated to produce the to-be-inhibited response) will continue to experience that motivation even after time has passed. Thus, on Delay of Gratification tasks, the prepotency of the to-be-inhibited response (though modest) does not diminish over time. On the contrary, as the delay continues, the risk of failure *accumulates*, and so delay impairs performance on these tasks.

The Strength/Endurance account also provides a simple and effective explanation for why inhibitory tasks load onto two factors in factor-analytic studies. We propose that what distinguishes these two factors is whether the task in question taxes inhibitory strength or inhibitory endurance. Rather than describing these two factors as "hot" versus "cool", or "motivational conflict" versus "no motivational conflict", or "high working memory" versus "low working memory", we suggest they are best considered as "taxes inhibitory strength" versus "taxes inhibitory endurance". In other words, does the task require children to briefly resist a highly prepotent response, or does it require them to overcome a response that is less prepotent but lasts a long time? The "inhibitory strength" factor comprises tasks such as the Day/Night task and the Whisper task, in which the to-be-inhibited response receives strong activation that lasts a short time – taxing strength, but not endurance. In contrast, the "inhibitory endurance" factor comprises tasks such as the Gift Delay task and the KRISP task, in which the prepotency of the to-be-inhibited response is more modest but lasts for a longer time – taxing endurance, but not strength. Table 2 offers a suggested taxonomy of the strength and endurance demands made by some common measures of inhibitory control. While these tasks do appear to principally tax *either* strength *or* endurance, in theory it should be possible for a task to tax both.

Importantly, the Strength/Endurance account can explain findings that other accounts cannot. For example, Allan and Lonigan (2011, 2014) tested two sets of tasks that differed in their motivational component, and found that both sets loaded onto a single factor. This is inconsistent with the "hot"/"cool" account, but entirely consistent with the Strength/ Endurance account, which suggests that these tasks *should* load on a single factor, since they all tap inhibitory strength. Likewise, the Strength/Endurance account can explain the otherwise anomalous finding from Carlson and Moses's (2001) factor-analysis study – in particular, why the Whisper task loads on the same factor as the Day/Night task, and the KRISP task loads on the same factor as the Gift Delay task. In the Whisper task, children must briefly suppress their tendency to respond with their typical voice as each new stimulus is presented. In consequence, this task requires brief suppression, and loads on the inhibitory strength factor (as does the Day/Night task). In the KRISP task, children must delay making a response while they work through the four pictures searching for differences between these pictures and the target picture. Thus, this task taxes inhibitory endurance, and loads with the Gift Delay task.

The studies by Carlson and Moses (2001) and Allan and Lonigan (2011, 2014) greatly enhance our understanding of why inhibitory tasks load onto two factors, in large part because of their clear methodological descriptions. An examination of other factor-analytic studies suggests that their data are often less straightforward to interpret. A common problem is that tasks are not described in sufficient detail to determine whether they tax inhibitory strength or inhibitory endurance. This is perhaps not surprising, since the authors would have been unaware of this particular distinction, and cannot be criticised for not anticipating it. Nevertheless, difficulties in interpreting the data remain.

As an example, on the Tower task – a Go/No Go variant – children take turns with an experimenter adding blocks to a tower. This task might be assumed to tax inhibitory strength, and as such, should be expected to load with the Day/Night task, and not the Gift Delay task. However, the picture gleaned from the data is not so straightforward. The Tower task has variously been reported to load with the Day/Night task (Pauli-Pott, Dalir, Mingebach, Roller & Becker, 2014); with the Gift Delay task (Carlson & Moses, 2001); or with both, in a single factor (Denham, Warren-Khot, Bassett, Wyatt, & Perna, 2012). We suggest that whether the Tower task taxes inhibitory strength or inhibitory endurance depends on how it is administered. Crucially, on No-go trials, how long does the experimenter wait before adding a block? If the block is added quickly, the task may tax inhibitory strength; if it is added after a longer delay, it may tax inhibitory endurance. Many studies do not describe the Tower task (or other tasks) in sufficient detail to determine which aspect of inhibition is being taxed. Greater clarity on this point will be essential in future studies.

The proposal that the two inhibitory factors are best distinguished by considering the temporal aspect of the child's response is not entirely new. Indeed, many previous accounts note that tasks which load on one of the two factors require children to sustain suppression of a prepotent response over time. Carlson and Moses (2001) suggested that tasks which loaded on their "low working memory" factor required children to *delay* responding. Likewise, Allan and Lonigan (2014, p43) suggested that "hot" tasks required children to delay responding (in addition, these tasks involve to-be-inhibited responses with high motivational salience). Garon (2016) proposed that "hot" tasks required children to resolve motivational conflict between short- and long-term goals, which inherently requires delaying responding in order to achieve the long-term goal. By our account, inhibitory endurance is simply the ability to achieve the ongoing suppression of an inappropriate prepotent response. Thus, proposing inhibitory endurance as a distinct factor from inhibitory strength provides a succinct explanation of why inhibitory tasks load onto two separate factors.

How do inhibitory strength and inhibitory endurance develop?

Acquiring a better understanding of how these two distinct ways of using inhibitory control develop should be a primary goal for future research. To that end, we outline briefly what is currently known about the development of inhibitory strength and inhibitory endurance.

There is considerable evidence to suggest that inhibitory strength improves through infancy and into early childhood (e.g., Carlson, 2005; Garon et al., 2008; 2016; Petersen et al., 2016). Put simply, what develops is the ability to suppress responses of greater and greater prepotency. The first measures of inhibitory strength to be mastered are infant-appropriate Simple tasks, such as the Detour reach task (Diamond & Gilbert, 1989). In these tasks, inhibitory demands are particularly modest, as children do not intend to make the to-be-inhibited responses in these tasks (e.g., making a direct reach). These tasks are generally passed by around 12 months. Children next become able to cope with the inhibitory demands of Complex tasks, such as the Baby Stroop task (resist saying "baby" to a picture of a small cup – Hughes & Ensor, 2005). These tasks make moderate demands on inhibitory strength, because of the weak stimulus-response associations on the task (i.e., the word "baby" is only moderately associated with the concept *small*). Finally, children become able to pass the most demanding tests of inhibitory strength, in which children are required to resist strong stimulus-response associations (e.g., resisting saying "black" to a *black* card in the Black/White task – Simpson & Riggs, 2005a).

Thus, inhibitory strength typically increases until around the end of the fifth year, when it reaches broadly adult-like levels. At this age, children are unlikely to make an error because of poor inhibitory strength. Nevertheless, children older than five years can still make errors on such tasks – this is particularly likely to occur when task cues are difficult to monitor. For example, the Simon Says task taps inhibitory strength, yet remains difficult for many 5-year-olds (Strommen, 1973). On this Go/No-go variant, children are told to follow the experimenter's instructions on Go trials, but not on No-go trials. Both the Go and No-go cues are presented by the same instructor, in the same tone of voice. The only thing that distinguishes them are the words "Simon says…", placed before Go trials. Many 5-year-olds find this task difficult because they struggle to detect the no-go cue (i.e., the *absence* of the words “Simon Says…” – Marshall & Drew, 2014; see also Winter & Sheridan, 2014). This difficulty with cue monitoring arises not just in measures of inhibitory control, but across a range of executive functions (see, Chevalier, 2015, for a review). For example, children struggle to identify non-transparent switch cues on tests of cognitive flexibility (e.g., Chevalier, Wiebe, Huber & Espy, 2011). Nevertheless, while cue monitoring can remain a challenge, we suggest that by about five years of age an important milestone is reached in inhibitory development: at this age, typically developing children have sufficient inhibitory strength to stop *any* prepotent response.

An important aim for future research is to identify the mechanisms that underpin developmental improvements in inhibitory strength. We suggest that both improvements in *capacity* and improvements in *strategy* should be considered. On the first point, the development of inhibitory strength may involve increases in the capacity to directly reduce the activation of to-be-inhibited responses. This is the prevailing view in the adult literature: this overt stopping function is thought to arise within a specific neural pathway – one deploying the prefrontal cortex, in conjunction with the basal ganglia (see Aron, Robbins & Poldrack, 2004, 2014). Most adult research on inhibitory control uses Go/No-go tasks (particularly the Stop-Signal variant – e.g., Aron et al., 2003). As with developmental tasks, adult Go/No-go tasks require the brief suppression of prepotent responses. The most parsimonious way to reconcile the adult and developmental literatures is to propose that Go/No-go tasks tax inhibitory strength in both adults and children. From this perspective, improvements in inhibitory strength during development could be explained by the maturation of the fronto-basal-ganglia networks (Rubia, Smith, Taylor, & Brammer, 2007; Smith et al., 2017).

An alternative *strategic* mechanism to explain improvements in inhibitory strength proposes that children learn to slow their responding in tasks in which they detect the presence of an inappropriate prepotent response (Simpson et al., in press). This view suggests that inhibitory strength increases as children acquire a “slow down” strategy, rather than as the product of increasing capacity for overtly stopping.

Understanding the development of inhibitory endurance is less straightforward, as to do so we first need to identify which tasks best measure this aspect of inhibitory control. Most of the data concerning the development of inhibitory endurance has come from Delay of Gratification tasks. However, there are several different types of Delay of Gratification task, and so we need to consider which type measures inhibitory endurance the best. Recently, useful steps have been taken in this regard: Garon (2016) identified three categories of Delay of Gratification task, labelled *Choice*, *Wait* and *Temptation* tasks. Choice tasks typically present children with a series of decisions in which they choose between receiving a small treat now, or a larger treat later. In Wait tasks, children are placed in front of a desirable reward, and told that if they wait until the experimenter returns, they will receive a larger reward. In Temptation tasks, children are asked to suppress a response to a tempting stimulus (for example, they are told not to look while an exciting gift is being wrapped). On Choice and Wait tasks, successful waiting means the child gets a larger reward, while on Temptation tasks, successful waiting means the child receives social approval.

All of these tasks involve some form of temporal judgement about rewards. However, we suggest that only Wait tasks and Temptation tasks measure inhibitory endurance, since unlike Choice tasks, they place children in a waiting situation that continues over time. The tasks involve a wait during which the child must maintain the suppression of a prepotent response. While Choice tasks oblige the child to make a one-off selection between alternatives – a smaller reward *now*, or a larger reward *later* – there is little need for inhibitory endurance. As the decision is made at a single moment in time, there is no opportunity to rescind it, and so no need to maintain that choice.

Based on the data from Wait and Temptation tasks, it is clear that inhibitory endurance improves during the preschool years (e.g., Atance & Jackson, 2009; Mischel, 2014; Steelandt et al., 2012; Pecora et al., 2014). However, at present the literature does not allow us to draw precise conclusions about its developmental trajectory. It was only possible to make precise proposals concerning the development of inhibitory strength because of the recent meta-analysis of Petersen and colleagues (2016), which considered development over several years across many tasks. A similar meta-analysis of Delay of Gratification tasks is needed before such proposals can be made about the development of inhibitory endurance.

Despite the limitations of the current data, we speculate that the development of inhibitory endurance is likely to be considerably more protracted than inhibitory strength. Delay of Gratification tasks require children to use their inhibitory endurance to resist tempting stimuli. There is evidence that even adults' inhibitory endurance is sometimes insufficient to resist particularly strong temptations (Park, Peterson & Seligman, 2006; Tsukayama, Duckworth & Kim, 2012). Since adults' capacity to resist temptation is far from perfect, it will be an important challenge for developmental researchers to track how inhibitory endurance develops – and in particular to determine when "adult" levels of endurance are reached.

Finally, how do improvements in inhibitory endurance come about? There is evidence that with age, children increasingly use strategies to resist responding on tests of inhibitory endurance (for example, they resist playing with a forbidden toy by engaging in distracting activities: Pecora et al., 2014). Use of this "distracting" strategy increases with age, consistent with the idea that improvements in inhibitory endurance involve an increase in strategy use. However, there is also evidence from the adult literature to suggest that tasks which tax inhibitory endurance can activate the fronto-basal-ganglia networks described above (e.g., Abi-Jaoude et al., 2018; Berman et al., 2012). If these networks are involved with inhibitory endurance, then it is plausible to suggest that their maturation leads to an increased capacity for inhibitory endurance. The protracted development of inhibitory endurance is consistent with changes in both strategy use *and* capacity driving improvement at different ages, though it is for future research to comprehensively address this issue.

The real-world importance of inhibitory strength and inhibitory endurance

The distinction drawn between inhibitory strength and inhibitory endurance is not merely useful for describing performance on lab-based tasks. It also has clear relevance to important real-world outcomes. Both inhibitory strength and inhibitory endurance are associated with important – but different – aspects of cognitive, social and emotional development. In preschool children, inhibitory strength is associated with several different kinds of reasoning, as well as with a range of early academic outcomes. In contrast, inhibitory endurance is associated with both concurrent and later measures of self-regulation, with measures of behavioural adjustment and emotional regulation, and with academic outcomes in adolescence. As we now illustrate, the Strength/Endurance distinction is likely to have impact well beyond the study of inhibitory control itself.

Improvements in inhibitory strength are associated with the development of a range of preschool cognitive abilities. These abilities include theory of mind (Carlson & Moses, 2001), counterfactual reasoning (Beck, Carroll, Brunsdon & Gryg, 2011), lying and deception (Evans, Xu & Lee, 2011), symbolic reasoning (Sabbagh, Moses & Shiverick, 2006), strategic reasoning (Carroll, Riggs, Apperly, Graham & Geoghegan, 2012), and drawing (Riggs, Jolley & Simpson, 2013). The development of inhibitory strength has also been associated with performance on more general measures of academic ability, particularly those relating to mathematics in early to middle childhood (Allan, Hume, Allan, Farrington & Lonigan, 2014; Bull, Espy & Wiebe, 2008; Cragg & Gilmore, 2013). Conversely, improvements in inhibitory endurance are particularly associated with the development of self-control. Self-control is a broad construct, defined as the capacity to regulate behaviour, thought, and emotion (Bandura, 1989; Metcalfe & Mischel, 1999; Vohs & Baumeister, 2004). Preschoolers' inhibitory endurance predicts subsequent outcomes on wide-ranging measures of self-control (e.g., Kochanska, Coy & Murray, 2001). Effective inhibitory endurance is also associated with behavioural adjustment (Kim et al., 2014), peer co-operation (Bassett, Denham, Wyatt, Warren-Khot, 2012) and the absence of ADHD symptoms (Pauli-Pott et al., 2014). Finally, inhibitory endurance is associated with academic outcomes in adolescence, when educational achievement depends more on self-control than reasoning ability (Duckworth & Seligman, 2005).

Performance on tasks which measure inhibitory strength and inhibitory endurance usually correlate. However, when this covariance is removed, it is often found that the predictive value of inhibitory strength and inhibitory endurance are exclusive: domains whose performance is predicted by inhibitory strength are not predicted by inhibitory endurance, and vice versa (see Garon, 2016, for a review). Consequently, maintaining this distinction between two ways of taxing inhibitory control offers both greater precision and greater explanatory power than treating all measures of inhibitory control as equivalent. For example, for both Theory of Mind tasks and measures of strategic reasoning, children's performance is significantly associated with measures of inhibitory strength, *but not* with inhibitory endurance (Bellagamba et al., 2015; Carlson & Moses, 2001; Carlson, Davis & Leach, 2005). Conversely, for behavioural problems and social-emotional aspects of school readiness, children's performance is associated with measures of inhibitory endurance, *but not* inhibitory strength (Bassett et al., 2012; Mann, Hund, Hesson-McInnis & Roman, 2017; Mulder, Hoofs, Verhagen, van der Veen & Leseman, 2014).

Importantly, the Strength/Endurance account can explain why the precise pattern of relations described above comes about. Performance on tasks taxing inhibitory strength is associated with domains that require the *brief* suppression of inappropriate prepotent responses (e.g., reasoning). Conversely, performance on tasks taxing inhibitory endurance is associated with domains which require the *sustained* suppression of inappropriate prepotent responses (e.g., emotion regulation).

To illustrate: inhibitory strength is used to overcome briefly activated prepotent responses, such as those often found in reasoning tasks. In such tasks, the incorrect response is only briefly activated, because it loses its prepotency once the correct response is known. Consider Counterfactual Reasoning tasks (Beck et al., 2009; Drayton, Turley-Ames & Guajardo, 2011) where children are asked how the location of an object would be different if the past had also been different (e.g., "What if the car had gone the other way, which garage would it be in?"). Asking the counterfactual question about the car's location draws a child's attention to its *current* location – making this a prepotent, but incorrect, response. However, once a child has calculated the correct counterfactual response – of selecting the other garage – then the prepotency of the incorrect response disappears. In this way, this and other reasoning tasks usually contain briefly activated to-be-inhibited responses. When reasoning can eliminate incorrect responses, they can be briefly resisted (prior to this elimination) with inhibitory strength.

Conversely, inhibitory endurance is used to overcome more persistent prepotent responses. For example, emotional regulation can require children to control behaviour which arises from their negative emotions (e.g., feelings of frustration that might lead them to give up on a difficult maths task). In general, there are no simple ways to make such negative emotions go away – they can rarely be made to disappear just by reasoning about them (see Gross, 2015, for a review). Instead, negative emotions often have to be tolerated, and this calls for inhibitory endurance, to provide sustained resistance to the inappropriate actions that they engender. Similarly, self-control requires sustained resistance to desires for immediate gratification: desires which cannot easily be escaped through reason (see Duckworth & Seligman, 2015, for a review). When reasoning cannot eliminate inappropriate responses, their sustained presence must be borne with inhibitory endurance.

Conclusion

This article identified two unanswered questions about the development of inhibitory control: why do inhibitory tasks differ so much in difficulty, and why do they load onto two factors, not one? We propose that both questions can be answered by recognising that, while inhibitory control is a single construct, it can be taxed in two different ways. The first way, which we refer to as inhibitory strength, reflects the need to suppress highly prepotent responses. The second, which we refer to as inhibitory endurance, reflects the need to suppress prepotent responses that last a long time.

Making explicit the distinction between inhibitory strength and endurance gives new coherence to our understanding of inhibitory development. It explains varying performance across tasks, and resolves previously problematic findings from factor-analytic studies. Inhibitory strength is associated with the development of reasoning and early academic ability. In contrast, inhibitory endurance is associated with self-control, behavioural/ emotional adjustment and later academic achievement. Inhibitory control is a domain-general process that has a significant role in many diverse aspects of child development. Having a better understanding of what we are actually asking children to do when we administer particular measures of inhibitory control will improve research across a range of developmental domains, and will give researchers clearer and better grounds for selecting tasks in future.

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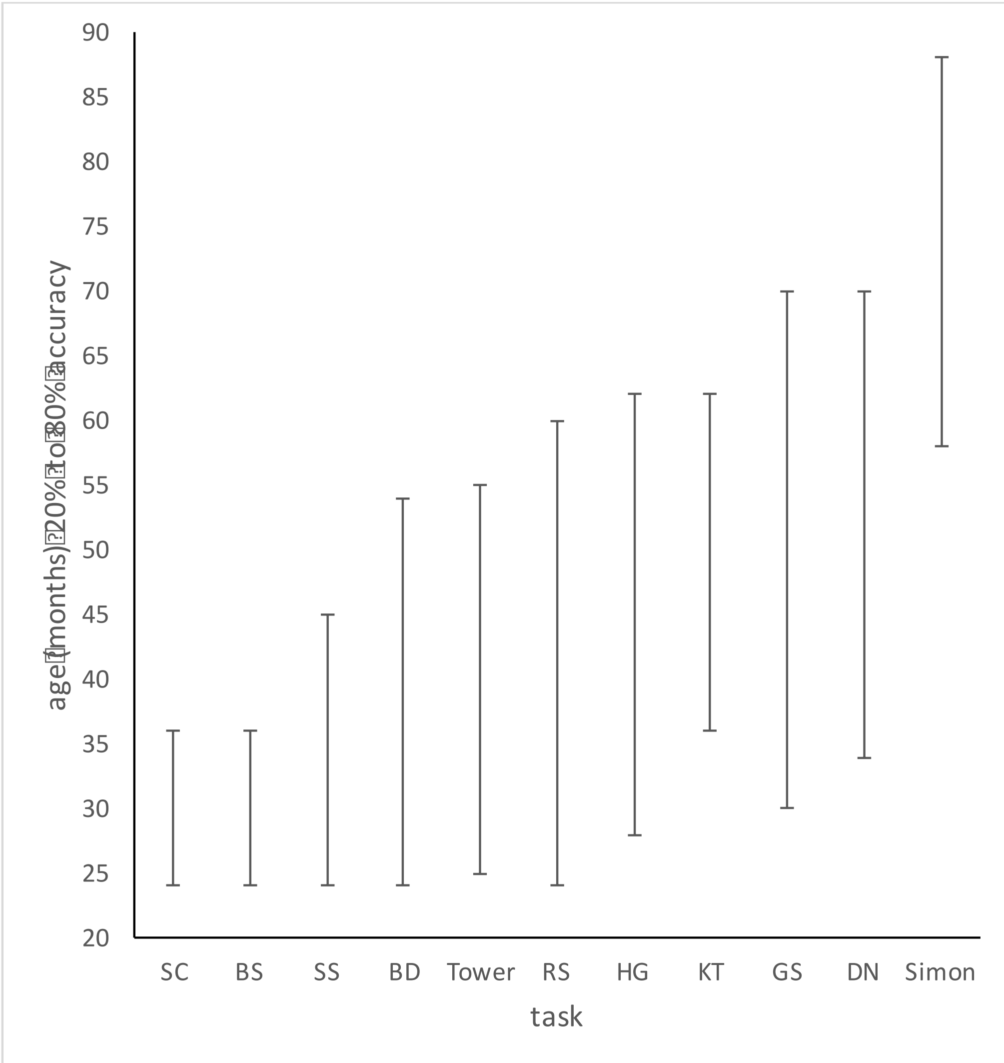
Table 1. A summary of the methods used in the tasks shown in Figure 1 (tasks presented in approximate increasing order of difficulty).

Task	**Task type**	**Method**
Spatial Conflict	SRC	Stimuli are presented on left/right of a monitor. Child responds by selecting left/right key. On inhibitory trials, the stimulus is on the opposite side from correct response key.
Baby Stroop	SRC	Child says small object belongs to "mommy"; and big object belongs to "baby".
Shape Stroop	SRC	Child points to pictures of small object embedded within pictures of larger, different object.
Bear/Dragon	Go/No-go	Child follows commands from the bear puppet, but ignores commands from the dragon puppet.
Tower	Go/No-go	Child takes turns with an experimenter to add blocks to a tower.
Reverse Sort	SRC	Child sorts card A into tray labeled with card B; and card B into tray labeled with card A.
Hand Game	SRC	Child sees gesture A, makes gesture B; and sees gesture, B makes gesture B (making finger or fist).
Knock/Tap	SRC	Child sees gesture A, makes gesture B; and sees gesture, B makes gesture B (hitting table with open/closed hand)
Grass/Snow	SRC	Child points to card B when experimenter say A; and to points to card A when experimenter say B.
Day/Night	SRC	Child sees picture A says B; and sees picture B says A.
Simon Says	Go/No-go	Child performs action only when preceded by "Simon says…" (hears command and sees action).

Table 2. The relative demands for inhibitory strength and inhibitory endurance made by some common developmental tasks.

Task	Inhibitory strength demands	Inhibitory endurance demands
Black/White, Day/Night, Grass/Snow, Whisper	high	low
Baby Stroop, Bear/Dragon, Shape Stroop, Spatial Conflict	moderate	low
Forbidden Toy, Gift Delay, KRISP, Marshmallow	low	high

Figure 1. The relative difficulty of Inhibitory tasks. The 'useful age range' describes the age range in which group accuracy was between 20% and 80% (from Petersen et al., 2016).



SC: Spatial Conflict (Gerardi-Caulton, 2005); BS: Baby Stroop (Hughes & Ensor, 2005); SS: Shape Stroop (Kochanska et al., 1997); RS: Reverse Categorization (Carlson et al., 2004); Tower, (Kochanska et al., 1996); BD: Bear/Dragon (Jones et al., 2003); HG: Hand Game (Simpson & Riggs, 2011); GS: Grass/Snow task (Simpson & Riggs, 2009); KT: Knock/Tap (Korkman et al., 1998); DN: Day/Night task (Gerstadt et al., 1994); Simon: Simon Says (Matthews & Drew, 2014).