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Abstract

The "less is more" hypothesis suggests that one reason adults and children differ in their language acquisition abilities is that they also differ in other cognitive capacities: for instance, the relatively poor memory and/or processing abilities of children may make them more likely to over-regularize inconsistent input (Singleton & Newport, 2004; Hudson Kam & Newport, 2005). We investigate this hypothesis by placing adults under a high cognitive load using a standard task. Does their tendency to over-regularize in a simultaneous language-learning task increase? Results indicate that although the cognitive load is high enough to impair overall learning, neither the presence of load nor poor working memory predicts greater over-regularization. This suggests that if the "less is more" hypothesis explains over-regularization in children, the relevant cognitive capacity is not one that was impaired by our load task.
Keywords: language acquisition; over-regularization; statistical learning; memory; processing; development

Introduction

Children and adults differ both qualitatively and quantitatively in their ability to acquire a new language. Adults have difficulty with many aspects of language acquisition, from phonetic perception (Werker & Tees, 1984; Werker & Lalonde, 1988; Kuhl, 2004), to language processing (Clahsen & Felser, 2006), to certain aspects of syntax (e.g., Johnson & Newport, 1989; Birdsong, 2006). Scientists have proposed many theories to account for the difference between children and adults; these theories differ in both the degree and type of contribution made by pre-existing language-specific biases. Although nearly everyone agrees that (due to the inherent logical problem of induction posed by language learning) some bias must be necessary to explain successful language acquisition, explanations about the nature of the bias – and the difference between children and adults – vary considerably.

Some argue that there is a fundamental difference between first- and second-language acquisition. They posit that acquisition in children is guided by an innate Universal Grammar and by language-specific acquisition procedures, whereas adult acquisition is directed by more domain-general learning mechanisms (e.g., Bley-Vroman, 1990). However, there are many other possibilities, since children and adults also differ profoundly in their cognitive capabilities, knowledge, assumptions, and typical linguistic input. For one thing, learning a second language is made more difficult by interference from the first language; the evidence that experience with a first language influences acquisition of a second language is extensive (e.g., Mayberry, 1993; Iverson et al., 2003; Tan, 2003; Weber & Cutler, 2003; Hernandez, Li, & MacWhinney, 2005). This observation overlaps considerably with the related point that adult brains are less malleable than the brains of children (Elman et al., 1996; MacWhinney, 2005). Adults and children also differ in their style of learning (Ullman, 2004) and in the nature of the social support (Snow, 1999) and linguistic input (Fernald & Simon, 1984) they receive.

The observation that children perform more poorly than adults across most domains of cognitive ability, including memory and processing speed, has led to another hypothesis, often called "less is more." It suggests that the relative cognitive deficits in children may actually *help* with language acquisition by enabling them to isolate and analyze the separate components of a linguistic stimulus (Newport, 1988), or by leading them to over-regularize inconsistent input (Hudson Kam & Newport, 2005; Singleton & Newport, 2004). Indeed, it is apparent that children over-regularize while adults often do not. Deaf children exposed to the inconsistent sign language of hearing parents will over-regularize that language and produce regular grammatical forms (Singleton & Newport, 2004), as will children exposed to inconsistent input in an artificial language (Hudson Kam & Newport, 2005; Goldowsky, 1995). By contrast, adult language learners are known to produce highly variable, inconsistent utterances, even after years of experience with the language and after their grammars have stabilized (Wolfram, 1985; Johnson, Shenkman, Newport, & Medin, 1996).

The difference between children and adults has also been found in non-linguistic domains. If adults must predict some phenomenon (e.g., a light flashing or a certain card being drawn from a deck), they will tend to probability match: if the phenomenon occurs 70% of the time, they will expect it 70% of the time they are asked (see, e.g., Myers, 1976; Shanks, Tunney, & McCarthy, 2002, for an overview). Children are more likely to predict that the phenomenon will occur closer to 100% of the time (e.g., Weir, 1964; Derks & Paclisanu, 1967). A similar pattern has been found in causal reasoning: children over-regularize by assuming that causes are deterministic, while adults do not (Schulz & Sommerville, 2006).

Although the tendency toward over-regularization is well-established, the reason for the difference between adults and children is far from clear. As previously mentioned, the "less is more" hypothesis suggests that over-regularization may be due to some aspect of children's cognitive capacities, such as their poorer memory or slower processing speed (Newport, 1988). Adults do tend to over-regularize more when the input is complex, when the probabilities involved are small (Gardner, 1957; Weir, 1964; Gluck & Bower, 1988; Hudson Kam & Newport, 2009), or when lexical retrieval is more difficult (Hudson Kam & Chang, 2009). This may be because more complex input imposes more of a load on their cognitive resources. The hypothesis is also supported by empirical (Kersten & Earles, 2001) and computational (Elman, 1993) work suggesting that learning is easier when early input is simpler (although that work does not speak directly to the issue of over-regularization). In general, there has been little research that directly measures or manipulates memory or processing speed and evaluates whether these are associated with different degrees of over-regularization in adults.

Here we begin to investigate this question more directly. Our goal is to evaluate whether we can effectively turn adults into children by placing them under cognitive load. If deficiencies in the particular capacities involved in the load tasks are what cause children to over-regularize, then adults under heavy load should behave more like children in their pattern of over-regularization. We find that, although the cognitive load is high enough to impair adult performance in other ways – and although their working memory capacity predicts overall performance on the task – neither increased cognitive load nor poor working memory predicts or leads to increased over-regularization. This suggests that, if the "less is more" hypothesis is the explanation for childrens' tendency to over-regularize, the cognitive capacity that is "less" in children is not one that is impaired by the load tasks we used.

Method

75 adults were recruited from the University of Adelaide and surrounding community and were paid $10 for their participation. In the first part of the experiment, individual differences in working memory capacity were measured using a standard complex span task (Conway, Jarrold, Kane, Miyake, & Towse, 2007; Unsworth, Redick, Heitz, Broadway, & Engle, 2009). In the second part of the experiment, subjects completed a word-learning task (modelled on the paradigm described by Hudson Kam and Newport (2009)) in which they were taught 10 two-word labels from a new language. Interspersed with the word-learning task, participants in the OPERATIONAL LOAD and VERBAL LOAD conditions completed an interference task (involving either solving equations or reading sentences aloud, respectively). In a control condition, the NO LOAD condition, participants performed the word-learning task only. Specific details of the initial complex span task and the subsequent word-learning task follow.

Complex span task

Complex span tasks are widely used to measure the capacity of the working memory system (Conway et al., 2005; Unsworth et al., 2009). In a complex span task, items to be remembered (e.g., random letters, digits, shapes, or spatial locations) are interspersed with an unrelated cognitive activity (e.g., solving equations, reading sentences, or evaluating the symmetry of patterns). After several trials, participants are asked to recall the items to be remembered in the correct serial order. This sort of task is differentiated from a simple span task (e.g., Digit Span from the Wechsler scales), which only includes the memorization component; it has been argued that complex span tasks provide a measure of working memory (as opposed to span memory) because they entail the requirement to process as well as to store information. Complex span tasks have been shown to correlate with cognitive processes that are believed to depend on working memory (Conway et al., 2007; Unsworth & Engle, 2007), and are linked to disorders including Alzheimer's disease (Rosen, Bergeson, Putnam, Harwel, & Sunderland, 2002). They have also been widely used to explore age differences in working memory capacity (Case, Kurland, & Goldberg, 1982; Salthouse & Babcock, 1991).

Two common span tasks incorporate demands on either operational span (Turner & Engle, 1989) or on verbal span (Daneman & Carpenter, 1980), respectively. In an operational span task, participants are presented with equations such as $4/2+2=3$ and told to say, as quickly as possible, whether the equation is correct. In a typical verbal span task, subjects are presented with an 11-15 word sentence and told to say, as quickly as possible, whether the sentence makes sense. In order to enable comparison across participants, in the first part of the experiment all participants were presented with an operational span task regardless of condition. On each trial people first saw an equation and were asked whether it was correct or not. After each response, a random letter was shown. At the end of a set of *n* letters, participants were asked to repeat the list of letters in order, given unlimited time to do so. To make sure that they understood the task, they were first trained on two sets of two trials each. The full task comprised two sets each of sizes ranging from an *n* of three to an *n* of seven, for a total of 50 trials. For each participant a working memory capacity score was calculated, reflecting the number of correct letters recalled in the correct position.

Word-learning task

After the complex span task, all participants took part in an artificial language learning task modelled after a similar task described by Hudson Kam and Newport (2009). Their language contained 51 words, including 36 nouns and 12 verbs, among other lexical items, taught over the course of eight separate sessions extending for 9-12 days. Of critical interest in their study was the evaluation of performance on the determiners, which were associated with nouns in an inconsistent fashion: participants heard the main determiner only 60% of the time. In one condition, they heard nothing the other 40% of the time; in four other conditions, they heard increasingly more *noise* determiners (e.g., two determiners (each 20% of the time), and so forth up to 16 determiners (each 2.5% of the time)). Performance was measured in a sentence completion task in which participants had to provide the noun and determiner associated with a scene and sentence.

We sought to remove extraneous elements of the task so as to focus on the determiner-production aspect while still retaining the important details. We therefore presented participants with a "language" of 10 nouns, all two-syllable nonsense words[1] mapped to images representing common objects.[2] Each noun was followed by a one-syllable determiner:[3] the *main* determiner occurred 60% of the time, and each of the four *noise* determiners occurred 10% of the time. The specific mapping of the word to the meaning and which determiner was the *main* determiner were randomized for each participant.

Over the course of the task, participants saw 200 trials of image-label pairs. On each trial, an image appeared on the computer screen and, at the same time, the person heard a female voice provide the label: for instance, they might see a picture of a baby and hear churbit mog. In the NO LOAD condition, participants went to the next trial by clicking a next button; in the two load conditions, the image remained visible for 1.5 seconds and then the next phase of the trial began automatically (as explained below). In all conditions, learning was tested with 10 questions every 50 trials, for a total of 40 test questions. At each test, the participant was presented with an image and asked to verbally produce the label for it, which the experimenter wrote down. No feedback was given.

Subjects in the two load conditions completed the same word learning task, except that after each image-label pair, they were asked to perform an unrelated task designed to increase their cognitive load. In the OPERATIONAL LOAD condition, the task was modelled after the operational span test (Turner & Engle, 1989): participants were presented with an equation and told to respond as quickly as possible whether it was correct or not. Half of the equations were correct, and half gave an answer that was one digit away from correct. In order to encourage them to be as fast and correct as possible, a running total of their number correct and elapsed time was displayed on the screen. In the VERBAL LOAD condition, the task was modelled after the verbal span test (Daneman & Carpenter, 1980): participants were presented with an 11-15 word sentence, told to read it aloud, and then asked to respond as quickly as possible whether it was sensible or not. Half of the sentences were sensible, and half were made non-sensible by replacing a content word with a semantically inappropriate one.[4] As before, accuracy and elapsed time was displayed in order to encourage peak performance.

Results

There are three natural questions we must answer in order to properly understand this experiment. First, is the load task difficult enough? Second, did participants in either of the load conditions over-regularize by producing the *main* determiner more than 60% of the time? Third, did individual differences in performance on the initial complex span task predict performance on the word-learning task? The answer to the first question is an essential pre-requisite to interpreting the answers to the other two because if the load task was not challenging enough, comparisons between conditions are meaningless. The answers to the other two bear directly on the questions motivating this work: does putting adults under cognitive load cause them to make the same over-regularization errors that children do? Are adults with poorer performance on the complex span task (and hence lower working memory capacity) more likely to make those errors? We address each of these questions in turn.

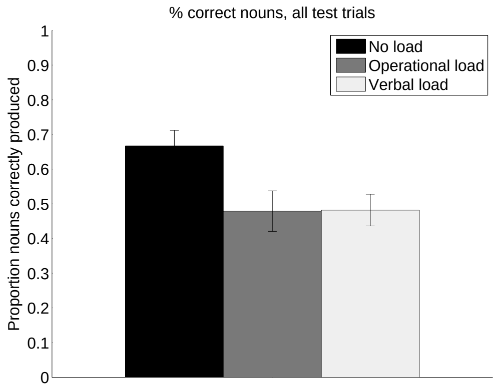

Figure 1: Performance by condition in the noun-learning task. Participants in the two load conditions learned significantly fewer nouns, indicating that the load task provided sufficient cognitive challenge to impair performance.

Was the load task difficult enough?

There are several ways to evaluate whether the load tasks were sufficiently challenging to the cognitive capacities of our participants, whilst still being easy enough so that people could acquire at least some of the image-label mappings in the word-learning task. One indication is that participants in both conditions scored far above chance on the load items, suggesting that they took that task seriously.

To evaluate the degree of difficulty the tasks imposed, we can compare how well participants in each of the three conditions learned the correct noun-image mappings. One would expect that performance would be substantially worse in the two load conditions if the secondary task provided a sufficient challenge to the cognitive capacities of our participants. To explore this, we coded each person's answers as *correct* if the noun they produced was identical to or phonologically similar (e.g., wolin instead of wolid) to the correct noun for that image. Figure 1 demonstrates that participants in both load conditions got fewer nouns correct than in the NO LOAD condition, indicating that the interference tasks were, indeed, imposing significant strain on their cognitive resources. There was no difference in the number of nouns correct between the OPERATIONAL LOAD and VERBAL LOAD conditions.[5]

[1]Noun words used were: dragnip, raygler, churbit, tramdel, shelbin, pugbo, wolid, foutray, nipag, and yeetom.

[2]Objects used were: babies, balls, beds, birds, books, cars, cats, cups, dogs, and shoes.

[3]The five determiners were: mot, ped, sib, kag, and zuf.

[4]For example, a typical sentence is "Cats really love to sit in the sun, since they are desert animals" while the corresponding non-sensible sentence would replace animals with chimneys.

[5]A one-way Anova on nouns correct by condition was significant: $F(2,72) = 4.63, p = 0.0129$. Post-hoc comparisons using the Tukey-Kremar test indicated that the mean score for the NO LOAD condition (M=0.667, SD = 0.05) was significantly different than the

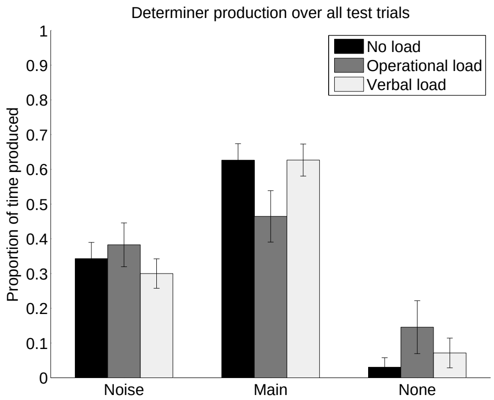

Figure 2: Performance by condition in determiner production. There was no significant difference between conditions in tendency to over-regularize, and in no condition did people produce the main determiner beyond the 60% it appeared in the input.

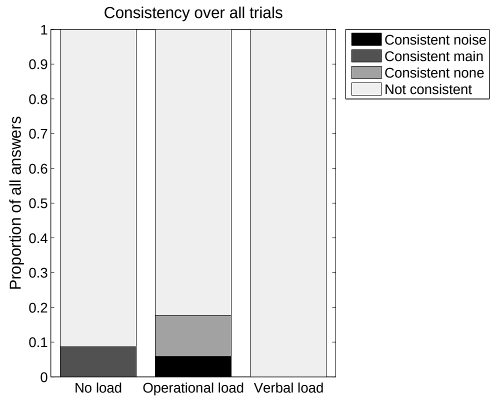

Figure 3: Individual consistency in determiner production by condition. For the most part, few participants showed any consistency in their pattern of determiner usage, and those in the load conditions did not tend to be more consistent.

Did adults over-regularize more when under cognitive load?

The central question motivating this research was whether adults placed under cognitive load could be made to look more like children. To evaluate this, following Hudson Kam and Newport (2009), we excluded all participants who did not get at least 9 out of the final 20 nouns correct on the test trials.[6] Then, on every valid trial (i.e., every trial for which a correct noun was produced), we calculated the percentage of time either the *main* determiner, a *noise* determiner, or *no* determiner was produced. Figure 2 demonstrates that there were no significant differences between conditions in terms of *main* determiner production: that is, participants in the load conditions did not over-regularize.[7] If anything, participants in the OPERATIONAL LOAD condition tended to *under*-regularize, which is the opposite of what one would expect if limited available memory or processing power was the driving force behind over-regularization.

This is suggestive, but because it is an analysis of mean performances this outcome may be hiding individual over-regularization in different directions. To evaluate this possibility, we followed Hudson Kam and Newport (2009) and set a "consistency threshold" of 90%: each participant was coded as *consistent main*, *consistent noise*, or *consistent none* if they produced the determiner type in question on at least 90% of the valid trials, and *not consistent* if they did not.[8] Figure 3 shows that few participants were consistent in any way, and differences between conditions were minor. In order to determine if the tendency to over-regularize changed as they acquired more of the language, we repeated the analyses shown in both Figure 2 and 3 at each of the four stages of testing. There were no differences in behavior at any stage.

Does working memory span have any effect on performance?

The results presented thus far suggest that people with less available working memory capacity (i.e., those in the two load conditions) did not over-regularize the main determiner more than did those in the control condition. Our experiment also provides another way to evaluate how working memory capacity affects over-regularization: by analyzing whether individual differences in performance on the initial complex span task predicts differential performance on the word-learning task. As one would expect, performance on the complex span task is positively and significantly correlated with the ability to learn the noun-image mappings ($\rho = 0.3811, p = 0.0013$): participants with greater working memory capacity learned more noun labels. However, there is no relation between working memory capacity and the tendency to produce the main determiner ($\rho = 0.1066, p = 0.387$), nor do the scatterplots indicate a non-linear relationship.

Discussion

On first glance, our findings might appear to contradict those of Hudson Kam and Chang (2009), who found that over-regularization in adults could be diminished by improving the ease of lexical retrieval. There are three notable differences here. First, they aimed to make adults *less* like children by making the cognitive load easier, rather than to make adults act *more* like children by making it harder. It is possible that there is an inherent asymmetry to adults' performance: that it is relatively easy to make adults over-regularize less, but that getting them to regularize more is difficult. This is certainly the case in the decision-making literature, in which great efforts have been made to stop adults from probability match-

mean for the OPERATIONAL LOAD ($M = 0.479, SD = 0.05$) and VERBAL LOAD ($M = 0.482, S = 0.05$) conditions, but the latter two were not significantly different from each other.

[6]This resulted in 23 subjects in the NO LOAD condition and 17 in each of the others. We ran each of these analyses without this exclusion and results were qualitatively identical in all cases.

[7]One-way Anova on main determiner production by condition: $F(2,54) = 2.64, p = 0.0806$. To further explore this outcome, a post-hoc comparison using Tukey-Kramer indicated no significant difference between any of the conditions compared pairwise.

[8]Results are qualitatively identical even with thresholds of 70% or 80%: there are more consistent participants in those cases, but still no difference between conditions.

ing (e.g., Shanks et al., 2002). Second, and more importantly, the study by Hudson Kam and Chang (2009) examined a different aspect of cognitive load (lexical retrieval rather than working memory capacity). It is possible that differences in lexical retrieval abilities are related to differences in over-regularization between children and adults, but that differences impaired by our load task were not. Third, our language was far simpler than theirs; it is possible that our participants treated the task like paired-associate learning rather than like learning a language with rich internal structure, unlike adult learners in other studies that tasked load (Pitts Cochran, McDonald, & Parault, 1999). We think this would be a rather surprising explanation of our findings, given that the task itself (learning determiner-noun pairings) was the same in both studies, and the main difference was the complexity of the rest of the system they were embedded in; however, it is an open question that we seek to resolve with future work.

The central issue, of course, is what abilities *were* impaired by our load task? In many ways, the two load tasks were quite different: one involved solving equations, while the other involved reading sentences aloud and answering questions about them. Despite this, it has been shown that the complex working memory tests related to these tasks tend to load highly on the same broad working memory factor (e.g., Oberauer, Süß, Wilhelm, & Wittmann, 2003). It may therefore not be a surprise that both load tasks had similar effects. The interesting aspect of this is that these tasks were specifically designed to create a load on multiple different cognitive capacities at once: unlike simple span tasks (such as Digit Span on the Wechsler), which capture only the storage component of memory, these require processing as well. In general, these load tasks should be disrupting many aspects of cognition: among other things, they require people to retrieve information from long-term memory (word meanings in the VERBAL LOAD condition, number and symbol meanings in the OPERATIONAL LOAD condition), to store information in short-term memory (the words in the current sentence or numbers in the current equation), to manipulate representations (to determine the correct answer to the questions), to regulate attention, and to perform the load task while simultaneously learning word-referent mappings. It is interesting that, despite their generality, the load tasks still did not lead to over-regularization in word learning.

How might we interpret these results? One possibility is that the "less is more" hypothesis is incorrect: that children's tendency to over-regularize does not stem from differences in cognitive capacity. Such a possibility is consistent with previous studies finding no effect of load on adult learners (Ludden & Gupta, 2000) as well as other empirical findings in language acquisition showing that children with better memories or faster processing speed actually do *better* at learning language (e.g., Fernald, Perfors, & Marchman, 2006; Rose, Feldman, & Jankowski, 2009).

That said, we cannot be certain that "less is more" is incorrect. It is in theory possible that our load tasks did not sufficiently challenge our subjects enough, and that more difficult ones would result in more over-regularization. This is unlikely, not only because the participants anecdotally seem to have found the task extremely difficult (one person called it the hardest psychology experiment he had ever done), but also because the load tasks had such strong effects on the ability to learn the nouns in the first place. The task would somehow have to be difficult enough to cause over-regularization but not so difficult as to render the task impossible: a balancing act that, if nothing else, seems unlikely to precisely describe the state of child language learners.

This point, however, raises the converse possibility: perhaps our language-learning task was so difficult (such that even in the no-load condition, participants were only about 70% correct overall[9]) that with longer training, the pattern we observed might change. While always a possibility, we think this is more unlikely than other explanations, since we observed no detectable change in tendency to over-regularize over the course of the experiment.

Another possibility is that, because our load task items were interspersed rather than concurrent with the words to be learned, it was less of a burden on concurrent memory and processing speed, and more of a burden on executive control. If so, this would suggest that the differential abilities between children and adults is not due to cognitive control, as has been suggested in a different context (Thompson-Schill, Ramscar, & Chrysikou, 2009). We plan to explore this issue in future work using a concurrent load task like verbal shadowing.

Even if our load task does impair memory and processing speed, there remain some likely possibilities for how the "less is more" hypothesis might be correct and still be consistent with our results. In addition to memory and processing speed, children and adults also differ in the ability to use metacognitive strategies (e.g., Flavell, Green, Flavell, Harris, & Astington, 1995). It may be that adults' ability to introspect and reason about their own cognition makes them more likely to rely on explicit rather than implicit learning (Ullman, 2004) – a difference that has been hypothesized to be the root of child-adult differences in language acquisition. Such metacognitive ability might also make adults more likely to try to capture or imagine patterns in the input that do not exist; this tendency has been suggested as an explanation for why adults probability match in non-language tasks (Estes, 1976). It might result from a generalized preference for simplicity (or tendency to ignore exceptions) on the part of children. It is also possible that having limited memory or processing abilities is especially important for language learning *as a child* but not as an adult, analogously to a similar hypothesis found in other developmental domains (Turkewitz & Kenny, 1982). A great deal of work remains to be done to investigate the many possibilities that remain open.

[9] Keeping in mind that, since there were 10 objects and it was a free-response task, this is actually far above chance performance.

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