T1 Title: A Novel Approach to Measuring the Developmental Interactions Between Working Memory and Inhibitory Control in Young Children

T2 Contributors, Affiliations, and Persistent IDs (recommend ORCID iD)

Chris Jarrold

University of Bristol

ORCID iD: https://orcid.org/0000-0001-8662-0937

Lead on study design and lead author. Shared responsibility for data analysis.

Tengfei Wang

Zhejiang University

ORCID iD: https://orcid.org/0000-0002-1585-4143

Local lead for data collection. Contributor to study design. Shared responsibility for data analysis.

Kailing Li

University of Bristol

ORCID iD: https://orcid.org/0000-0003-2563-2162

Task implementation. Contributor to study design. Shared responsibility for data analysis.

T3 Date of Preregistration

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T4 Versioning information

1

T5 Identifier

TF1

T6 Estimated duration of project

4 months

T7 IRB Status

Ethical approval is being sought by the Department of Psychology and Behavioral Sciences Medical Ethics Committee at Zhejiang University and will be in place before testing begins.

T8 Conflict of Interest Statement

None

T9 Keywords

Working Memory; Inhibition; Children; Executive Control

T10 Data accessibility statement and planned repository

Data access via download; usage of data for all purposes (public use file)

T11 Optional: Code availability

No, we don't plan to make the code available

T12 Optional: Standard lab practices

<<T12 Optional: Standard lab practices>

Abstract

A1 Background

Previous studies of executive control in children have tended to employ different tasks to measure different potential executive functions.

A2 Objectives and Research questions

Here we employ two novel tasks that orthogonally manipulate the working memory and inhibitory control demands within each paradigm.

A3 Participants

Children in three age groups (3-4-, 4-5-, and 5-6-year olds) will be assessed, with 48 children in each group.

A4 Study method

Participants will be given 6 conditions of a choice reaction time task formed by the crossing of two levels of inhibition with three levels of working memory load. The task involves determining which spatial response location is associated with each stimulus. They will also receive 9 conditions of a selective response task formed by crossing three levels of inhibition with three levels of working memory load. The task involves making ‘go’ responses to half the stimuli while withholding a response to the other stimuli.

Introduction

I1 Theoretical background

One potential definition of executive control is that it reflects the combination of goal representation in working memory and the inhibition of goal-irrelevant responses. Studies of the development of executive control in children have therefore attempted to measure each of these constructs (and, often, children's ability to engage in 'shifting' in addition). However, previous work has tended to use separate tasks to measure working memory and inhibition. One the one hand this increases the confounding effect of task-specific variance, but, on the other, the measures employed are often not process pure (for example, tests of inhibition often have a memory component to them).

I2 Objectives and Research question(s)

In this study we test two novel tasks - one involving pre-potent response inhibition in a choice reaction time task, the other involving behavioural inhibition in a selective response task. In each we orthogonally manipulate the memory load across conditions of the tasks by varying the number of stimulus-response associations that have to be maintained. This allows us to examine main effects of both working memory and inhibitory load, and their interaction, in children of different ages.

I3 Hypothesis (H1, H2, …)

H1 - we predict main effects of working memory load, inhibitory load, and age in both tasks.

H2 - we predict an interaction between working memory load and inhibitory load in each age group on the assumption that both functions draw on a common pool of executive control capacity.

However, while this theoretical model is plausible, it is not the only model of executive control. It is also the case that an interaction is only expected when executive capacity is exceded by the combined demands of the task. This point where capacity is exceded is likely to differ across the two age groups. This could emerge as a three-way interaction between factors, but this depends on the relatively difficulty and sensitivity of the different conditions of each task.

I4 Exploratory research questions (if applicable; E1, E2, ...)

E1 - we will examine the correlations between the different conditions of each task, and between the corresponding conditions of the two different tasks.
E1a - a question of interest is whether the two tasks tap separable forms of inhibition (i.e., do they inhibitory aspects of a given task correlate across the conditions of that task, but not with the other task and vice versa).

E2 - we will examine the effects of response shifts across successive trials in low inhibition conditions of the choice reaction time task, and of both response and location shifts in the high inhibition conditions of this task.

E3 - we will explore the reliability and sensitivity of a range of dependent measures in addition to accuracy and response time, specifically: response time variability in both tasks, a composite measure of accuracy and response time in both tasks (Draheim, Hicks, & Engle, 2016), and signal-detection measures of 'accuracy' in the selective response task.

E4 - we will examine the correlations between indices of inhibition and memory extracted from the experimental tasks and the questionnaire-based measure of behavioral executive and effortful control.

Method

M1 Time point of registration
Registration prior to creation of data

M2 Proposal: Use of pre-existing data (re-analysis or secondary data analysis)
No

Sampling Procedure and Data Collection.

M3 Sample size, power and precision
We aim to recruit 48 participants in each of 3 age groups (kindergarten Year 1 = 3-4-year-olds, kindergarten Year 2 = 4-5-year olds, kindergarten Year 3 = 5-6-year-olds).
Because this study uses novel tasks it is not possible to make an a priori estimate of effect sizes. These samples are comparable to those in previous work, and the

combined total of 144 is sufficient to allow for individual differences analyses (see below).

M4 Participant recruitment, selection, and compensation
Children aged between 3 and 6 years will be recruited from kindergartens in Hanghzou, China. Children are from mid- and high-SES families.

M5 How will participant drop-out be handled?
If participants complete all conditions of one task their data will be included in the analysis of that task. However, if they fail to complete any of the conditions of the task we will explore whether they have completed sufficient conditions to allow their performance in missing conditions to be imputed.

M6 Masking of participants and researchers
Masking is not judged to be necessary. Participants will be assigned to a task and condition order prior to any data collection and the experimenter will be aware of that assignment

M7 Data cleaning and screening
In the choice reaction time task reaction times will be trimmed using the Median Absolute Deviation (MAD) method described by Leys, Ley, Klein, Bernard & Licata (2013), using a criterion of +/- 3 MAD. This trimming will take place at the level of the condition within each task (i.e., medians and MADs will be calculated for each participant separately in each condition). Any identified outliers will be removed.
We will explore whether the same approach is feasible in the selective response task. However, because this task limits the amount of time available for participants to make a response it is highly likely that reaction time distributions will be curtailed, which may make the MAD approach inappropriate. If so, then we will select an appropriate cut-off to remove any particularly fast responses in the conditions of this task.

M8 How will missing data be handled?
See M6. No other missing data are anticipated.

M9 Other information (optional)

Conditions and design.

M10 Type of study and study design
This is an experimental study.
The one between-participants factor is age, with three levels (kindergarten years 1, 2,

& 3).
The remaining factors are within-participant factors, and are:
Task, with two levels (choice reaction time, selective response), inhibitory load, and memory load.
The latter two factors are nested within the factor of task, in that they differ for each task:
In the choice reaction time task there are two levels of inhibitory load (no inhibition, high inhibition) and three levels of memory load (no memory, medium memory, high memory), creating 6 conditions.
In the selective response task there are three levels of inhibitory load (no inhibition, high commission inhibition, high omission inhibition) and three levels of memory load (no memory, medium memory, high memory), creating 9 conditions.

A questionnaire measure will also be administered.

M11 Randomization of participants and/or experimental materials
The order of task presentation will be counterbalanced across participants, with half of the participants in each age group receiving all conditions of the choice reaction time task before all conditions of the selective response task, and vice versa for the other half of the participants in the group.

The order of presentation of conditions within each task will also be counterbalanced. Specifically, all of the conditions with the same level of inhibition within a task will be blocked together, though presented in a varying order across participants within these blocks. The order of presentation of the inhibition blocks will also be counterbalanced across participants. This produces a total of 24 possible orderings.

Trials within the conditions of each task are presented in a pseudorandom order that has been developed by a randomisation code with the constraint of ensuring equal presentations of each stimulus but with no immediate repetitions of a stimulus across successive trials. In addition, for the choice reaction time task the code further constrains a comparable number of response shifts vs. response stays across successive trials, and (for the high inhibition conditions) a comparable number of location shifts for response shift and response stay trials.

M12 Measured variables, manipulated variables, covariates
Reaction times and accuracy of all keypress responses will be recorded. Both will form dependent variables for the analyses although any analysis of reaction times will

employ only those associated with correct responses.

In addition, we will calculate response time variability in each condition and employ this as a further dependent variable, and we will explore the utility of a combined accuracy-RT measure (Draheim, Hicks, & Engle, 2016).
For the selective response task we will calculate signal detection based measures of sensitivity and bias which will also be employed as dependent variables.
For this task we will also measure the number of omission and commission errors made in each condition.

H1, H2, E2 and E3 will be tested using all of the above dependent variables given that our exploratory research question (E3) aims to examine the extent to which different measures are reliable and sensitive. However, we may place some of these analyses in supplementary material to any paper rather than reporting all of them in the body of the text.
E1 will also be examined using this range of variables, again with potential use of supplementary materials. However, in addition we will explore indexing inhibitory load in the high inhibition conditions of the choice reaction time task in two ways: we will calculate absolute inhibition accuracy and RT effects by subtracting accuracy and RTs for spatially compatible trials from accuracy RTs for spatially incompatible trials; we will use regression to control for the variance in accuracy and RT on spatially compatible trials when correlating performance on the spatially incompatible trials.
E4 will be examined using structural equation modelling of the most appropriate indices of performance that emerge from the above analyses.

M13 Study Materials

Each condition of each task involves a stimulus set of four items (pictures of animals). Within each task these animals are only employed in one condition, although they are duplicated across tasks.

M14 Study Procedures

There are six conditions within the choice reaction time task, formed by crossing two levels of inhibition (no inhibition and high inhibition) and three levels of working memory load (no, low, and high). On any given trial participants will see a screen which is blank apart from the presence of response buttons at the bottom left and bottom right for 350ms, immediately afterwards, an object will appear either in the centre, middle-left or middle-right of the screen and participants have to select the left or right response button depending on the response mapping for that particular stimulus. Participants will

receive a total of 24 trials for all ‘no inhibition’ conditions, and 48 trials for all ‘high inhibition’ conditions (with 24 trials for left stimuli and 24 trials for right stimuli) in a pseudo-random order.

The task varies for each condition. For the ‘no memory and no inhibition’ condition, participants will see an animal object presented in the centre of the screen, an arrow pointing in either a left or right direction also appears below the animal (i.e., the stimulus set could be two owls with different features accompanied by an arrow to the left and two elephants with different features accompanied by an arrow to the right). Participants will be instructed to press the left button in response to the left arrow, and the right button in response to the right arrow. In the ‘low memory and no inhibition’ condition, participants will first learn two rules, for example, when you see a cat, press the left button and press the right button if you see a dog. Participants will again see an animal object that appears in the centre of the screen, and participants need to press the corresponding button (note, to avoid immediate stimulus repetitions and to balance the number of stimuli used in each condition, the stimulus set would consist of two different cats and two different dogs). In the ‘high memory and no inhibition’ condition, participants will again learn rules before making a judgement on which key to press in response to each animal appearing in the centre of the screen. However, for this condition, participants will be required to remember four rules instead of two, with two animals corresponding to the left button and two animals to the right button (i.e., cow or duck press left and rabbit or giraffe press right).

The three high inhibition conditions (‘no memory high inhibition’, ‘low memory high inhibition’, ‘high memory high inhibition’) differ from the three no inhibition conditions in that each animal appears on either the left or right of the screen. This leads to spatially compatible and incompatible trials for each presentation position: in the compatible trials, animals appear on the same side as the response; in the incompatible trials, animals appear on the opposite side from the response. Incompatible trials therefore induce spatial conflict and response inhibition demands (the Simon effect).

Equal numbers of each of the 4 stimuli will be presented in each condition. Similarly, the number of compatible and incompatible trials in the high inhibition conditions will be equated across all stimuli. As already noted, immediate repetition of any given stimuli will be avoided. The trial sequence in any of the high inhibition conditions will ensure an equal number of ‘location stay’ and ‘location switch’ transitions. Similarly, the number of ‘response stay’ and ‘response switch’ transitions (making the same response vs. making the other response) will be balanced, although the absence of stimulus repetition means that response switches will be twice as common as response stays. In addition, the number of transitions in each of the four combinations of these two

transition types will be balanced within each condition.
Anticipated testing time = 10 minutes.

There are nine conditions of the selective response task. This is a Go/No-Go task where memory load is added to the task so that participants need to remember different rules for ‘go’ and ‘no-go’ trials. On any trial a blank screen is presented for 500ms followed by the presentation of a stimulus in the centre of the screen for 1000ms. The task involves pressing a key (the space bar) for stimuli associated with a go response within 2500 ms of the appearance of the stimulus to advance to the next trial and withholding any key press for stimuli associated with a no-go response. Accuracy and reaction time (for just go responses) will be recorded. The nine task conditions are formed by crossing three levels of memory load with three levels of inhibitory load.
In no memory conditions, two animal pictures correspond to a go response and two animal pictures correspond to a no-go response and a ‘tick’ cue is presented underneath each animal associated with a go response. In low memory conditions, participants will again be presented with four pictures, but these are grouped into two pairs (i.e., two cats associated with a go response and two dogs associated with a no-go response). The participant is told these two rules at the start of the condition and has to hold them in mind. In high memory conditions there are again four animals but they are all from distinct classes and so the participant has to hold in mind the four rules that determine which two animals are associated with a go response and which two are associated with a no-go decision.
Conditions with a low level of inhibition (no memory low inhibition, low memory low inhibition, high memory low inhibition) will contain a total of 20 trials, made up of 50% ‘go’ trials and 50% ‘no-go’ trials. Conditions with a high level of commission inhibition (no memory high commission inhibition, low memory high commission inhibition, high memory high commission inhibition) will contain a total of 50 trials, made up of 80% ‘go’ trials and 20% ‘no-go’ trials. In these conditions the greater frequency of a go responses means that a greater degree of inhibition is needed to withhold a no-go response. Conditions with a high level of omission inhibition (no memory high omission inhibition, low memory high omission inhibition, high memory high omission inhibition) will also contain 50 trials, made up of 20% ‘go’ trials and 80% ‘no-go’ trials. In these conditions the infrequency of a go responses means that the participant needs to employ sustained attention to avoid making omission errors to the go stimuli.
Equal numbers of each of the 4 stimuli will be presented in the 3 low inhibition conditions. The frequency of go vs no-go stimuli in the other conditions is determined

by the condition rules described above; however, the two go stimuli will occur as often as each other as will each of the two no-go stimuli. Immediate repetition of any given stimuli will be avoided.
Anticipated testing time = 20 minutes.

The Children's Behaviour Questionnaire will be given to parents https://research.bowdoin.edu/rothbart-temperament-questionnaires/instrument-descriptions/the-childrens-behavior-questionnaire/

M15 Other information (optional)

Analysis plan

AP1 Criteria for post-data collection exclusion of participants, if any
Any participant who is not significantly above chance ($p<.05$) in terms of accuracy for their average performance across all conditions of a task will be excluded from data analysis for that task.

Two attention check questions will be built into the Children's Behaviour Questionnaire given to parents. If a parent fails to complete both of these questions correctly then their questionnaire data will not be included in any correlational analyses (their child's behavioural data will still be analysed).

AP2 Criteria for post-data collection exclusions on trial level (if applicable).

AP3 Data preprocessing
For the high inhibition conditions of the choice reaction time task only, an inhibition index will be calculated for RT and accuracy by subtracting performance on spatially compatible trials from that seen on spatially incompatible trials (see M12)

AP4 Reliability analysis (if applicable).

AP5 Descriptive statistics
See M12

AP6 Statistical models (provide for each hypothesis if varies).

AP7 Inference criteria
Bayesian ANOVAs will be used to test H1, H2, and E2. These will test the need to include each of the main effects and interactions in the best fitting model, with the factors being driven by the design (e.g., for H1 the factors for each task will be memory load, inhibitory load, and age). Because the manipulation of inhibitory load in the selective response task operates in two opposing directions relative to the low inhibition condition (prompting either omission or commission errors) we may supplement the main analysis of this task with analyses that separately compare each pair of high inhibition conditions (either high commission inhibition or high omission inhibition) with the 'baseline' conditions performed under low inhibition.

E2 and E4 will be examined using individual differences approaches. Correlations between variables will initially be examined using Pearson r values, while E4 will be examined using structural equation modelling. We plan to extract latent variables of memory load and inhibitory load from each task and then i) inter-correlate these and ii) test their relation to the questionnaire measure.

E3 will be explored by simply comparing (without formal statistical inference) the relative patterns of effects and inter-relations between constructs using the range of dependent measures we will collect/extract.

AP8 Exploratory analysis (optional)

AP9 Other information (optional)

Other information, optional

O1 Other information (optional)
This study is our first experimental test of these novel measures with children. However, we will shortly be starting a similar study that will employ these measures longitudinally with a larger sample of children across a wider age range. We may conduct comparisons between the current data set and the data emerging from this other study.

References

R1 References

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