

**INHIBITORY CONTROL IS A RATE-LIMITING FACTOR TO PRESCHOOLERS'
USE OF IRREGULAR INFLECTION**

by

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Abstract

We investigated whether children's inhibitory control is associated with their ability to produce irregular verb forms as well as learn from corrective feedback following their use of an over-regularized form. Forty-eight 3.5 to 4.5 year old children were tested on the irregular past tense and provided with adult corrective input via models of correct use or recasts of errors following ungrammatical responses. Inhibitory control was assessed with a three-item battery of tasks that required suppressing a prepotent response in favor of a non-canonical one. Results showed that inhibitory control was predictive of children's initial production of irregular forms and not associated with their post-feedback production of irregulars. These findings show that children's executive functioning skills may be a rate-limiting factor on their ability to produce correct forms, but might not interact with their ability to learn from input in this domain. Findings are discussed in terms of current theories of past-tense acquisition and learning from input more broadly.

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Chapter 1

Introduction

A central goal of language acquisition research is to understand the processes that contribute to children's production of language errors. For instance, although for many verbs in English (e.g., walked, picked, kissed) the past tense is formed by adding –ed to the verb's stem, there is a second category of verbs that instead form the past tense by a change in the verb's stem (e.g., run – ran) or zero-marking (e.g., put – put). In natural language, children spend many years creating a regularized past tense form for a stem that normally takes an irregular past-tense form (e.g., saying “falled” instead of “fell”), a phenomenon called “overregularization” (OR). Perhaps most intriguing is that, individual children differ in their ability to successfully produce irregular forms (Marcus, 1993). The main goal of the present study was to explore these potential differences in relation to children's inhibitory control to gain insight into how such skills might support the development of an adult grammar.

Executive Function and Correct Irregular Past Tense Production

There are several reasons one might expect inhibitory control to be associated with irregular past tense production. Executive function more broadly has been linked to a number of linguistic situations in which children need to select the most appropriate response from a range of possible alternatives. Notably, cognitive mechanisms including inhibitory control have been associated with children's ability to use linguistic evidence to resolve a syntactic ambiguity in online sentence processing (Woodard, Pozzan, & Trueswell, 2016), use context to differentiate between homophones (e.g., knew and new) (Khanna & Boland, 2010), and resolve referential ambiguity through perspective taking (Nilsen & Graham, 2009). In the case of resolving a syntactic ambiguity, Woodward, Pozzan, and Trueswell (2016) suggest that inhibitory control skills are engaged when one must suppress the habitual interpretation of a sentence in order to

interpret the linguistic material in a manner that is consistent with the current task demands. Resolving a lexical ambiguity (i.e., homophone processing) might require suppressing the contextually determined irrelevant word meaning (Khanna & Boland, 2010). In a similar way, the successful production of irregular past tense verb forms may rely on the suppression of a prepotent tendency to apply regular inflection in favor of a less common construction. It is on this basis that we hypothesize a link between inhibitory control and children's ability to produce irregular past tense verb forms. It seems plausible that inhibitory control may serve as a rate-limiting factor to children's production of irregular past tense verb forms by contributing to children's ability to successfully perform this behavior, but not accounting entirely for successful production of a correct inflection.

Indeed, some theories of irregular past tense production highlight an explicit role for inhibitory control. These theories, sometimes called dual system theories (e.g., Marcus et al., 1992; Pinker, 2000; Ullman, 2001), argue that regular and irregular inflections are processed by two distinct mechanisms. The first is a system that is responsible for producing regular inflection, and is instantiated with a "procedural" memory mechanism that specifies the "add – ed" behavior. Importantly this system is thought to represent our first and easiest approach to generating the past tense of a novel or known verb. The second is a lexical memory system that is responsible for representing the exceptions, which are thought to be learned individually through experience. In order to correctly provide irregular inflection, children need to inhibit a prepotent response of applying the regular rule in order to use the irregular form that is retrieved from memory. It seems plausible that, in addition to the natural blocking mechanism that is employed when the memory trace is sufficiently strong, it may also be necessary to block the habitual or

prepotent output in order to consider alternatives. Therefore, one might expect individual differences in inhibitory control to predict past tense production based on this theoretical account. To the extent that we find evidence of an association between inhibitory control and irregular past tense production, it may provide support for this model of morphological representation over competing models that do not obviously include inhibitory control as a necessary mechanism.

To date, little is known about whether individual differences in children's inhibitory control might relate to the ability to successfully produce irregular past tense verb forms. To our knowledge, the only other paper to address this question directly comes from Ibbotson and Kearvell-White (2015) who recently found that 5-year-old children who performed better at a Sun/Moon Stroop task also performed better at a past tense elicitation task with *both* regular and irregular inflection. These findings seem to indicate that individual variation in grammatical ability can, in fact, be accounted for by individual variation in inhibitory control. However, the Stroop task employed in this study required that children provide a linguistic response ("sun" or "moon"). Because a verbal response is required, children must meet certain linguistic performance demands to succeed (e.g., a child might be shy and therefore less productive in their language use). It is therefore unclear whether the observed effect is due to individual differences in inhibitory control, or simply individual differences in children's ability to meet the linguistic performance demands of the task. In addition, the authors chose to group both regular and irregular verbs together in their dependent variable measure. Because we are unable to evaluate the influence of inhibitory control on irregular verbs independently, we cannot draw clear conclusions regarding the nature of the underlying cognitive architecture of this system. In the

present study, we address these limitations by measuring inhibitory control through a 3-item battery of tasks that did not require a verbal response and by focusing only on irregular verbs.

Considering the Role of Inhibitory Control in Learning Irregular Forms

The hypothesis that inhibitory control is associated with this process is predicated on theoretical models of how irregular past tense production occurs. Yet, an alternative reason is that inhibitory control might play an important role in learning irregular past tense forms from input. Inhibitory control is associated with learning from input in a variety of domains, including theory-of-mind, language, and mathematics (e.g., Benson, Sabbagh, Carlson, & Zelazo, 2013; Blair & Razza, 2007; Bull & Scerif, 2001; Espy et al., 2004). For instance, difficulty inhibiting a prepotent response on a Stroop task has been shown to predict lower mathematical ability (Bull & Scerif, 2001; Bull, Johnston, & Roy, 1999). Espy et al. (2004) demonstrated this finding to be consistent even after controlling for age, maternal education, vocabulary, and other aspects of executive function (e.g., set shifting and working memory). Here, we suggest that inhibitory control may also play a parallel role in promoting uptake of irregular past tense verb forms, just as it promotes learning from input in other domains.

The input that children receive when learning a language can be divided into two general categories. The first is positive evidence, which is any correct utterance spoken in a language. The second is negative evidence, which is information about what is not allowed in a language. Although children do not often receive explicit corrections about the mechanics of language, such as “no, that is the wrong way to say that,” they are likely to hear a grammatically correct repetition of their utterance by the parent in response to the error such as the following (Farrar, 1990; Strapp & Federico, 2000):

CHILD: The ball falled down.

MOTHER: The ball fell down.

Some researchers argue that recasts are a more informative form of negative feedback than explicit denials, because recasts are closely modeled on the child's own speech (Bohannon & Stanowicz, 1988; Saxton, 1997, 2000). Where a denial simply informs the child that an error exists, it does not inform the child about the nature of the error or provide a correct alternative utterance. When recasts are provided, greater improvement can be expected in the grammaticality of child speech, and intuition regarding irregular verb forms more closely approximates that of adults in comparison to when positive evidence is provided (Chouinard & Clark, 2003; Proctor-Williams & Fey, 2007; Saxton, 2000; Saxton, Backley, & Gallaway, 2005; Saxton, Kulcsar, Marshall, & Rupra, 1998; Strapp, Bleakney, Helmick, & Tonkovich, 2008). Thus, it seems plausible that inhibitory control may promote learning differentially depending on the type of input children receive regarding their language errors.

There is some reason to believe that inhibitory control may be particularly related to learning from recasts, because of their connection with the cognitive processes associated with error-monitoring. When children use a past tense verb form, it is possible that they are making a prediction about whether that verb forms the past tense with regular or irregular inflection. Recasts, but not models, provide feedback to the child's erroneous predictions. Perhaps, this feedback activates a process of prediction-error signaling; wherein the unexpected contrast of the adult form with the child's form signals to the child the prediction was inaccurate. Prediction-error signaling is thought to play a role in learning more broadly. When a prediction is formed based on a previously learned association, prediction-error is cause to re-evaluate the basis of one's prediction (see, Schultz, 2015). In the specific instance of OR errors, it seems plausible that

recasts alert the child of their erroneous prediction by activating this prediction-response mismatch system, encouraging the child to adjust their prediction in order to reduce the future probability of prediction-error. Thus, due to the direct contrast that recasts provide, we hypothesize that recasts promote learning through signaling a prediction-error. If true, then one would expect that individual differences in inhibitory control would be related to learning from recasts, but not models.

Current study

The current study had two primary aims: (1) to investigate the relationship between inhibitory control and children's production of irregular past tense verb forms and (2) to explore whether inhibitory control promotes learning irregular past tense verb forms from input. To test this, children watched a puppet show designed to elicit OR errors of known verbs from children. After the experimenter recorded the participant's initial errors, the pair then re-watched the videos that corresponded to verbs that the child previously overregularized. While talking about the puppet show the second time, the experimenter provided the correct form either just after the participant erred by recasting the error (recast condition) or before the participant made the error by modeling correct use (model condition). Later, children were given a production test in which they were asked to complete a sentence by providing a past tense verb form and a comprehension test in which they were asked to judge the grammaticality of the OR and irregular forms. Finally, children's inhibitory control was assessed with a three-item battery of tasks (Grass/Snow, Bear/Dragon, and Less is More) that required suppressing a prepotent response in favor of a non-canonical one (e.g., pointing to a white square when the experimenter said "grass") without requiring a verbal response from the child. We hypothesized that performance on the inhibitory

control battery would predict performance on the initial past tense elicitation task and the post-feedback learning outcome measures, such that more advanced inhibitory control would correlate with a higher rate of correct irregular past tense verb form use in all dependent variable measures. We also hypothesized that inhibitory control would interact with the type of input children receive about OR errors, such that more advanced inhibitory control would promote a higher rate of post-feedback correct irregular past tense production in the recast condition.

Chapter 2

Method

Participants

Forty-eight native English-speaking, typically developing children participated in the study. Participants were 3.5 to 4.5 years-old (3;6 – 4;5) (*mean age* = 46.38 months, *SD* = 3.65, 27 females). Participants were recruited from an online participant database comprised of families that had previously participated in studies at Queen’s University or were recruited from various locations in the surrounding community area. Participants were primarily from White, middle-class families. Bilingual participants were not excluded from analysis.

Materials

Inhibitory Control Measures. We used 3 standardized tasks designed to measure inhibitory control:

1. Grass/Snow (Carlson & Moses, 2001)

In the Grass/Snow task, children were asked to place their hands on top of two hand-shaped felt pieces centered on a board beneath a green and a white square. Children were asked to name the colors of grass (green) and snow (white). The experimenter then explained that in this “silly” game when she said the word “grass” they were to point to the *white* card and when she said the word “snow” they were to point to the *green* card.

Children passed each trial if they pointed to the correct colored card for the prompt (i.e., white for grass and green for snow) and failed if they pointed to the incorrect colored card for the prompt (i.e., green for grass and white for snow) or if they pointed to both colored cards. The

total task score for each participant was the proportion of correct responses over 16 trials (possible range: 0-16).

2. *Bear/Dragon* (Reed, Pien, & Rothbart, 1984)

In the Bear/Dragon task, children were introduced to a “nice” bear puppet and a “naughty” dragon puppet. The experimenter explained that in this game, children were to do what the bear asks them to do (e.g., touch your nose), but *not* what the dragon asks them to do.

Only trials in which the dragon provided a command were scored. Each dragon trial was given a score of 4 if the child successfully inhibited the commanded action, a score of 3 if the child performed a “strategic movement” (e.g., sitting on hands to prevent themselves from performing the action), a score of 2 if the child partially performed the commanded action (e.g., lifted hand to nose and then put it down), a score of 1 if they performed an incorrect action, and a score of 0 if they performed the commanded action. A total task score was calculated by summing across all 5 dragon trials (possible range: 0-20).

3. *Less is More* (Carlson, Davis, & Leach, 2005)

In the Less is More task, children were presented with two trays of jellybeans: one that contained a larger amount (5 jellybeans) and one that contained a smaller amount (2 jellybeans). The experimenter asked children to indicate which amount they would prefer. All children in the current sample indicated a preference for the larger amount of jellybeans. Children were then introduced to a “naughty” monkey puppet named Chris and told that Chris would receive the reward that the children chose and the reward not chosen would go to them. In other words, children were asked to point to a smaller reward (2 jellybeans) to receive a larger reward (5 jellybeans).

For each trial, children received a score of 2 if they successfully pointed to the smaller reward, a score of 1 if they hovered over the larger amount before pointing to the smaller amount, and a score of 0 if they pointed to the smaller reward. A total task score was calculated by summing across all 16 trials (possible range: 0-32).

Language Development Measure. The Peabody Picture Vocabulary Test (PPVT) 4th edition (D. M. Dunn & Dunn, 2007) was used to assess whether children's vocabulary development influences their ability to produce irregular past tense forms. In this task, the child was presented with 4 pictures and asked to point to the picture that matches a given vocabulary word.

Procedure

Arrival. To begin the appointment, a female experimenter explained the study and consent process to the parent; parents were informed of the predictions for the outcomes of the study as a part of the consent process. Then the experimenter engaged the child in playing together with some toys while the parent read and signed the consent forms. Testing began once the parent had completed the consent forms and the child had provided verbal assent.

Testing Session. Total testing time took approximately 45 minutes. Children completed the PPVT before beginning the pre-test and the inhibitory control battery following the production and comprehension tasks. Children were given a t-shirt or a \$10 gift card to a children's bookstore at the end as a thank you for participating in the study.

Initial Past Tense Elicitation Task. After completing the PPVT, we tested children's initial production of irregular past tense verb forms. We used a total of twelve real verbs that all take an irregular past tense form: blow/blew, build/built, draw/drew, drink/drank, eat/ate,

give/gave, read/read, send/sent, sing/sang, take/took, throw/threw, and write/wrote. Each verb was chosen to be causative, transitive, and telic. In addition, two known verbs with regular inflection were used to prime the use of regular inflection and ensure that children understood the task. The regular verbs used were show/showed and hug/hugged, also chosen to be causative, transitive, and telic.

Twenty-eight videos were created that depicted puppets acting out 14 different verb-actions (twelve irregular, two regular; see verbs listed above). There were two corresponding videos for each verb and each was approximately 10-15 seconds long.

To begin the task, the experimenter told the child that they were going to watch some videos of puppets acting out everyday actions. She explained to the child that while the videos were playing she would tell them what is happening and when the videos were finished playing the child was to tell her what had just happened. To ensure that children understood the task and to prime the use of the regular inflection, the pair first watched the videos that demonstrated the two known regular verbs (4 total videos). While the videos were playing the experimenter described the action (e.g., “I think he is going to show her a toy. Look! He’s showing her a toy!”). At the end of each video, the experimenter prompted production of the past tense by asking children, “What happened?” Children were praised for providing an inflected form during regular verb trials (e.g., “Yeah! Good job!”). Within each trial, children were encouraged to produce the verb again when no inflection was provided until they either produced an inflected form or were prompted three times. Children were required to provide a correct response for at least 3 of the 4 regular verb videos to continue the task. If a child did not provide a correct

response for 3 of these videos, they watched all 4 videos again; only one participant had to re-watch the videos.

After watching all 4 regular verb videos, children then watched the 12 irregular verb videos. Children saw a total of 24 videos illustrating 12 target verbs (2 trials per verb), all of which took an irregular past tense form. While the remainder of the videos played, the experimenter provided a brief narration that described the action (e.g., “I think he is going to blow up that balloon. Look! He’s blowing up the balloon.”). At the end of each video, the experimenter prompted production of the past tense of each target verb by asking children, “What happened?” The experimenter recorded children’s responses during the task. No feedback was provided during this portion of the task.

The child passed each trial by correctly producing the irregular past tense form and failed when they produced an overregularized or otherwise incorrect form of the verb. The total task score, therefore, was the proportion of correct responses over 24 trials. Regular verb trials were not included in the task score.

Feedback Task. Following the initial past tense elicitation task, the experimenter assigned 8 target verbs to either one of two within subjects conditions: A model condition or recast condition. The experimenter assigned 4 target verbs to the each condition; condition assignment was tracked to ensure that verbs were assigned equally across conditions. Verbs for this task were chosen when the child produced an OR form during both trials in the previous task. The experimenter and child then re-watched the corresponding videos.

While these videos were playing the experimenter would describe the action (e.g., “I think he is going to blow up that balloon. Look! He’s blowing up the balloon.”). After videos

depicting verbs in the model condition, the experimenter would model correct use of the irregular past tense form (e.g., “Oh, he just blew up that balloon.”) without prompting the child for a response. After videos depicting verbs in the recast condition, the experimenter prompted production of the past tense of each target verb by asking children, “What happened?” The experimenter then recast OR errors that occurred in these trials (e.g., If the child said, “He blowed up that balloon.” the experimenter responded, “Oh, he *blew* up that balloon.”).

Production Task. Children’s production of the past tense of the 8 target verbs from the feedback task was tested using a probe modeled after Berko’s ‘Wug’ test (Berko, 1958). In this test, children were told that they were going to look at some pictures with the experimenter. There were two pictures per trial and two trials per verb. Children were first shown a picture depicting the target verb, which the experimenter described (e.g., children saw a picture of a girl stacking blocks and the experimenter said, “She’s building a tower!”). Children were then shown a second picture depicting the completed action and instructed to finish the experimenter’s accompanying sentence (e.g., children saw a picture of a girl with a tower of blocks and the experimenter says, “She just b____.”). There were two trials per verb.

Comprehension Task. Children completed a second post-test probe designed to assess their preference for the irregular versus OR past tense form of the 8 target verbs from the feedback task. This was a forced choice task. In a variety of language measures, children show worse performance in production tasks compared to comprehension tasks, such as looking time measures, choice tasks or acceptability ratings, even when the production and comprehension measures appear to be assessing the same competency. Therefore, a production task alone may not be a sensitive enough measure of learning outcomes. One way to assess comprehension is by

asking children to rate different forms in an acceptability judgment task (Ambridge & Rowland, 2012). However, since children rate each form independently, the acceptability task never directly measures children's preference for one form over the other (e.g. if a child rates both *threwed* and *threw* as acceptable, that may not necessarily mean that they have no preference for one over the other). An important complement to the production measure, therefore, is a forced-choice measure of comprehension.

In this task, the experimenter introduced the child to two puppets. She then informed the child that the puppets sometimes talk funny and don't always agree about how to say things, and it is the child's job to help them by indicating who said each sentence the correct way. Each puppet then took a turn saying a sentence, one offering an OR form and the other an irregular form of each of the 8 target verbs from the feedback task. The puppet that produced the correct form was counterbalanced, so neither was consistently right or wrong. There were two trials per verb.

Chapter 3

Results

Inhibitory Control and Correct Irregular Past Tense Production

The first aim of this work was to explore whether children's inhibitory control might be associated with their ability to produce irregular past tense verb forms. The scores of the 3 inhibitory control tasks (Grass/Snow, Bear/Dragon, and Less is More) were averaged and standardized to create a composite inhibitory control score for each participant. Not all of the inhibitory control measures were intercorrelated, however the internal consistency of the aggregate score was high (*Cronbach's* $\alpha = 0.79$). The aggregate was significantly correlated with PPVT scores ($r(47) = 0.33, p = 0.02$), trending towards significance with age ($r(47) = 0.26, p = 0.08$), but not significantly associated with sex, $t(46) = 1.51, p = 0.14$. These findings are consistent with previous research (see, Carlson, 2005), providing evidence that our inhibitory control data is typical.

In order to test whether inhibitory control was associated with a higher rate of production of correct irregular past tense verb forms, we ran a linear regression model using the `lm` function in the R package `QuantPsy` with initial irregular past tense production as the outcome variable and inhibitory control composite scores and age as predictors. In order to determine which potential predictors to include in this model, we first examined the intercorrelations of our set of potential predictors (sex, age, PPVT) with the dependent measure (initial production) (see Table 1). Age was the only significant correlation to emerge, $r(46) = 0.38, p = 0.02$. The results of this test found that the model with age included differed significantly from the model without age as a covariate, $R^2 \text{ change} = 0.17, F(2, 45) = 5.70, p < 0.01$. This suggests that the effect of inhibitory

control changes depending on age. The results of the regression model also indicated that inhibitory control composite scores significantly predicted children’s use of irregular past tense verb forms, $\beta = 0.31$, $t(45) = 2.28$, $p = 0.03$. Age predicted initial irregular past tense verb form use at a level approaching, but not reaching standard statistical significance, $\beta = 0.25$, $t(45) = 1.82$, $p = 0.08$. Children that scored higher on the inhibitory control measures, indicating more advanced performance, correctly produced irregular past tense verb forms more often than children with lower inhibitory control task scores. In addition, older children provided the corrected irregular past tense form more frequently than younger children. This result suggests that children with more advanced inhibitory control are better able to produce correct irregular past tense verb forms.

Table 1: Means, standard deviations, and correlations

Variable	<i>M</i>	<i>SD</i>	1	2	3	4
1. sex	0.56	0.50				
2. age	46.29	3.67	-.13			
3. ppvt	80.79	16.96	-.06	.03		
4. ic	-0.00	0.99	.22	.26	.33*	
5. initial	5.75	4.80	-.06	.33*	.26	.38**

Note. * indicates $p < .05$; ** indicates $p < .01$. *M* and *SD* are used to represent mean and standard deviation, respectively. ic = inhibitory control.

Inhibitory Control and Learning Irregular Forms from Input

The remainder of the analyses includes 37 of the original 48 participants. The exclusion of participants is accounted for as follows. For the feedback task, the experimenter randomly assigned 8 verbs to one of the 2 conditions (positive and negative evidence) described above. In

order for all participants to start at the same baseline level, verbs were assigned in the feedback task for which children committed OR errors during both of the verb's trials in the initial production task. Eight children did not make OR errors during both trials of at least 8 verbs and were, for this reason, not included in the following analysis. In addition, 3 children chose not to complete the post-feedback production task and were, therefore, also excluded.

Preliminary Data Analysis. Before running the analyses to address the question of whether inhibitory control relates to children's ability to learn irregular past tense verb forms from input, it was important to establish the validity of our learning outcome measures. Learning outcomes were measured using two different post-feedback test probes described above: the production and comprehension tasks. These tasks were not significantly correlated with each other, $r(36) = -0.08, p = 0.63$. In addition, comprehension scores did not correlate with vocabulary development, $r(39) = -0.04, p = 0.82$. This suggests that this task might not be measuring the same cognitive construct as the production measure. Further, the measure had low internal consistency (*Cronbach's* $\alpha = 0.45$). It is possible that the verbal instructions provided to children at the beginning of the task did not clearly state the objective or, as this task came at the end of the series of verb tasks, children became either fatigued or disinterested. For these reasons, we chose to exclude the comprehension measure from any further analysis. On the other hand, performance on the production task was significantly correlated with semantic development as measured by the PPVT, $r(36) = 0.37, p = 0.02$. This suggests that children's ability to produce the correct irregular past tense form of a verb following adult corrective input is linked to general progress in language development. Although not surprising, this finding is important because it speaks to the validity of the feedback task and the production measure used.

We calculated a production score for each participant by summing across all 16 trials featuring the 8 target verbs in the past tense (2 trials per verb), yielding scores potentially ranging from 0 – 32 (*Cronbach's* $\alpha = 0.78$). For this task, children received a score of 0 if they provided an OR form (e.g., failed), a score of 1 if they provided an uninflected form (e.g. fall), and a score of 2 if they provided an irregular form (e.g., fell). A production score of 32 indicates production of the correct (irregular) past tense form for all 16 trials of the 8 target verbs.

Visual inspection of the distribution of the data indicated that production scores ($M = 6.49$, $SD = 5.85$) were positively skewed (see Figure 1). Inspection of the Q-Q plot (see Figure 2) and standardized skewness statistic ($SE = 3.04$) confirmed that the data violated the assumption of normality required for regression. A natural log transformation was performed to correct this violation. Inspection of the frequency histogram (see Figure 3), Q-Q plot (see Figure 4), and standardized skewness statistic ($SE = 0.01$) following the transformation indicated that the transformed production scores ($M = 1.19$, $SD = 0.73$) were normally distributed. No other violations of the assumptions of regression were found.

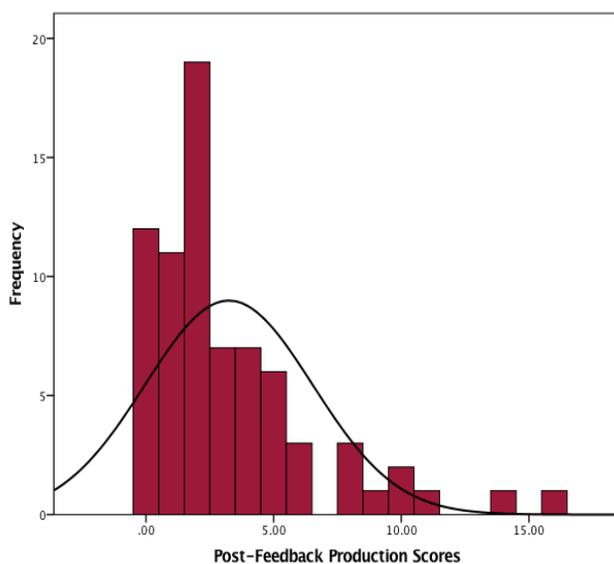


Fig. 1: Distribution of Post-Feedback Production Scores¹⁸ before Natural Log Transformation

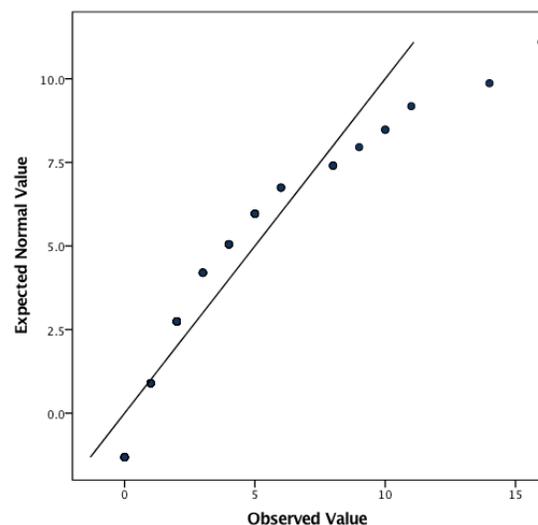


Fig. 2: Normal Q-Q Plot of Post-Feedback Production Scores before Natural Log Transformation

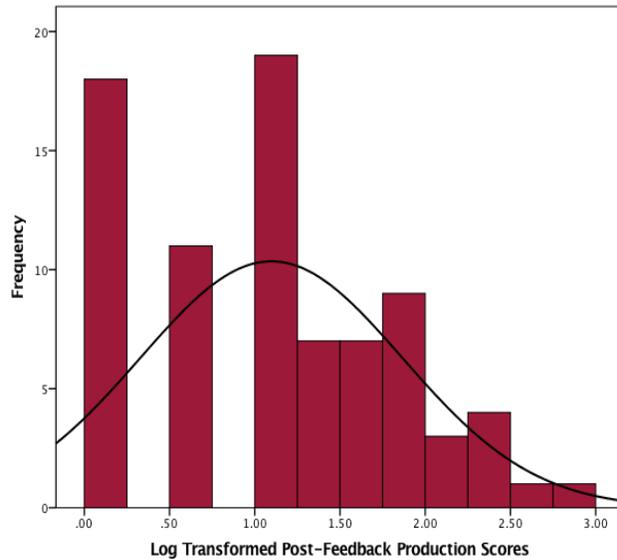


Fig. 3: Distribution of Post-Feedback Production Scores after Natural Log Transformation

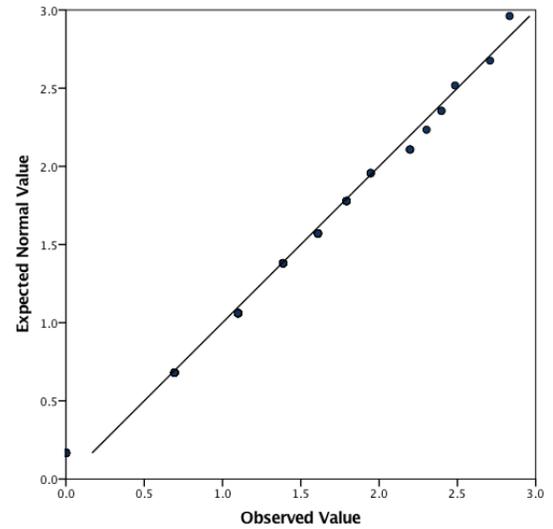


Fig. 4: Normal Q-Q Plot of Post-Feedback Production Scores after Natural Log Transformation

Differences in Post-Feedback Production of Irregulars Between Conditions. Previous research comparing negative and positive input in grammar development has found that children revise initial errors at a higher rate following recasts than following models (e.g., Saxton, 2000). We ran a linear mixed effects regression model controlling for inhibitory control, age, vocabulary development and the interactions of these variables with condition using the `lme` function in the R package `nlme` to assess whether our data followed the pattern of past work. The results of the regression indicated that condition predicted production scores at a level approaching but not reaching significance, $b = 3.35$, $t(33) = 1.78$, $p = 0.08$. In this model, condition was dummy coded with the value 0 corresponding to the model condition and the value 1 corresponding to the recast condition. Thus, the positive coefficient indicates that the negative evidence condition led to a higher rate of post-feedback correct production of irregulars than the positive evidence condition.

Relation Between Inhibitory Control and Learning from Input. The second aim of this work was to explore whether inhibitory control promotes learning irregular past tense verb forms from input. The above-mentioned linear mixed effects model controlling for age, ppvt, and the interaction of these variables with condition was used to evaluate whether inhibitory control predicted learning outcomes. The results of this analysis also revealed that inhibitory control did not predict children’s ability to learn from input, $b = 0.16$, $t(33) = -1.26$, $p = 0.22$. Moreover, inhibitory control did not interact with condition to predict irregular past tense form production, $b = 0.11$, $t(33) = 0.74$, $p = 0.47$. Thus, we did not find evidence in support of our hypothesis that inhibitory control promotes learning from input in the domain of irregular past tense production, even when accounting for the two categories of input children typically receive about OR errors.

Within this model, the interaction term between condition and PPVT significantly predicted post-feedback production scores, $b = -0.02$, $t(33) = -2.08$, $p = 0.05$. The unstandardized simple slope for the recast condition is -0.006 and the unstandardized simple slope for the model condition is 0.01 (see Figure 5). Examining

the simple slopes revealed that children further along in vocabulary development produced more correct irregular past tense forms in the model condition than the recast condition. This finding

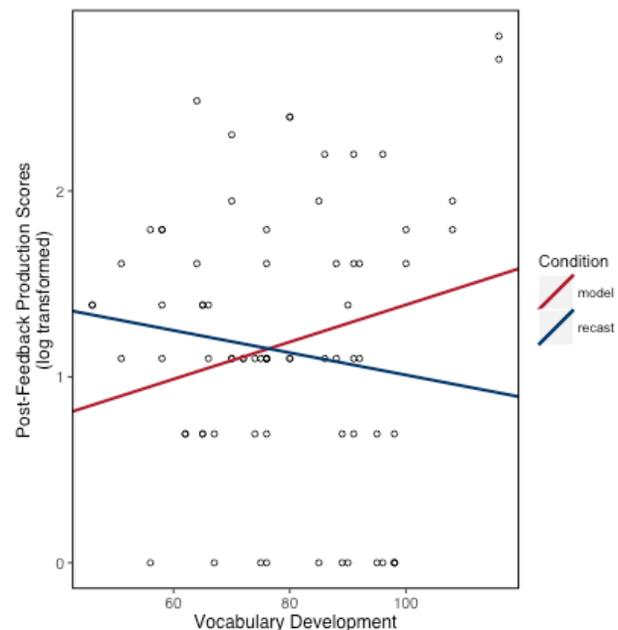


Fig. 5: Post-Feedback Production Scores Moderated by Vocabulary Development

suggests that vocabulary development moderates children's ability to learn from adult corrective feedback. We will discuss the potential implications of these results at length in the discussion section below.

Chapter 4

Discussion

This study explored the relation between inhibitory control and the production of irregular past tense verb forms to better understand the factors underlying the success of the system responsible for past tense production. Specifically, we elicited children's use of known irregular past tense forms and provided feedback for OR errors in 2 conditions (positive and negative evidence). Children also completed a 3-item inhibitory control task battery. We hypothesized that inhibitory control would be a rate-limiting factor to children's successful production of correct irregular past tense verb forms as well as their ability to learn from input following OR errors. Our findings suggest that appropriate use of irregular past tense forms may be partially predicated on children's developing inhibitory control.

ORs have been a central focus in what is a larger debate concerning the structure of linguistic representation. The focal question of this debate is, broadly, whether language is processed via a single associative mechanism (e.g., Rumelhart & McClelland, 1986; Ramscar, 2002; Tomasello, 2000) or via two separate systems, as in rule-symbol models (e.g., Marcus, Pinker, Ullman, & Hollander, 1992; Pinker, 2000; Ullman, 2001). Differentiating these single and dual process models of past tense production is difficult because both can account for key phenomena in past tense production. One way in which the two models might be differentiated, however, is with respect to the cognitive mechanisms underlying their success. ORs of English past tense provide opportunity to test specific claims about these contrasting characterizations of morphological representation. The present study also sought to provide insight into the

underlying cognitive architecture of the system responsible for past tense production by exploring the relation between inhibitory control and OR errors.

Two central findings emerge from this work. The first is that individual differences in inhibitory control partially account for individual differences in the production of irregular past tense forms. Specifically, children with higher inhibitory control composite scores (indicating that they were further along in inhibitory control development) produced a higher number of correct, irregular past tense verb forms during the initial elicitation task. We believe the most parsimonious explanation of this result to be that correct response for both the initial past tense elicitation task and the inhibitory control battery of tasks required children to inhibit a competing response. If dual systems theories (e.g., Marcus et al., 1992; Pinker, 2000; Ullman, 2001) are correct, there are two potential sources of OR errors. One is that children may not have learned the irregular past-tense form and so simply apply the default, rule-generated form. The second is that even though the irregular past-tense form has been encoded, the cognitive processes that are associated with either retrieving the irregular form from memory or with inhibiting the rule may fail. In addition to the natural blocking mechanism that is employed when the memory trace is sufficiently strong, it may also be necessary to block the habitual or prepotent output in order to consider alternatives.

On the other hand, if single systems theories (e.g., Rumelhart & McClelland, 1986; Ramscar, 2002; Tomasello, 2000) are correct, one might not predict an association between inhibitory control and past tense production. This model posits that both regular and irregular forms are implemented in a single associative memory system; all past tense forms are learned individually through experience (see e.g., Tomasello, 2000). It is easy to produce a form when

there is a large amount of evidence that that form is grammatical. There are two ways the representation for a verb can be strengthened, allowing it to be more easily produced. The first way is to hear the verb more often in input; when a form (e.g., sang or walked) is encountered more frequently the representation becomes stronger. The second way is to encounter a specific construction (e.g., add -ed) frequently in input. When a particular construction is encountered more frequently, a representational schema is established, which strengthens the representation of all forms that use that construction. On this model, ORs are thought to result from competition between analogous forms. When a child attempts to produce an irregular form (e.g., fly-flew), that construction faces competition from phonologically similar forms (e.g., lie-lied, dye-died). OR errors occur because the stronger representation of the generalized construction dominates the weaker representation of the correct irregular form. This model would not straightforwardly predict a relation between inhibitory control and past tense production because the competition between forms does not involve suppressing a prepotent response, but instead involves a comparison between the strength of two representations.

The second central result was that, regardless of the category of corrective input offered, inhibitory control did not predict children's ability to learn from adult corrective feedback following OR errors. Moreover, inhibitory control did not differentially predict children's ability to make use of either type of corrective input – models or recasts. Yet, we did find that condition was a predictor of children's rate of post-feedback correct irregular past tense production, independent of inhibitory control. Children revised their initial errors at a higher rate in the recast condition as compared to the model condition. Though this finding did not reach standard statistical significance, the direction of this statistical trend follows the pattern of previous

findings (Chouinard & Clark, 2003; Proctor-Williams & Fey, 2007; Saxton, 2000; Saxton et al., 1998; 2005; Strapp et al., 2008), providing additional support for the claim that recasts provide a unique advantage to the language learner.

Previous research has provided evidence that EF is important for aspects of conceptual development. For example, executive function – in particular, response-conflict executive function (e.g., Stroop tasks) – has been shown to mediate children’s ability to make use of negative feedback in Theory of Mind development. Benson, Sabbagh, Carlson, and Zelazo (2013) conducted a training study and found that individual differences in EF predicted the extent to which children with initially poor false-belief performance improved following training. The authors speculate that children maintain beliefs that lead them to make erroneous predictions. In order to develop accurate representations of false-beliefs, children need to integrate new, incongruent information into their already established belief, requiring them to change their mind. The theorized role of EF in this development is in helping integrate incongruent information with prior knowledge. However, EF may not be important for associative learning processes.

It is possible that correcting OR errors does not a matter of belief change in the same way as other instances of conceptual change. That is, perhaps children do not *believe* that the OR form of a verb that takes an irregular past-tense form is correct. Instead, it is a matter of strengthening the representation of the irregular form so that the inhibitory processes that we show are important for successful irregular past-tense production can be succeed. If this were true, we might expect that the efficiency of children’s associative memory processes would be important for correcting OR errors immediately following feedback.

Some evidence that this improvement in performance does, in fact, reflect an associative learning process comes from our findings involving children's PPVT performance. Recall that PPVT scores interacted with the type of feedback that children received to predict their post-feedback use of correct irregular past tense verb forms. Specifically, children that were further along in vocabulary development more frequently provided the correct irregular past tense verb form after being provided a model of correct usage than following a recast of the OR error. In contrast, recasts appeared to cue production of the irregular forms more than models for children that scored lower on the PPVT. This finding indicates that associative learning processes may play a role in learning irregular past tense verb forms from input. However, the precise nature of the role of these associative processes in learning irregular forms from input may change with development. It is possible that children that are further along in vocabulary development are better able to track the occurrence of each form in the input they receive. Perhaps, extensive negative and positive evidence is required to establish and strengthen the association between the stem and the irregular form. As children gain experience producing the irregular form, it may become easier to track its occurrence in input and update their linguistic constructions accordingly, thus, accounting for children's ability to make more efficient use of models as they advance in vocabulary development. In any case, the ability to make efficient use of positive evidence suggests that children need only form an association between the present and past tense forms of an irregular verb. Future work would benefit from exploring this potential developmental difference further.

Is successful irregular inflection the result of good inhibitory control or working memory?

We have suggested here that having the ability to inhibit a habitual response in favor of a non-dominant response underlies children's successful production of correct irregular past tense verb forms. Yet, it is possible that another executive function may underlie the success of this system. Among EF researchers, there is considerable disagreement regarding the nature of inhibition. Some researchers argue that inhibitory control is a derivation of working memory, rather than a separate cognitive skill (Miller & Cohen, 2001; Munakata et al., 2011). Specifically, this view posits that a representation can be more or less robust and that a prepotent response is enacted when the representational strength of a goal is weak. On the other hand, researchers have argued that inhibition *is* dissociable from working memory (Wright & Diamond, 2014; Zanto, Rubens, Thangavel, & Gazzaley, 2011). Evidence that these skills are dissociable comes from work that shows that when working memory demands are held constant, an increase in inhibitory control related task demands is sufficient to impair performance. For instance, Wright and Diamond (2014) varied whether the hearts and flowers task started with "congruent" (i.e., participants push a button on the same side as the stimulus) or "incongruent" (i.e., participants push a button the opposite side of the stimulus) trials and found that children erred more often and reacted slower on the incongruent trials no matter the order of presentation. Additionally, Zanto et al. (2011) found that when adult participants were asked to attend to only one layer of two superimposed stimuli, they demonstrated enhancement of the attended-to layer, but no suppression of the not-attended-to layer. Such findings suggest that distinct cognitive mechanisms may be important for the enhancement versus suppression of a stimulus. To the extent that inhibitory control and working memory rely on distinct cognitive mechanisms, it

remains unclear whether the current findings definitively capture the effects of poor inhibitory control, rather than working memory, performance.

Limitations

It is important to acknowledge that although we collected data on children's grammaticality judgments after providing them with corrective feedback, we were unable to interpret this data, as this measure did not appear to relate to vocabulary development or scores on the post-feedback production task. Children show poorer performance in production tasks as compared to comprehension tasks for a variety of language measures. For this reason, it is possible that we were unable to fully assess whether or not children learned irregular past tense verb forms from the feedback provided. Thus, future work would benefit to measure this competency in order to more fully assess the associations explored in the present study.

It is also important to note that even though feedback led to improved performance within this sample, it is unclear whether these findings would replicate in a more naturalistic context. Our design tested children's immediate gain from feedback, however a larger scale design may provide a more ecologically valid measure of learning. A study with multiple sessions could test whether immediate gain maps onto learning in a more normative time frame. Important consolidation may occur in the days or weeks following feedback. Saxton, Backley, and Gallaway (2005) found that recasts, but not various forms of positive evidence, were associated with the use of correct, grammatical forms after a lag of 12 weeks. Perhaps there is an "offline" learning that children experience between exposure to negative evidence and the next attempt to recreate that or similar utterances. In order to measure delayed effects of exposure to recasts, we would need to conduct one or more follow-up sessions with participants.

Conclusion

In summary, this study provides evidence that individual variation in inhibitory control is predictive of grammatical ability with regard to past tense formation. Specifically, we found that inhibitory control may be a rate-limiting factor on children's ability to provide irregular inflection. In contrast, we did not find evidence that IC was associated with children's abilities to make use of adult corrective input following the production of an OR verb form. These findings suggest that inhibitory control is associated with irregular past-tense production because inhibitory control is an integral part of the cognitive architecture of the past-tense production system. Therefore, our findings also support dual systems theories that explicitly feature a role for inhibitory processes.

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