The persistence of priming:

Exploring long-lasting syntactic priming effects in children and adults

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Abstract

The implicit learning account of syntactic priming proposes that the same mechanism underlies syntactic priming and language development, providing a link between child and adult language processing. The present experiment tested predictions of this account by comparing the persistence of syntactic priming effects in children and adults. Four-year-olds and adults first described transitive events after hearing transitive primes, constituting an exposure phase that established priming effects for passives. The persistence of this priming effect was measured in a test phase as participants described further transitive events but no longer heard primes. Their production of passives was compared to a baseline group who described the same pictures without any exposure to primes. Neither immediate nor long-term priming effects differed between children and adults but both children and adults showed significant immediate and persistent effects of the priming when the test phase occurred immediately after the exposure phase and when a short delay separated the exposure and test phase. The implications of these results for an implicit learning account of syntactic priming are discussed.

Keywords: syntactic priming; implicit learning; language development; passives

1. Introduction

The widely attested phenomenon of syntactic priming – an unconscious process whereby prior experience of a syntactic structure increases the likelihood of a speaker producing or expecting to hear that syntactic structure in subsequent utterances – has been important for establishing that both adults and children access abstract representations of syntactic structures in comprehending and producing language across a range of modalities (see Branigan & Pickering, 2017; Pickering & Ferreira, 2008; Rowland, Chang, Ambridge, Pine, & Lieven, 2012 for reviews). Nonetheless, the nature of the mechanism underlying priming has remained the subject of debate, not least because it has been shown that priming effects are long-lasting, in the sense that they persist beyond the immediate occurrence of the prime, (Bock & Griffin, 2000). This casts doubt on early assumptions that priming reflects transient activation of syntactic representations (Pickering & Branigan, 1998). Instead, speakers' representations of syntactic structures appear to be susceptible to lasting change caused by prior experience (priming); priming effects therefore appear to reflect a mechanism of implicit learning or tuning within the language system (Bock & Griffin, 2000; Dell & Chang, 2014; Ferreira & Bock, 2006; Reitter, Keller, & Moore, 2011). It is further argued that an error-based implicit learning mechanism underlies both syntactic priming and language acquisition (Chang, Dell, & Bock, 2006). This account is based on training and priming performance in a connectionist, error-based learning model (Chang et al., 2006; Chang, Janciauskas, & Fitz, 2012) but it predicts certain behavioral results. Firstly, priming effects should be long-lasting in all speakers, young and old. Further, if error-based learning underlies syntactic priming, then this model predicts there should be age-related differences in priming effects depending on whether the speaker's syntactic representations are in acquisition or not. This paper therefore examines the long-term persistence of syntactic priming effects in children as well as adults, and whether these groups show the predicted age-related differences in such effects.

2. Syntactic priming effects as evidence for language representations and mechanisms

2.1 Syntactic priming as evidence for abstract syntactic representations

Languages have systematic ways for describing events: syntactic structures provide rules for how to map conceptual elements of an event onto structural elements of a sentence. These rules are abstract, based on categories of words (such as noun, verb) and so can be applied to any appropriate combination of lexical items such that speakers can understand and produce entirely novel sentences. For example, *transitive* events, those in which one participant acts upon another participant such as *chasing*, can be described in sentences with an *active* syntactic structure (1) or a *passive* syntactic structure (2). Such sentence structures can be represented in abstract terms involving syntactic categories, such as subject and object noun phrases (NP), verbs, and morphosyntactic elements, such as auxiliaries, verbal inflections and prepositions. Such representations may also specify the rules for how these items are combined, in terms of word order and the order in which participant roles (e.g. agent, patient) map onto syntactic roles (subject, object; compare examples 1 and 2).

(1) The big hairy dog chased the little cat
Subject $NP_{[agent]}$ Verb Object $NP_{[patient]}$

(2) The little cat was chased by the big hairy dog
Subject $NP_{[patient]}$ Aux. Verb Prep. Object $NP_{[agent]}$

One strand of evidence that speakers do recruit abstract syntactic representations in language processing comes from syntactic priming studies in which participants repeat syntactic structure but not lexical content or other features across utterances (Bock, 1989; Bock & Loebell, 1990). For example participants are more likely to describe an event with a passive if they had recently produced a passive than if they had recently produced an active

(Bock, 1986); parallel patterns of effect have been observed within comprehension (Thothathiri & Snedeker, 2008a). Syntactic priming effects have thus been key in demonstrating the existence of mental representations of language structure across a range of speakers (see Mahowald, James, Futrell, and Gibson, (2016) for a meta-analysis). Syntactic priming has been used in the same way as in adult studies to show that young children also possess abstract syntactic representations (e.g. Huttenlocher et al., 2004; Thothathiri & Snedeker, 2008b). However, the nature of the mechanisms that underlie such effects are still very much under debate.

2.2 Syntactic priming as implicit learning in adults

Early accounts of syntactic priming explained priming as transient activation of such representations during comprehension and production (Bock, 1989; Bock & Loebell, 1990; Branigan, Pickering, Liversedge, Stewart, & Urbach, 1995; Pickering & Branigan, 1998). However, further evidence suggests that priming effects are not just immediate responses to syntactic experiences: they lead to long-lasting changes in speakers' use of structures (Bock & Griffin, 2000; Hartsuiker, Kolk, & Huiskamp, 1999). Bock and Griffin (2000) found that the effect of hearing and producing a prime sentence on participants' description of target events persisted over ten intervening trials: when participants heard and repeated a passive prime, they were more likely to use a passive to describe a transitive target ten trials later than when the prime had been an active sentence. Bock and Griffin proposed that syntactic priming in adults may be the result of implicit learning processes in which language representations adapt to recent experience. When a speaker produces (or hears) a sentence with one syntactic structure, this experience tunes the language processor to that particular mapping of an event type (e.g. transitive event) to a syntactic form, (e.g. passive, as opposed to the alternative form, active). The processor remains tuned to repeat such mappings until subsequent experience (such as experience of the alternative syntactic structure for the same event type) effects a change in the tuning. The filler trials in their study were syntactically unrelated to the prime and target trials so did not influence the status of the language processor's weightings for how to map transitive events to syntactic structures, (see also Bock, Dell, Chang, & Onishi, 2007; Hartsuiker et al., 2008). Further experimental evidence has supported this theory showing that patterns of language production in adults are influenced by the patterns of syntactic structures they are exposed to both within and across experimental sessions, (Hartsuiker et al., 2008; Kaschak, 2007; Kaschak, Kutta, & Schatschneider, 2011; Kaschak, Loney, & Borreggine, 2006). Persistent priming effects are not compatible with a transient activation of static representations account (Pickering & Branigan, 1998). As such it is argued that they reflect a model of language processing and representation which involves an implicit learning mechanism, (Chang, Dell, Bock, & Griffin, 2000; Malhotra, Pickering, Branigan, & Bednar, 2008; Reitter et al., 2011; see Hartsuiker et al., 2008 for discussion).

A variety of implicit learning explanations of priming have been proposed. One set of accounts describe long-term effects of priming as resulting from unsupervised learning within memory and spreading activation mechanisms (e.g. Malhotra et al., 2008; Reitter et al., 2011). An alternative set of explanations propose that long-term priming effects reflect learning through prediction, due to either a rational learning mechanism (Jaeger & Snider, 2013) or a supervised learning mechanism (Chang et al., 2006). Here, we focus on the latter, error-based supervised learning approach because this is the only model of priming that is embedded within broader psycholinguistic processes (Dell & Chang, 2014) and is also designed to account for children's learning of syntactic structures (Chang et al., 2006; Dell & Chang, 2014). This account of syntactic priming is therefore of particular theoretical interest because it links adult and child language processes (Peter & Rowland, 2018).

Chang et al. (2006)'s model instantiates implicit learning through prediction and error-based learning mechanisms. It is based on the premises that speakers predict upcoming linguistics elements as they process input and that they adjust their representations of structures based on mismatches between predicted and experienced input (Dell & Chang, 2014). Children's learning about syntactic categories and their development of syntactic representations is also driven by this prediction and error-based learning mechanism. Indeed, it is argued that syntactic priming effects are a vestige of the mechanism that supports syntactic development (Chang et al., 2006).

In this model, syntactic priming occurs because processing a prime structure causes that structure's weighting to be increased to reflect recent experience. In particular, dispreferred or rarer structures will be more likely to show priming effects because processing a dispreferred structure generates greater prediction error. This leads to a greater adjustment to the dispreferred structure's weighting, increasing the likelihood of it being re-used (primed) (Chang et al., 2006; Reitter et al., 2011). This predicted *inverse preference effect* (Jaeger & Snider, 2008) is well supported by the literature. For example, Hartsuiker and colleagues observed that dispreferred structures showed increased and persistent priming over dominant structures relative to pre-priming baselines (Hartsuiker et al., 1999; Hartsuiker & Westenberg, 2000). As such, implicit learning via priming reflects an inherent bias for speakers to reduce future error during processing (Dell & Chang, 2014; Fine & Jaeger, 2013; Jaeger & Snider, 2013). The language processor constantly adjusts the weightings of syntactic representations to reflect the way that events are mapped onto syntactic structures both in the language as a whole and within a given discourse (Jaeger & Snider, 2013). This tuning leads to immediate and long-lasting syntactic priming effects because such weight changes persist until further experience of alternative structures causes further adjustments to the relative weighting of each structural representation.

This process was simulated in a connectionist model in which a serial recurrent network was trained on an input language and subsequently acquired syntactic structures and showed syntactic priming patterns that matched adult human behavior (Chang et al., 2006). The goal of the present work is to explore the behavioral evidence for such a mechanism. Other aspects of the model are supported by children's behavioral evidence: young children use grammatical features such as gender and number to predict upcoming words whilst listening to language (Lew-Williams & Fernald, 2007; Lukyanenko & Fisher, 2016). This suggests that prediction mechanisms are in place in early language processing. More recent evidence suggests that older children can learn from prediction errors (Fazekas, Jessop, Pine, & Rowland, 2020). Furthermore, children's language production is susceptible to immediate syntactic priming effects (e.g. Huttenlocher et al., 2004), even at early stages of language production (Bencini & Valian, 2008; Foltz, Knopf, Jonas, Jaecks, & Stenneken, 2020; Shimpi, Gámez, Huttenlocher, & Vasilyeva, 2007).

But as already noted, this account makes further predictions about priming effects in children: firstly, if syntactic priming results from an implicit learning mechanism, children should also show evidence of learning from syntactic priming. That is, exposure to particular syntactic structures should have a long-lasting effect on the type of syntactic structures children produce. As others have noted, such observed priming effects within an experiment do not reflect grammatical learning ab initio, since for priming to occur within an experiment, the child must have an existing representation (Kidd, 2012a, 2012b; Savage, Lieven, Theakston, & Tomasello, 2006). Rather, such learning would, like in adults, indicate tuning of their syntactic representations to match the input language children are hearing. However, the mechanism whereby the processor adapts to recent experience to more accurately predict the correct structure in future events (Jaeger & Snider, 2013) is the same mechanism theorized to support language learning more broadly (Chang et al., 2006). Therefore, evidence of within-experiment adaptation to recent experience also provides indirect evidence that an error-based learning mechanism may underlie language acquisition (Peter & Rowland, 2018).

Secondly, if priming effects reflect an implicit learning mechanism based on prediction error, then children should show greater susceptibility to priming than adults. Priming effects are modulated by the degree of error experienced, with more surprising primes leading to greater learning (Chang et al., 2006; Fine & Jaeger, 2013; Jaeger & Snider, 2013). It is therefore predicted that children, who have less well-developed representations of syntax than adults, are likely to experience greater error in prediction and therefore to show greater priming and learning effects (Fazekas et al., 2020; Peter, Chang, Pine, Blything, & Rowland, 2015; Rowland et al., 2012). To illustrate with the example of priming passives: at three to four years of age, children's knowledge of the passive structure is still being established (Messenger & Fisher, 2018), therefore this representation is likely weakly weighted. By contrast their representation for the active structure, which is acquired earlier, will be more strongly weighted. When encountering a transitive description, children should be less likely than adults to expect a passive structure and should therefore experience a greater prediction error when the expected active structure does not emerge. This greater prediction error should in turn lead to a greater adjustment of the relative weightings of their transitive representations, increasing the weighting for the passive and resulting in a greater likelihood of the passive structure begin selected for a subsequent utterance. By contrast, whilst adults may not be likely to predict a passive, their greater experience of the language will mean that encountering a passive is for them less surprising, leading to a smaller weighting change in their representations and a correspondingly smaller likelihood of selecting the passive structure for a subsequent utterance. Such effects will emerge on immediate priming trials but will also be reflected in their production of target descriptions beyond the immediate priming trial, such as in a post-priming test phase (Kidd, 2012a). This is because these adaptations are postulated to accumulate and persist until changed by further syntactic experience (Chang et al., 2006; see also Fazekas et al., 2020).

This study examines whether behavioral evidence from children supports these predictions by examining whether children show long-lasting effects of priming and by comparing immediate and long-term priming effects in children and adults. The remainder of the introduction will review existing evidence regarding syntactic priming as implicit learning in children and will outline the areas for further research in this area.

2.3 Syntactic priming as implicit learning in children

There is growing evidence that children show a lasting effect of syntactic input – repeated experience of complex syntactic forms over weeks or even months increases children's comprehension and production of these forms (Branigan & Messenger, 2016; Huttenlocher, Vasilyeva, Cymerman, & Levine, 2002; Savage et al., 2006; Vasilyeva, Huttenlocher, & Waterfall, 2006). For example, Savage, et al. (2006) examined longer-term priming for passives: children aged 4;11 described five target trials immediately after hearing and repeating five prime sentences with high overlap (e.g. *it got pushed by it*), and subsequently described five further target items one week later and (or) one month later. They found long-term priming effects relative to control participants when there was reinforcement after one week, (but see Kidd, 2012b, for contrasting results and discussion). On a more immediate timescale, even a small amount of experience can have a lasting effect: Branigan and McLean (2016) showed that the effect of a single prime on children's description of transitive targets persisted over two fillers between primes and targets.

A few studies have shown that following a blocked exposure to passive primes, children continue to produce more passives relative to their baseline production of passives, (Kidd, 2012a, 2012b) or compared to those exposed to active primes (Huttenlocher et al., 2004). For example, Huttenlocher, et al., (2004, Experiment 3) examined whether five-year-olds showed long-term priming effects of transitive (active: *a dog chased a cat*, or passive: *a cat was chased by a dog*) structures. They examined children's description of a block of ten target trials immediately after they had heard a block of ten prime trials (e.g. ten passives) and found that those who heard passive primes produced more passive targets than those who heard active primes. Furthermore, there was no difference in the use of target constructions in the last half of the trials compared to the first half. They concluded that priming effects are long-lasting in children in support of an implicit learning account of priming. Kidd (2012b) also showed evidence of persistent priming for passives in five-year-olds: Children first described a set of target pictures of transitive events to establish their baseline use of active and passive transitives. In a priming phase, they then described 12 target items after hearing and repeating a passive prime; this established a priming effect for passives. In an immediate post-test they described six further targets over which the persistence of the priming effect was measured. Kidd observed that children's use of passives increased over the priming phase and persisted beyond it into the post-test phase such that five-year-olds produced more passives in the post-test than in the baseline. Kidd concluded that the accumulation of priming across the experiment and persistent use of passives above the pre-test baseline reflected implicit learning for the mapping of transitive events to the passive structure.

By contrast, there is limited evidence for greater priming in children than adults. A handful of studies have compared priming across age groups on the same task but have not shown the predicted interaction between age and priming, (Messenger, Branigan, & McLean, 2011, 2012; Rowland et al., 2012), though children show greater effects of prime verb bias than adults (Peter et al., 2015). One study showed that priming may have a longer-lasting effect in children than in adults: Branigan and Messenger (2016) tested children and adults in two syntactic priming tasks separated by a week. For adults, the magnitude of priming was the same in the second session as in the first; they did not show an increase in their production of passives across the two sessions that would indicate a lasting and cumulative effect of exposure to passive primes. By contrast, the children produced more passives in the second priming task than in the first. This suggests that they experienced a long-term, cumulative effect of exposure to passive primes in the first session that persisted and affected their production of transitive structures in the second session, although there was no baseline measure of structural preferences in this study to confirm that these effects were related to the priming.

2.4 Further directions for syntactic priming as implicit learning

These studies provide evidence that priming effects have an immediate and lasting effect in children. One avenue for further research is to test the developmental predictions of the implicit learning model. This model predicts that children who are still acquiring language should be more sensitive to priming due to the greater prediction error that weaker representations yield when they are recruited for comprehension or production. This greater error should lead to greater immediate priming and a greater likelihood of long-term priming (Chang et al., 2006; Ferreira & Bock, 2006). The current study explores whether there are age-related differences in the persistence of syntactic priming effects within a session and when target structure production is measured relative to a baseline and in a test phase that does not include the prime structures (cf. Branigan & Messenger, 2016).

Secondly, most studies with children have measured long-term priming after exposing participants to only one prime structure, e.g., passive transitives, which may be problematic on different levels. One potential limitation is that this may highlight the aim of the task to children. By modelling only one way of describing the pictures, children may infer that they should also use this way of describing the pictures (see Kidd (2012b) for further discussion). An alternative limitation is that, under the kind of mechanism proposed in the implicit learning account, using only one structural alternative over the course of a priming phase would raise the weighting of that structure considerably above typical levels making its reuse inevitable (Kaschak, 2007). Kaschak et al. (2006) found that in adults, input skewed towards one construction led to stronger persistence of that construction and weaker persistence of the alternative (see also Thothathiri & Snedeker (2008a) and Jaeger & Snider (2013), Study 3). By contrast, evidence that syntactic priming shows lasting effects from varied exposure would demonstrate that such effects occur without reinforcement of the target structure only. This would also be more indicative of the reality of such learning mechanisms; languages are learnt from a varied input and in the case of passives in particular, from a much more sparse exposure. The current study therefore examines whether priming effects are persistent in children even when the exposure to prime structures is mixed (i.e. both actives and passive primes are presented).

A final avenue for further research is to examine whether persistent priming effects are observed in younger children. The evidence to date is based on samples of children ranging in age between four and seven years, with mean ages of between four years, eleven months and five years, seven months (Huttenlocher et al., 2004; Kidd, 2012a, 2012b; Savage et al., 2006), which is relatively late in syntactic development. Syntactic priming studies have demonstrated immediate syntactic priming effects for passives in children aged three to four years (Bencini & Valian, 2008; Messenger, Branigan, McLean, & Sorace, 2012; Shimpi et al., 2007); under the error-based learning account, we should also expect to observe implicit learning effects of syntactic priming at these earlier stages of language development (Peter & Rowland, 2018). The current study builds on these studies to examine whether long-term priming can be observed in children at the younger end of the age range for observed syntactic priming effects.

3. The present study

This paper seeks to address these issues by comparing the persistence of priming in children versus adults based on a mixed priming exposure, and by testing long-term priming effects in younger children aged three and four. It examines the effect of exposure to syntactic structures on participants' immediate and delayed description of transitive events which can be described with either active or passive sentence structures.

Specifically, the study measured the persistence of priming for the *passive* structure which was predicted to be particularly susceptible to implicit learning effects because it is generally dispreferred, infrequent and late-acquired. The passive is structurally more complex than the active alternative, (involving non-canonical mapping of participant roles to sentence positions and additional morpho-syntactic marking; see example sentence (2)) and is typically only used when the discourse focusses the patient or demotes the agent. Correspondingly, passives are infrequent in spoken English (Svartvik, 1966), particularly in child-directed speech (Gordon & Chafetz, 1990). As such, passives are late acquired: though children have begun to acquire knowledge of the passive by three years (Messenger & Fisher, 2018) and are susceptible to priming of passives at this age (Bencini & Valian, 2008; Shimpi et al., 2007), they display difficulty comprehending and producing them until relatively late on (e.g. Messenger, Branigan, & McLean, 2012) suggesting a protracted period of learning. As such, the passive is likely weakly represented by young children, meaning it should be strongly susceptible to priming manipulations (Chang et al., 2006; Rowland et al., 2012). We would not expect young children, or even adults, to *spontaneously* use passives to describe the transitive events in the task, therefore, the effects of priming should be readily observed. In sum, passives provide an ideal test case for examining learning effects from syntactic priming.

To examine immediate and persistent priming effects on children's and adults' descriptions of transitive events, the present study used a two-phase method similar to previous studies incorporating an exposure phase and a test phase (Huttenlocher et al., 2004; Kaschak et al., 2006; Kidd, 2012a, 2012b). The immediate effect of priming was examined in the exposure phase: Participants described pictures of transitive events after hearing the experimenter produce syntactic primes; to avoid reinforcing the use of a single structure, participants heard *both* active and passive primes. The proportion of passive sentences (50%) that participants experienced in the exposure phase was higher than that they would normally hear in spoken English, (passive structures typically account for approximately 4%[1] of input utterances; Gordon & Chafetz, 1990). This mixed exposure to both active and passive structures should therefore constitute a strong priming experience for passives relative to typical input and should raise the usage of the passive above baseline levels without, crucially, reinforcing one structure over another.

The persistence of the priming effect was tested over a number of unprimed trials in the test phase that followed. Participants continued to describe pictures of transitive events but in this phase the experimenter produced syntactically unrelated descriptions on their turn thus there was no priming from the experimenter. The persistence of the priming effect was tested across two different timecourses. One group, the immediate test group, completed the test phase immediately following the exposure phase (as in previous studies, e.g. Huttenlocher et al., 2004; Kidd, 2012b); the other, the delayed test group, completed the test phase after a short, filled delay between the exposure and test phase, extending the results of previous research. The immediate and long-term effect of priming was examined relative to a third group of participants who described the same target pictures but were never exposed to either active or passive primes. These participants heard syntactically unrelated descriptions

[1] This estimate included adjectival passives; the incidence of verbal passives was lower still.

throughout the experiment such that they still completed the same task but without experiencing priming. This condition provided a baseline measure of children and adults' use of passives across the experiment.

3.1 Predictions

In line with all previous syntactic priming studies, participants, both children and adults, were predicted to be more likely to produce a passive immediately after hearing a passive prime than immediately after hearing an active prime. The error-based implicit learning account further predicts that this tendency should be greater in children than adults. It was also predicted that participants who experienced passives would produce more passives in the exposure phase than participants in the baseline condition, who should be unlikely to spontaneously use passives without priming and should therefore show a general preference for active structures (Bencini & Valian, 2008). No difference between participants in the immediate test versus delayed test priming conditions was predicted for the exposure phase since at this stage of the experiment, their experience is identical.

The main measurement of interest, however, was the frequency of passives each age group produced in the priming versus baseline conditions in the test phase: If priming persists beyond the immediate exposure, then those in the priming conditions were predicted to produce more passives in the test phase than those in the baseline condition. However, if priming effects are not long-lasting, the use of passives should decay quickly once exposure to the passive primes ceases and no difference between the priming and baseline conditions should be observed. The manipulation of the timing of the test phase allowed an additional level of measurement for persistence – the effect of priming may persist only to the immediate test or it may persist across a short, filled delay as well. These effects were compared across children and adults to explore age-related differences in the persistence of syntactic priming. If priming relies on an error-based learning mechanism, immediate priming effects should be greater in children than in adults which should consequently be reflected in a greater tendency for persistent priming effects (greater production of passives in the post-test relative to the baseline) in children too.

4. Method

4.1. Participants

The participants were 97 pre-school children (59 girls) with an age range of 39 months (3;3 years) to 58 months, (4;10 years; mean age 50 months (4;2 years)), who were assigned to the immediate test (N=32) , delayed test (N=33) or baseline (N=32) condition (see Table 1). A further 28 children were tested but excluded from the dataset because they completed the exposure phase but declined to complete the test phase (12); in the exposure phase of priming conditions they produced 7 or more 'Other' responses (8); in the baseline condition they produced 11 or more 'Other' responses in the exposure phase (2)[2]; due to experimenter error in setting up or recording the experiment (3); the length of the delay between their exposure and test phases was outlying (more than 2.5 standard deviations longer) compared to other participants (3). The research received approval from the University of Warwick, Humanities and Social Sciences Research Ethics Committee (HSSREC). Children were tested in local pre-school nurseries or the laboratory; parents provided written consent for their participation.

Only monolingual children with no language delays or disorders reported were included. Additional measures of children's expressive vocabulary (from the Clinical Evaluations of Language Fundamentals (CELF) Preschool-2 UK test; Wiig, Secord, & Semel, 2006) and memory for word repetition (Early Repetition Battery (ERB), Preschool Repetition

[2] Different exclusion criteria were used because participants in the control condition used more varied structures to describe the pictures, meaning some produced a larger number of 'Other' responses; only those who were potentially unable to use transitive structures (never produced any or produced only one) were excluded. Conversely, to avoid inflating the priming effects based on small numbers of target responses, in the priming conditions, only participants who did not produce target structures on at least half of the trials were excluded.

(PSRep) test; Seeff-Gabriel, Chiat, & Roy, 2008) were collected, (see Table 1 and section 4.4. Procedure).

Table 1.

Mean group characteristics (standard deviations) with ranges for children and adults

Persistence condition	***Group***	***Age***	***Vocabulary (scaled score)[a]***	***Memory (scaled score) [b]***
Baseline	Children (*N*= 32, 18 girls)	48.9 (4.1) months 42.0 – 57.9	9.8 (2.2) 5 – 14	93.2 (12.3) 62 – 118
	Adults (*N*= 32, 26 female)	21.5 (5.8) years 18.3 – 41.3	-	-
Immediate test	Children (*N*= 32, 19 girls)	49.9 (4.9) months 39.9 – 58.0	11.3 (2.1) 7 – 16	98.5 (13.3) 74 – 123
	Adults (*N*= 31, 26 female)	23.8 (11.6) years 18.3 – 64.2	-	-
Delayed test	Children (*N*= 33, 22 girls)	51.4 (4.4) months 40.2 – 58.0	10.6 (2.0) 5 – 14	102 (13.7) 58 – 118
	Adults (*N*= 32, 23 female)	19.2 (0.7) years 18.3 – 20.5	-	-

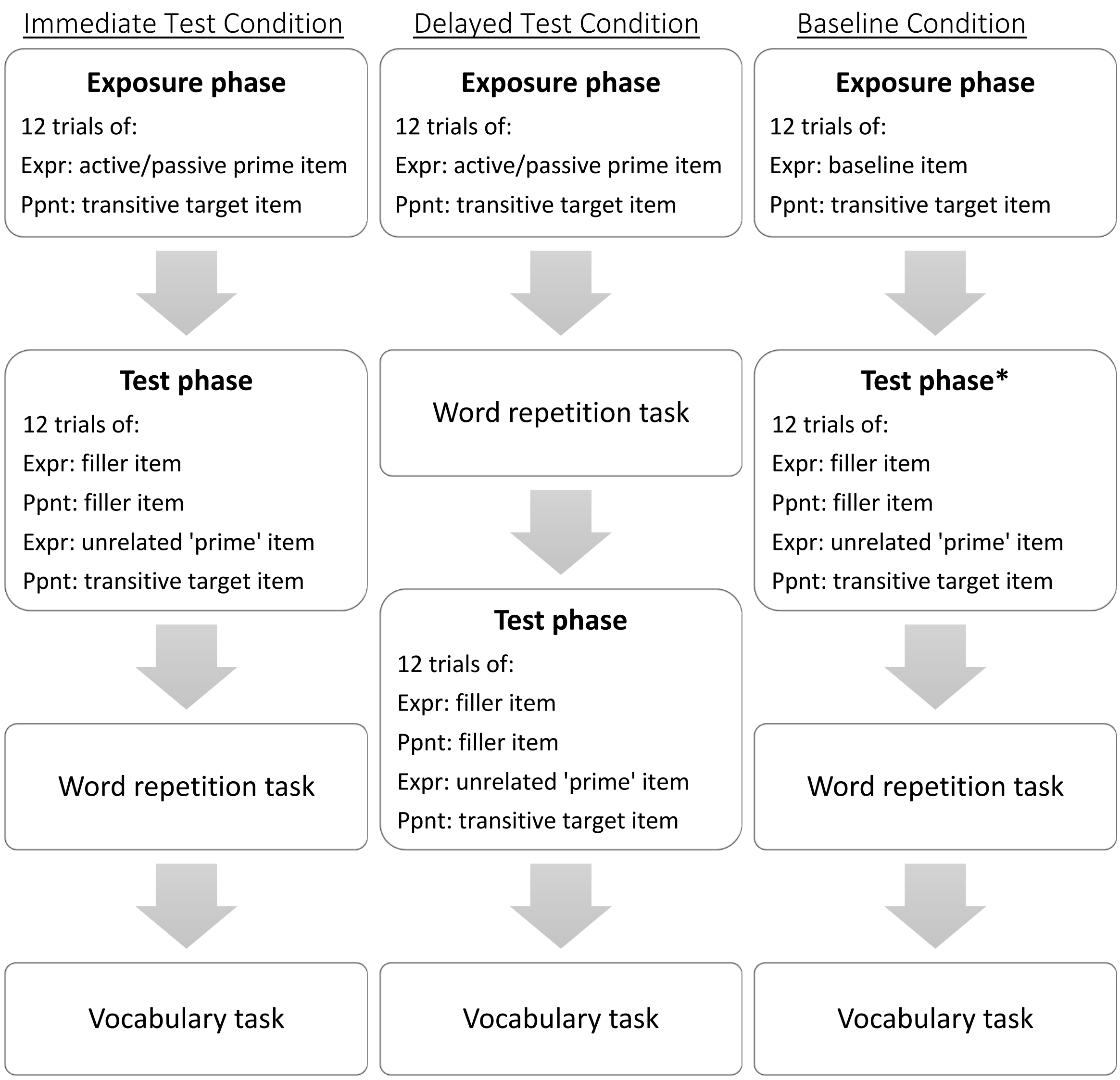
[a]CELF Preschool-2 UK Expressive Vocabulary test
[b]ERBattery PSRep test for children

The results of these measures for the three groups of children were tested in univariate analyses of variance (ANOVAs). There was no difference in age of the three groups (p = .11). Despite overlapping score ranges, there was a difference in the Expressive vocabulary across groups (F(2,83) = 3.86, p = .025); independent samples t-tests confirmed that the immediate test group had a higher mean vocabulary than the baseline group (t (56) = -2.71, p = .009) but there were no differences between the other group comparisons (*p*'s > .13). There was also a difference in the ERB scores across groups ($F(2,83) = 3.30$, $p = .042$); independent samples *t*-tests confirmed that the delayed test group had a higher mean ERB score than the baseline group (t (58) = -2.57, $p = .013$), but there were no differences between the other group comparisons (*p*'s > .13).

A comparison group of 95 adults (75 female; mean age 21.5 years, range 18.3 – 64.2 years) also participated in the immediate test (N=32) , delayed test (N=31) or baseline (N=32) condition. Adults were recruited and tested at the University of Warwick; they either received course credit or payment for their participation. Two further adults were tested but excluded, one due to experimenter error with ordering the items and one because the length of the delay between their exposure and test phases was an outlier (more than 2.5 standard deviations longer) compared to other participants.

4.2. Design

The experiment had a 3 x 2 design: the condition participants were assigned to (baseline vs immediate test vs delayed test) and age group (children vs adults) were between-participants variables. For the participants in priming conditions (immediate test vs delayed test), who experienced primes in the exposure phase, there was a further within-participants variable of prime structure (active vs passive), (see Figure 1).



Notes:
Expr = experimenter’s card; Ppnt = participant’s card
Exposure phase – see Fig. 1a for example items; Test phase – see Fig. 1b for example items
* Half of the baseline condition participants completed the test phase immediately after the exposure phase; half of the baseline condition participants completed the word repetition task before the test phase.

Figure 1. *Experiment structure for each condition (immediate and delayed test, and baseline).*

4.3. Materials

4.3.1. Experimenter’s pictures

For the exposure phase of the immediate and delayed test conditions there were twelve prime items which depicted different transitive events and had an associated active and passive description (Fig.2a, left panel; see Appendix A for a complete list). Six different verbs (*feed*, *knock over*, *pinch*, *poke*, *shake*, *wash*) were used twice each, paired with a verb from each set (A and B) of the target items. The events were depicted with human and animal characters (see Fig.2) and had been used in previous priming experiments with participants of the same age (Messenger et al., 2012; Messenger & Fisher, 2011).

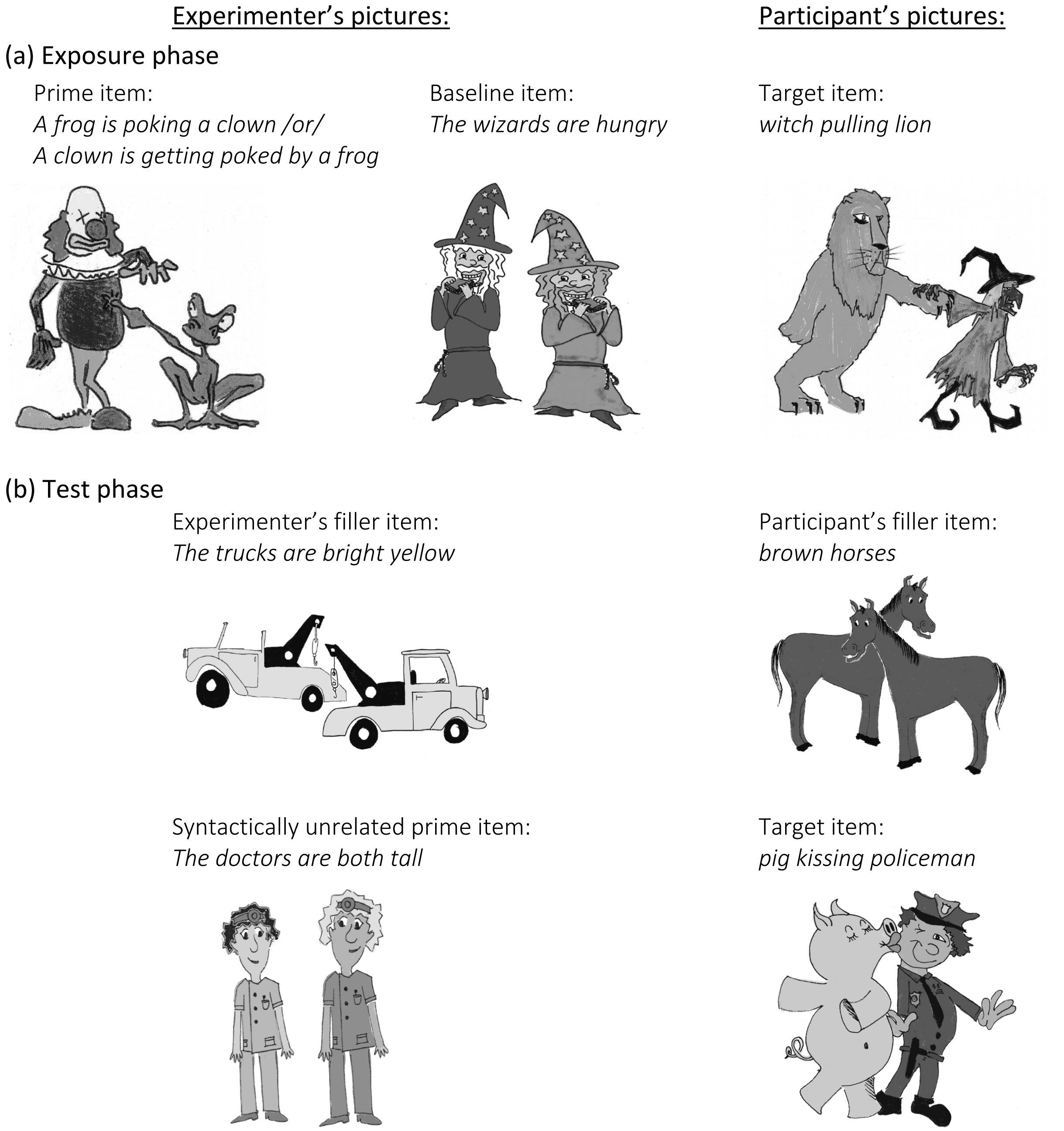


Figure 2. *Example pictures for experimenter and participants in the exposure phase (a) and the test phase (b). Prime items were used in the exposure phase of the immediate and delayed test conditions whereas baseline items were used in the exposure phase of the baseline condition; in the test phase items were the same across all conditions.*

For each item in the exposure phase, a corresponding baseline 'prime' item was also created in which a pair of characters were depicted and described with an adjectival phrase (i.e. a phrase that was syntactically unrelated to the transitive structure primes, e.g. *the wizards are really hungry*; see Fig.2a). These items were used in the exposure phase of the baseline condition, so as not to provide any syntactic priming prior to the baseline participants' description of the target events.

In the test phase no participants heard active or passive primes; the experimenter described pictures with syntactically unrelated 'primes' that consisted of a pair of characters or objects described with adjectival phrases, like the baseline items in the exposure phase of the baseline condition (see Fig.2b, left panel and OSF project (https://osf.io/tfjh2/) for a full list). In order to separate the individual target trials, a further 24 pictures of paired characters or objects described with adjectival phrases were created to serve as filler items (see Fig.2b, left panel): the experimenter and participant each described one filler item before the unrelated 'prime' and target item. As such, the trial structure within the test phase was: experimenter filler item, participant filler item, experimenter unrelated 'prime', target item (see Fig.1). Participants' target descriptions in the test phase were therefore separated by three intervening syntactically-unrelated sentences.

4.3.2. Participant's pictures

There were 24 target items depicting prototypical transitive events; these were split into two sets of 12, A and B, one of which was used in the exposure phase and one in the test phase. Twelve transitive verbs were each used twice with six occurring in set A (*bite*, *kick*, *kiss*, *lick*, *push*, *scratch*) and six occurring in set B (*carry*, *chase*, *pat*, *pull*, *squash*, *tickle*; see Appendix A for a complete list). The target sets were counterbalanced across the exposure and test phases between participants such that one participant described set A in the exposure phase and set B in the test phase and another described set B in the exposure phase and set A in the test phase. In the exposure phase, each target verb occurred once after an active prime and once after a passive prime, such that each participant heard six active primes and six passive primes, constituting a mixed exposure to transitive structures.

4.3.3. Other pictures

Four different items were created as practice items that started the experiment to introduce children to the purpose of the game (in the priming conditions, these depicted transitive events and children heard two active and two passive descriptions; in the baseline condition, these depicted paired characters and children heard adjectival phrases).

Eight further pictures depicting intransitive events (e.g. *the ballerinas are sitting, the cats are sleeping*) served as the matching 'snap' trials of the game (see section 4.4. Procedure below); four occurred at random intervals in the exposure phase and four occurred at random intervals in the test phase. The 'snap' trials maintained the guise of a fun card game to distract adult participants and motivate child participants.

4.4. Procedure

4.4.1 Snap task

Four lists of items were produced across which the prime structure in the exposure phase was counterbalanced and the target set (A or B) was counterbalanced between exposure and test phases. Baseline versions of each priming list were created by replacing the prime items in the exposure phase with baseline items. Participants received a randomized version of one list.

The task was presented as a card game, 'Snap', familiar to British children and adults (Branigan, McLean, & Jones, 2005), which involves players alternating at revealing a picture from the top of a deck of cards; when both players reveal matching pictures on consecutive trials the first player to shout 'Snap' wins the cards in play. The items were printed in colour on individual cards (6" x 4") to serve as cards in the game.

As a warm-up, children were asked to name the characters that were used in the items from colored pictures of individual characters. Then, the cards depicting target items, that had been arranged in the list order, were placed face-down in front of the participant, and the set of pre-arranged experimenter's items were placed face-down in front of the experimenter. The experimenter began each game by turning over their top card and describing it according to the script. They then encouraged the participant to turn over and describe their top card, this constituted the target response. The game proceeded in the same turn-taking fashion until all pictures had been described. Adults followed the same procedure as children but they were informed that the task and materials were designed to test young children. The experimenter's and participants' descriptions were audio-recorded for subsequent transcription and coding. All transcriptions were double-checked by a research assistant for accuracy.

The same task was used for the exposure and test phases. In the immediate test condition, the exposure and test phase items were included in the same card game and play continued seamlessly from exposure to test phase (see Fig.1). In the delayed test condition, the exposure phase and test phase were presented as two separate games of Snap, separated by a filled delay in which a word repetition task (see below) was administered to participants. Both the children's and adults' filler tasks involved single word repetition which constituted a filled lag between the exposure and test phases of the experiment that was otherwise unrelated to the task or items of the experiment. This created a mean delay of 137.2s (range: 108s – 183s, SD = 21.7) for child participants and a mean delay of 192.3s (range: 113s – 265s, SD = 42.6) for adult participants[3]. In the baseline condition half the participants completed the two phases as a single game (as in the immediate test condition) and half the participants

[3] Due to experimenter error, 8 adult participants completed a different digit span task as a filler – this involved repeating sequences of numbers of increasing lengths. The length of this test was within the range of the length of the backward word span task, therefore these participants were included.

completed the two phases as two games separated by a filled delay (as in the delayed test condition).

4.4.2. Vocabulary and word repetition tasks

Standardized measures of expressive vocabulary and memory were also collected for the child participants in order to characterize the sample further and to explore the relationship between any priming or persistence effects and individual characteristics. Evidence for whether factors such as vocabulary and working memory affect priming is mixed (Foltz, Thiele, Kahsnitz, & Stenneken, 2015; Kidd, 2012a, 2012b). 86 children (57 in the priming conditions) completed the Expressive Vocabulary sub-component of the CELF Preschool 2-UK, (Wiig et al., 2006); the remaining 11 children either refused or were unavailable to complete this task. This asks children to name objects, people or activities from colored pictures to provide a measure of children's referential naming abilities that is scaled by age. 86 children (57 in the priming conditions) completed the PSRep Test from the ERB (Seeff-Gabriel et al., 2008); the remaining 11 children either refused or were unavailable to complete this task. This asks children to repeat single words and nonwords of either one-, two- or three-syllables to provide a measure of their word repetition ability that is scaled by age (see Table 1). Children completed all 35 items of the PSRep test; those in the immediate test or baseline conditions completed the repetition test after the experimental task, whereas those in the delayed test condition completed the repetition test between the exposure and test phases to create an unrelated filled delay to these tasks. To create a similar filled delay for adults in the delayed test condition, adults completed a backward span task with words: they heard sequences of one-syllable words, starting with two words and increasing by one word after six trials; the test stopped after four or more errors at a given span length.

4.5. Coding

In total, 39/4608 target trials were eliminated (children: 30/2328 trials (1.3%); adults: 9/2280 trials (0.4%)) because of errors in prime production, (i.e. a prime picture was described with an active sentence when it should have been described with a passive sentence or vice versa), or because no target response was provided. Target responses were coded according to similar scoring schemes as used in previous studies (e.g. Huttenlocher et al., 2004; Kidd, 2012b). Only target descriptions that were thematically appropriate descriptions of the target were included and these were scored according to transitive structure: *Active* for a sentence appropriately describing the target event and containing an agent subject, verb, and patient object, and expressible in the alternative (i.e., passive) form; responses where participants dropped the subject (e.g. *kissing the policeman*) were coded as *Active* but responses where participants did not provide the object (e.g. *the pig's kissing*) were coded as incomplete. Sentences that appropriately described the target event and contained a patient subject, auxiliary, main verb past participle, plus optionally, *by*, and an agent object, and were expressible in the alternative (i.e., active) form were coded as *Passive*. As such, short passive responses (e.g. *the policeman is being kissed*) were coded as passive as well as full passive responses (e.g. *the policeman is being kissed by the pig*); responses where participants did not provide the verb or other material (e.g. *the policeman got*) were coded as incomplete. Incomplete utterances, utterances where the assignment of participant roles to nouns was reversed; and non-transitive utterances were coded as *Other*.

A more lenient scoring of the data included incomplete and reversed utterances as Passive or Active responses. Though this led to an increase in the number of passives that children, but not adults, produced[4], the analyses of this lenient scored data showed the same pattern of results as the stricter scoring described above.

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[4] In the exposure phase, 33 more of the children's responses were coded as passive under the lenient scoring and in the test phase, 16 more were; 1 more of the adults' responses in the exposure phase and 1 more in the test phase were coded as passive under the lenient scoring.

5. Results

The raw frequencies of target responses by group and condition are shown in Table 2; these data suggest that participants showed a preference to describe the targets with actives; across groups and conditions passives were dis-preferred. Figure 3 presents the passives produced by each group across conditions as mean proportions of transitive (active and passive) responses. This shows that participants in the priming conditions who were exposed to passives, both children and adults, tended to produce more passives than baseline participants in both the exposure and test phases.

In the priming conditions, 53/65 children (81.5%) produced at least one passive: 47/65 children (72%) produced one or more passives in the exposure phase and 31/65 (48%) produced one or more passives in the test phase. By contrast only 2 children (6%) in the baseline condition produced any passives across the experiment: one produced two passives in the exposure phase and two children produced one or more passives in the test phase. Adults were more likely to produce passives than children, particularly when not primed to do so: 53/63 adults (84%) in the priming conditions and 16/32 adults (50%, cf. 6% children) in the baseline condition produced one or more passives. In the priming conditions, 48/63 adults (76%) produced one or more passives in the exposure phase and 36/63 adults (57%) produced one or more passives in the test phase. In the baseline condition 12 adults (37%) produced one or more passives in the exposure phase and 12 adults produced one or more passives in the test phase. As such, the raw data suggest that children were very unlikely to produce passives in the absence of priming; adults who did not hear passives were less likely to produce passives than those adults who did, but they were more likely than children to spontaneously use passives.

Table 2.

Frequency of active, passive and other target responses in the exposure and test phases by age group, condition (and prime structure for participants in the priming conditions).

			Target responses					
			Exposure phase			Test phase		
Group	Condition	*Prime*	Active	Passive	Other	Active	Passive	Other
Children	Baseline		237	2	138	213	5	157
	Immediate test		255	49	74	251	30	98
		Active	*144*	*10*	*34*			
		Passive	*111*	*39*	*40*			
	Delayed test		254	64	77	266	46	82
		Active	*141*	*18*	*39*			
		Passive	*113*	*46*	*38*			
Adults	Baseline		293	24	67	296	32	56
	Immediate test		264	84	29	297	68	19
		Active	*144*	*30*	*15*			
		Passive	*120*	*54*	*14*			
	Delayed test		264	85	21	290	57	25
		Active	*150*	*24*	*12*			
		Passive	*114*	*61*	*9*			

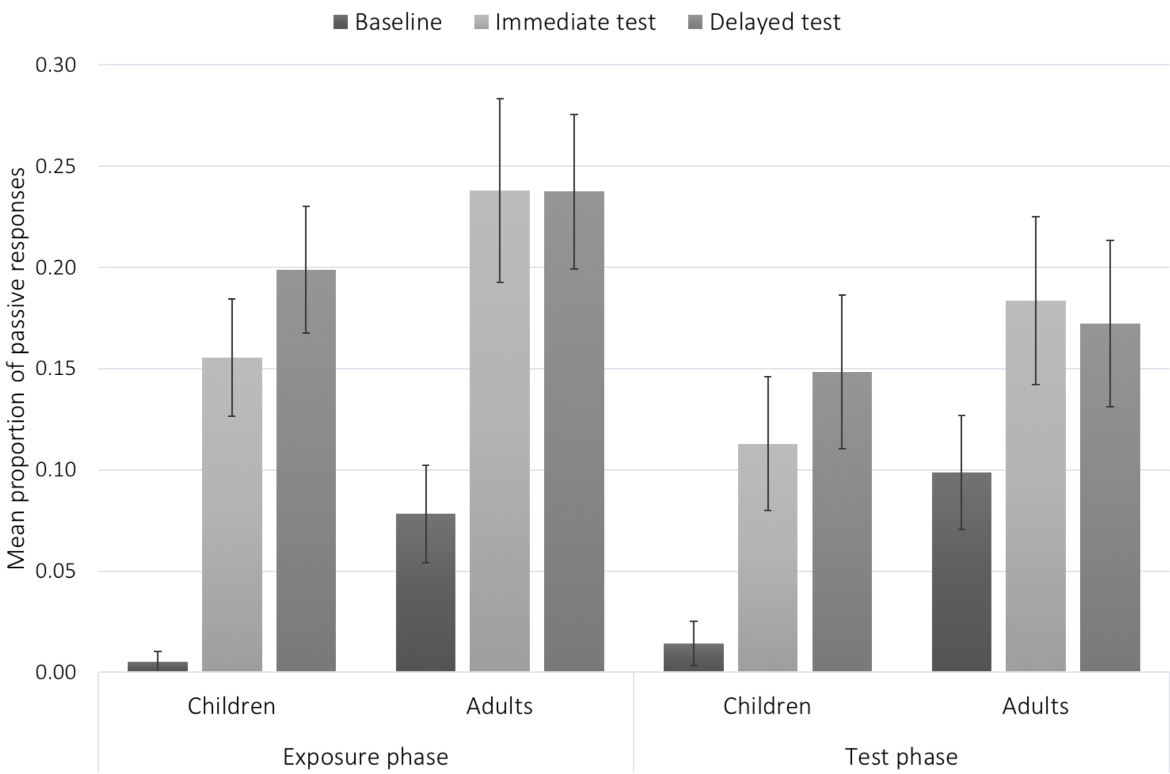

Figure 3. *Mean (se) proportion of passives produced by each age group in each condition in the exposure and test phases. Error bars represent the standard error of the group mean.*

5.1. Data analysis

The analyses examined the frequency of passive responses in the exposure and test phases separately. The response data were categorical (active or passive response), therefore they were analyzed in logit mixed effects models in R (R Core Team, 2015) using the *lme4* package (Bates, Mächler, Bolker, & Walker, 2014). Additionally, the *blme* package, (Dorie, Bates, Maechler, Bolker, & Walker, 2020) was used for the analyses comparing to the baseline condition since, in this condition, very few passives were produced by a small number of participants resulting in almost complete separation of the data. These predict the likelihood of a response given a binary choice (in this case passives, coded as 1; actives were coded as 0, other responses were excluded) and account for random effects of participants and items within the model (Baayen, Davidson, & Bates, 2008; Barr, Levy, Scheepers, & Tily, 2013; Jaeger, 2008). For all analyses, maximal models were fit with a full random effects structure including random slopes by participants for within-subjects predictors and by items for within-items predictors; where maximal models did not converge the random slopes structure was simplified by removing higher order terms that explained the least variance first until the model converged (Barr et al., 2013; see https://osf.io/tfjh2 for the anonymized dataset and R code). Correlation analyses explored whether there was any relationship between children's age, expressive vocabulary and verbal repetition scores and participants' production of passives in each phase of the experiment.

5.2. Exposure phase analyses

5.2.1. Immediate priming in the exposure phase

First, the responses of the participants in the two priming conditions were analysed to confirm that immediate priming occurred on a trial-by-trial basis in both groups (children and adults) and in both test conditions (immediate and delayed). This analysis also examined whether children showed a stronger immediate priming effect as predicted by error-based models of syntactic priming as implicit learning (Chang et al., 2006). These responses were fit to a model with Prime Structure (active vs. passive), Priming Condition (immediate test vs. delayed test) and Group (children vs. adults) as fixed effects to examine whether immediate priming occurred. Fixed effects were sum-coded using single contrast coding (Prime Structure: active = -0.5, passive = 0.5; Priming Condition: immediate test = -.05, delayed test = 0.5; Group: children = -0.5, adults = 0.5). The maximal model to converge included random slopes by participants for Prime Structure and by items for Prime Structure, Priming Condition and Group (Table 3). The model showed a significant effect of Prime: participants produced more passives following passive primes (M = 0.30) than following active primes (M = 0.12) yielding an 18% priming effect (see also Table 2). Neither the effect of Group nor the interaction between Prime Structure and Group were significant, suggesting that priming was not significantly greater in children (18.5% priming) than in adults (17% priming). There was no significant effect of Priming Condition, nor interaction with Prime Structure and – or Group. Note that, as stated above, the results did not change under the lenient scoring of the responses: though more of the children's responses were coded as Passive, the analysis of these data revealed a main effect of Prime only ($Z = 6.07$. $p < .001$) and no other significant effects or interactions (all Zs < 1.8, ps $> .08$).

Table 3.

Summary of maximally converging logit mixed effects models of priming in the exposure phase.

Predictor	*Coefficient*	*SE*	*Wald Z*	*p*
Immediate priming analysis				
Intercept	-2.09	0.24	-8.61	< .001
Prime Structure	1.85	0.34	5.47	< .001
Priming Condition	0.24	0.34	0.71	= .47
Group	0.45	0.35	1.30	= .19
Prime Structure x Priming Condition	-0.06	0.43	-0.13	= .90
Prime Structure x Group	-0.27	0.42	-0.63	= .53
Priming Condition x Group	-0.62	0.66	-0.94	= .34
Prime Structure x Priming Condition x Group	1.36	0.83	1.63	= .10
Priming vs baseline conditions analysis				
Intercept	-2.88	0.28	-10.12	< .001
Priming vs baseline contrast	3.39	0.63	5.35	< .001
Immediate vs delayed contrast	-0.21	0.31	-0.67	= .50
Group	0.96	0.36	2.61	= .009
Priming vs baseline contrast x Group	-1.71	0.89	-1.91	= .056

Immediate vs delayed contrast x Group	0.30	0.57	0.52	= .60

Correlation analyses revealed that children's individual priming effect (the difference between the proportion of passive responses to passive primes and passive responses to active primes, i.e. their propensity to repeat structure) was not correlated with age or memory measure (*r*'s< .13, *p*'s> .3, 2-tailed) but there was a marginal correlation with vocabulary score (*r*= .24, *p*= .07, 2-tailed).

5.2.2. Priming conditions vs baseline condition in the exposure phase

Second, the responses of the participants in the priming conditions were compared to participants in the baseline conditions to confirm that priming raised participants' production of passives above baseline usage. A logit mixed effects model with the predictors Condition (baseline vs. immediate test vs. delayed test) and Group (children vs. adults) was fit to the responses (Table 3). Since Condition had three levels, contrast coding was applied to generate two contrasts in the model: the first compared the priming conditions combined to the baseline condition (*priming vs baseline contrast*; baseline = -0.66, immediate test = 0.33, delayed test = 0.33) and the second compared the two priming conditions (*immediate test vs delayed test contrast*; baseline = 0, immediate test = 0.5, delayed test = -0.5). The maximal model to converge included random slopes by items for Condition and Group. The model showed that there was a main effect of Group: adults were more likely to produce passives than children. The *priming vs baseline contrast* was also significant: participants who were exposed to passives produced more passives than those who were not (see Fig.3). There was no significant difference in the passives produced in the immediate test vs delayed test conditions (as, indeed, none would be anticipated in the exposure phase). No other effects or interactions were significant. While the interaction between Group and the priming vs baseline contrast approached significance, this likely reflects group differences in the baseline condition rather than a numerical trend for greater priming in either group. Children rarely produced passives in the baseline condition (1 child produced passives, M passive responses = 0.5% (SE= .005)) whereas adults were more likely to produce passives (12 adults produced passives, M passive responses = 8% (SE= .02)). By contrast, in the priming conditions both groups showed a similar frequency of passive production (47 children produced passives, M passive responses = 18% (SE= .02); 48 adults produced passives, M passive responses = 24% (SE= .03).

Correlation analyses examined the relationship between children's individual characteristics and the frequency of passives that those in the priming conditions produced in the exposure phase (irrespective of prime condition (active vs passive), i.e. their propensity to produce passives). Frequency of passive production was not correlated with children's age or memory score (r's< .22, p's> .10, 2-tailed) but was correlated with vocabulary score (r= .27, p= .04, 2-tailed).

5.3. Test phase analyses

5.3.1. Priming conditions vs baseline condition in the test phase

The exposure phase increased participants' production of passives in the priming conditions relative to the baseline condition. To test the persistence of such priming, the responses in the test phase of the participants in the priming conditions were compared to those of the participants in the baseline conditions; children's responses were compared to adults to examine whether there were age differences in such persistence. A logit mixed effects model with the same Group and Condition predictors and contrasts as described above was fit to the passive responses. The maximal model to converge included random slopes by items for Group and Condition (Table 4). The model showed that there was a main effect of Group: across all conditions, adults produced more passives than children (see Fig.3). The priming vs baseline contrast was also significant indicating that those who were exposed to passives produced more passives in the test phase than those who were not exposed to passives. This suggests that the effect of the exposure phase persisted into the test phase. The immediate vs delayed contrast was not significant meaning that there was no significant difference in the passives produced in the immediate test vs delayed test conditions. This suggests that the effect of the exposure phase persisted into the test phase to the same extent, irrespective of whether the test phase followed the exposure phase immediately or after a short filled delay (see Fig.3). The interactions between Group and the Condition contrasts did not reach significance. Note that, as stated above, the analyses of the lenient scoring data revealed the same pattern of effects (though the effect of Group in this analysis was marginal, $Z = 1.94$, $p = .053$; no interactions with Group were significant, $Zs < 1.8$, $ps > .08$).

Table 4.

Summary of maximally converging logit mixed effects model of passive responses in the test phase.

Predictor	*Coefficient*	*SE*	*Wald Z*	*p*
Priming vs baseline conditions comparison				
Intercept	-3.88	0.38	-10.30	< .001
Priming vs baseline contrast	2.39	0.74	3.22	= .001
Immediate vs delayed contrast	-0.50	0.52	-0.96	= .33
Group	1.42	0.60	2.34	= .02
Group x Priming vs baseline contrast	-2.50	1.39	-1.80	= .07
Group x Immediate vs delayed contrast	0.66	0.97	0.68	= .50

Correlation analyses revealed that the number of passives that children in the priming conditions produced in the test phase was not correlated with their age, memory or vocabulary scores ($rs < .2$, $ps > .12$, 2-tailed) but there were moderate positive correlations with the number of passives they produced in the exposure phase (*r*= .51, *p*< .001, 2-tailed) as well as with their individual priming effect, how much more likely there were to produce passives after passive primes as after active primes, in the exposure phase (*r*= .39, *p*= .001, 2-tailed). This suggests that the children who produced more passives in the exposure phase and those who showed greater priming in the exposure phase produced more passives in the test phase.

Correlation analyses revealed that the number of passives that adults in the priming conditions produced in the test phase was moderately positively correlated with the number of passives they produced in the exposure phase (*r*= .32, *p*= .011, 2-tailed) but not with their individual priming effect in the exposure phase, (*r*= .02, *p*= .86, 2-tailed). This suggests that the number of passives they produced in the test phase was related to the overall number of passives they produced in the exposure phase, but how often these appeared after passive primes relative to active primes was not related to their use of passives in the test phase.

6. Discussion

To summarize the findings: participants, children and adults, who were exposed to passives in a short exposure phase consisting of active and passive primes produced more passives than those who did not receive this exposure. This immediate priming effect persisted beyond the exposure phase to a test phase, such that participants who had heard and produced passives were more likely to produce passives in the test phase than those who had not. This persistence occurred irrespective of whether the test phase occurred immediately or after a short, filled delay (approximately two to three minutes).

There was no evidence that children were more susceptible to priming than adults. Adults did show a greater tendency than children to produce passives, including in the baseline condition where participants were not exposed to any transitive structures. In this condition, children were very unlikely to produce passives – only two children produced any – whereas 16 adults produced at least one passive without hearing any passive primes.

Finally, children with higher vocabularies were more likely to produce passives in the exposure phase. The likelihood of children producing passives in the test phase was greater the more passives those participants had produced in the exposure phase and the greater the magnitude of their individual immediate priming effect was; there was no relationship between other individual characteristics of the children and their production of passives in the test phase. This suggests that children's patterns of production observed in the test phase were related to their experience with language in the exposure phase. By contrast adults were more likely to produce passives in the test phase the more passives they produced in the exposure phase but this was unrelated to the magnitude of their immediate priming effect.

The findings largely support theories that suggest that syntactic priming effects result from implicit learning mechanisms and predict that priming effects should persist beyond an immediate trial. This study provides a novel comparison of such effects in children and adults who experienced passive primes versus those in the baseline condition who did not, and shows that persistent priming occurs when children are exposed to both transitive structures, not just one. The results also extend previous research on this implicit learning effect of priming to younger children.

6.1. Persistent priming of passives in young children.

The current evidence suggests that between three and five years of age, children benefit from exposure to passives to help them produce this structure and that this experience has a lasting effect beyond the original exposure. This study builds on previous evidence by extending the age at which children have been shown to be susceptible to such long-term priming effects below that of previous studies to three-year-olds (Huttenlocher et al., 2004; Kidd, 2012a, 2012b; Savage et al., 2006); the children in the present study were on average nine months younger than the youngest children previously tested (Savage et al., 2006). The study examined priming and persistence of passives because, as argued in the introduction, it is an ideal test case for testing priming as implicit learning in children. Passives typically start to emerge around the third birthday in English-speaking children's production (Budwig, 1990) and comprehension (Abbot-Smith, Chang, Rowland, Ferguson, & Pine, 2017; Bencini & Valian, 2008; Messenger & Fisher, 2018), but children continue to make errors with this structure for many years afterwards (Armon-Lotem et al., 2016; Huang, Leech, & Rowe, 2017; Messenger, Branigan, & McLean, 2012). Therefore, they appear to have a protracted learning period for this structure, extending from shortly prior to the third birthday until the sixth or seventh birthday. That the children in the baseline condition were very unlikely to produce passives is in line with existing evidence from this literature on children's acquisition of the passive as well as with other studies involving baseline phases (Kidd, 2012a, 2012b) or control conditions (Bencini & Valian, 2008) in which children of similar ages rarely spontaneously produced passives. It therefore seems unlikely that this lack of passive production in the baseline condition is related to differences in the samples tested but simply reflects typical behavior for children of this age. This study shows that providing such children with passive exemplars increases their production of the structure relative to those who do not hear them, and that this effect persists in the short-term into their production several minutes later, suggesting a lasting influence of that experience. With an average participant age of 4;2 years, and an age range that extended down to 3;3 years, this study demonstrates that such immediate and lasting priming occurs at the earlier stages of children's acquisition of this structure.

In the present study, such priming and persistence occurred when children experienced both actives and passives, i.e. a mixed priming phase. This evidence is in line with other previous studies showing immediate priming on a trial-by-trial basis when children hear alternating syntactic forms (Branigan & McLean, 2016; Branigan & Messenger, 2016; Messenger et al., 2011; Rowland et al., 2012). It extends these findings and findings on implicit learning from priming, by showing that this priming persists even when the exposure is mixed. This suggests that long-term priming effects in children are not due to carryover effects of reinforcing of one structure within the session. Indeed, the persistence from a mixed exposure was relatively robust, occurring from a priming session in which children heard primes once and did not repeat them, extending over a test phase that included more targets than in previous studies, which were also separated by filler trials, and, in one condition, over a filled delay of about two to three minutes between the exposure and test phases.

6.2. Explanations for long-term syntactic priming

These findings therefore add to existing findings with older children (Huttenlocher et al., 2004; Kidd, 2012a, 2012b; Savage et al., 2006), adults (e.g. Bock & Griffin, 2000; Kaschak et al., 2006; Thothathiri & Snedeker, 2008a), and second language learners (Kaan & Chun, 2018; Nitschke, Kidd, & Serratrice, 2010; Shin & Christianson, 2012), in suggesting that syntactic priming effects involve a form of implicit learning for how to describe events. The picture of what such learning effects may be like for children is beginning to emerge: Existing research demonstrates that priming effects in children persist in the immediate-term, lasting across two fillers between a prime and target (Branigan & McLean, 2016), and that the effect of hearing and producing passives increases the likelihood of using passives for at least several minutes afterwards in younger (the present study) and older children (Huttenlocher et al., 2004; Kidd, 2012b). We also know that prolonged and repeated exposure to passives, over weeks or months, leads to increased production of passive structures and improves children's comprehension of passives (Branigan & Messenger, 2016; Huttenlocher et al., 2002; Savage et al., 2006; Vasilyeva et al., 2006).

The learning observed here is viewed, as characterized by Bock and Griffin (2000), as learning to produce language in terms of encoding particular events with particular structures, not necessarily acquiring those representations ab initio (see also Kidd, 2012a); even the youngest children tested here would likely have already begun to acquire such a representation prior to the experiment since passives typically emerge around three years of age in English (Messenger & Fisher, 2018). Thus, the experience within the experiment would arguably have strengthened their fledgling representations for encoding transitive events with passives. Nonetheless, these results support an account in which such continuous updating of syntactic representations is the outcome of the same mechanism by which such representations are initially acquired.

What remains to be understood is *how* therefore these short-term experiences translate into long-term learning. For example, models of syntactic priming predict that *comprehension* of structures is key to learning (Chang et al., 2006; Dell & Chang, 2014). The error-based implicit learning account of syntactic priming suggests that whilst comprehending a sentence, predictions are made about the upcoming words and structure. When the input does not match the prediction, for example if a different structure is used than previously, weight changes to the representations are made to reflect the mis-match between prediction and input, making the likelihood of that representation being predicted again match the input more closely. The processor remains tuned to its recent experience with how to encode a particular event with a particular structure until further experience changes this bias. This suggests that such priming effects and their persistence are related to comprehension processes. In this experiment, participants who heard passives in the exposure phase were more likely to produce passives in both the exposure and test phase. Under this account, this comprehension experience changed how participants encoded transitive events relative to baseline participants, rendering participants who experienced passives more likely both in the immediate- and longer-term to encode transitive events with passives than participants who had not experienced this input.

However, in the current study, there was also a relationship between the number of passives children *produced* during the exposure phase with how many they produced afterwards in the test phase; this suggests a role for their production experience in supporting the persistence of priming. Similarly, Branigan and Messenger (2016) found that children's production of passives on a second priming task was related to their production of passives on the first priming task a week earlier. These priming effects mirror findings that children's language development is best supported by interaction with adults, that is, increased turn-taking in conversations, not just increased input (Zimmerman et al., 2009). Relatedly, adults' production experience has been shown to yield superior learning of syntactic dependencies of an artificial language relative to comprehension experience because, it was argued, production processes involve more in-depth processing of syntax, (Hopman & MacDonald, 2018). Indeed, the role of comprehension in learning within the error-based implicit learning model is based on the premise that it reflects the production process of generating a syntactic representation (Dell & Chang, 2014). This suggests that there is a role for production experience in long-lasting syntactic priming and learning. The current study cannot however disentangle the relative contributions of comprehension and production experience, since all children in the priming conditions heard passive primes, and production was not systematically manipulated and varied amongst individuals; as such, this remains an issue for future research and models of syntactic priming to consider.

6.3. Comparison between children and adults

Interestingly, children and adults showed comparable immediate and long-term priming effects. This lack of interaction with age group is inconsistent with the predictions of the error-based implicit learning model (Chang et al., 2006). Children are expected to experience greater error in predicting upcoming sentences which should yield greater priming and learning effects for children than adults (Chang et al., 2006; Fazekas et al., 2020; Rowland et al., 2012). Other studies that have directly compared immediate priming in children and adults have similarly failed to observe this interaction in the predicted direction

(Branigan & McLean, 2016; Branigan & Messenger, 2016; Messenger et al., 2011; Messenger, Branigan, McLean, et al., 2012; Peter et al., 2015; Rowland et al., 2012). One aim of future research should be to explore whether the lack of evidence for this prediction is due to a lack of sensitivity in existing research to detect the effect or because this aspect of the implicit learning model does not accurately represent human behavior.

Another factor that will likely interact with the magnitude and longevity of priming effects is the aspect of syntax under manipulation. Previous studies with adults have shown that the longevity of priming effects varies across different structures with longer priming effects observed for ditransitive structures than transitives (Bock & Griffin, 2000; Bock et al., 2007). Most of the existing studies examining syntactic priming as implicit learning in children have focused on passive structures (the present study, Kidd, 2012a, b; Branigan & McLean, 2016; Branigan & Messenger, 2016; Savage et al., 2006; Vasilyeva et al., 2006; cf. Huttenlocher et al., 2002; Huttenlocher et al., 2004 but see Fazekas et al., 2020 for data with datives). Developmental differences may be particularly expected with passives because they are a late acquired aspect of syntax but conversely this makes them difficult for children to produce. Different results in terms of the persistence of priming may be observed with different structures, depending on the relative preference for each syntactic alternative, the age at which children acquire them, and the age at which children are tested. Therefore, broader developmental evidence for whether and how priming effects support language learning across different structural alternations is a question for future research to answer.

7. Conclusion

To conclude, syntactic priming effects have provided key evidence for the psychological reality of syntactic structures. More recently they have also been linked to adaptive mechanisms which underlie syntactic priming effects in adults and language learning in children. The priming effects observed here in younger children were largely consistent with predictions of such accounts for the persistence of syntactic priming. Therefore, the current study supports the idea that priming constitutes a form of implicit learning for how to express events with different syntactic structures, and that such mechanisms operate in the early stages of language development. This study failed however to support the developmental differences that error-based learning models make, both for immediate priming, like a number of previous studies, and for longer-term effects. Though further work is required to uncover the full nature of such learning mechanisms, the finding that children benefit from short-term experience of structures that they otherwise rarely hear or spontaneously produce provides behavioral evidence in support of models that link adult and child language processing (Dell & Chang, 2014).

Acknowledgements

I thank all of the Warwickshire-based nurseries, their teachers and the families who participated in this study. I also thank Hannah Ciurej and Chris Thatcher who supplied the artwork used as the stimuli. A number of research assistants assisted with data collection and transcription: I thank Ellie Frank, Amy Sullivan, Priya Silverstein, Palvir Sangha, Anitha Monahan and Zoe Gardler for their help. This work was supported by a Leverhulme Trust Early Career Fellowship [grant number: ECF-2011-099].

References

Abbot-Smith, K., Chang, F., Rowland, C., Ferguson, H., & Pine, J. (2017). Do two and three year old children use an incremental first-NP-as-agent bias to process active transitive and passive sentences?: A permutation analysis. *PLOS ONE*, *12*(10), e0186129. https://doi.org/10.1371/journal.pone.0186129

Armon-Lotem, S., Haman, E., Jensen de López, K., Smoczynska, M., Yatsushiro, K., Szczerbinski, M., … van der Lely, H. (2016). A large-scale cross-linguistic investigation of the acquisition of passive. *Language Acquisition*, *23*(1), 27–56. https://doi.org/10.1080/10489223.2015.1047095

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, *59*(4), 390–412. https://doi.org/10.1016/j.jml.2007.12.005

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, *68*(3), 255–278. https://doi.org/10.1016/j.jml.2012.11.001

Bates, D., Mächler, M., Bolker, B. M., & Walker, S. C. (2014). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Bencini, G. M. L., & Valian, V. V. (2008). Abstract sentence representations in 3-year-olds: Evidence from language production and comprehension. *Journal of Memory and Language*, *59*(1), 97–113. https://doi.org/https://doi.org/10.1016/j.jml.2007.12.007

Bock, K. (1986). Syntactic persistence in language production. *Cognitive Psychology*, *18*(3), 355–387. https://doi.org/https://doi.org/10.1016/0010-0285(86)90004-6

Bock, K. (1989). Closed-class immanence in sentence production. *Cognition*, *31*(2), 163–186. https://doi.org/https://doi.org/10.1016/0010-0277(89)90022-X

Bock, K., Dell, G. S., Chang, F., & Onishi, K. H. (2007). Persistent structural priming from language comprehension to language production. *Cognition*, *104*(3), 437–458. https://doi.org/https://doi.org/10.1016/j.cognition.2006.07.003

Bock, K., & Griffin, Z. M. (2000). The persistence of structural priming: transient activation or implicit learning? *Journal of Experimental Psychology: General*, *129*(2), 177–192.

Bock, K., & Loebell, H. (1990). Framing sentences. *Cognition*, *35*(1), 1–39. https://doi.org/https://doi.org/10.1016/0010-0277(90)90035-I

Branigan, H. P., & McLean, J. F. (2016). What children learn from adults' utterances: An ephemeral lexical boost and persistent syntactic priming in adult–child dialogue. *Journal of Memory and Language*, *91*, 141–157. https://doi.org/https://doi.org/10.1016/j.jml.2016.02.002

Branigan, H. P., McLean, J. F., & Jones, M. (2005). A blue cat or a cat that is blue? Evidence for abstract syntax in young children's noun phrases. In A. Brugos, M. Clark-Cotton, & S. Ha (Eds.), *BUCLD 29: The proceedings of the twenty-ninth boston university conference on language development* (pp. 109–121). Somerville MA: Cascadilla Press.

Branigan, H. P., & Messenger, K. (2016). Consistent and cumulative effects of syntactic experience in children's sentence production: Evidence for error-based implicit learning. *Cognition*, *157*, 250–256. https://doi.org/https://doi.org/10.1016/j.cognition.2016.09.004

Branigan, H. P., & Pickering, M. J. (2017). Structural priming and the representation of language. *Behavioral and Brain Sciences*, *40*, e313. https://doi.org/10.1017/S0140525X17001212

Branigan, H. P., Pickering, M. J., Liversedge, S. P., Stewart, A. J., & Urbach, T. P. (1995). Syntactic priming: Investigating the mental representation of language. *Journal of Psycholinguistic Research*, *24*, 489–506.

Budwig, N. (1990). The linguistic marking of nonprototypical agency: An exploration into children's use of passives. *Linguistics*, *28*(6), 1221–1252. https://doi.org/10.1515/ling.1990.28.6.1221

Chang, F., Dell, G. S., & Bock, K. (2006). Becoming syntactic. *Psychological Review*, *113*(2), 234–272.

Chang, F., Dell, G. S., Bock, K., & Griffin, Z. M. (2000). Structural priming as implicit learning: A comparison of models of sentence production. *Journal of Psycholinguistic Research*, *29*(2), 217–229. https://doi.org/10.1023/A:1005101313330

Chang, F., Janciauskas, M., & Fitz, H. (2012). Language adaptation and learning: Getting explicit about implicit learning. *Language and Linguistics Compass*, *6/5*, 259–278.

Dell, G. S., & Chang, F. (2014). The P-chain: relating sentence production and its disorders to comprehension and acquisition. *Philosophical Transactions of the Royal Society B:*

Biological Sciences, *369*(1634), 20120394–20120394. https://doi.org/10.1098/rstb.2012.0394

Dorie, V., Bates, D., Maechler, M., Bolker, B. M., & Walker, S. C. (2020). blme: Bayesian Linear Mixed-Effects Models. A package for R.

Fazekas, J., Jessop, A., Pine, J., & Rowland, C. (2020). Do children learn from their prediction mistakes? A registered report evaluating error-based theories of language acquisition. *Royal Society Open Science*, *7*(11), 180877. https://doi.org/10.1098/rsos.180877

Ferreira, V. S., & Bock, K. (2006). The functions of structural priming. *Language and Cognitive Processes*, *21*(7–8), 1011–1029. https://doi.org/10.1080/01690960600824609

Fine, A. B., & Jaeger, T. F. (2013). Evidence for Implicit Learning in Syntactic Comprehension. *Cognitive Science*, *37*(3), 578–591. https://doi.org/https://doi.org/10.1111/cogs.12022

Foltz, A., Knopf, K., Jonas, K., Jaecks, P., & Stenneken, P. (2020). Evidence for robust abstract syntactic representations in production before age three. *First Language*, *41*(1), 3–20. https://doi.org/10.1177/0142723720905919

Foltz, A., Thiele, K., Kahsnitz, D., & Stenneken, P. (2015). Children's syntactic-priming magnitude: lexical factors and participant characteristics. *Journal of Child Language*, *42*(4), 932–945. https://doi.org/DOI: 10.1017/S0305000914000488

Gordon, P., & Chafetz, J. (1990). Verb-based versus class-based accounts of actionality effects in children's comprehension of passives. *Cognition*, *36*(3), 227–254. https://doi.org/https://doi.org/10.1016/0010-0277(90)90058-R

Hartsuiker, R. J., Bernolet, S., Schoonbaert, S., Speybroeck, S., & Vanderelst, D. (2008). Syntactic priming persists while the lexical boost decays: Evidence from written and spoken dialogue. *Journal of Memory and Language*, *58*(2), 214–238. https://doi.org/https://doi.org/10.1016/j.jml.2007.07.003

Hartsuiker, R. J., Kolk, H. H. J., & Huiskamp, P. (1999). Priming word order in sentence production. *Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology*, *52*(1), 129–147. https://doi.org/10.1080/713755798

Hartsuiker, R. J., & Westenberg, C. (2000). Word order priming in written and spoken sentence production. *Cognition*, *75*(2). https://doi.org/10.1016/S0010-0277(99)00080-3

Hopman, E. W. M., & MacDonald, M. C. (2018). Production practice during language learning improves comprehension. *Psychological Science*, 095679761875448. https://doi.org/10.1177/0956797618754486

Huang, Y. T., Leech, K., & Rowe, M. L. (2017). Exploring socioeconomic differences in syntactic development through the lens of real-time processing. *Cognition*, *159*, 61–75. https://doi.org/10.1016/j.cognition.2016.11.004

Huttenlocher, J., Vasilyeva, M., Cymerman, E., & Levine, S. (2002). Language input and child syntax. *Cognitive Psychology*, *45*(3), 337–374. https://doi.org/10.1016/S0010-0285(02)00500-5

Huttenlocher, J., Vasilyeva, M., & Shimpi, P. (2004). Syntactic priming in young children. *Journal of Memory and Language*, *50*(2), 182–195. https://doi.org/https://doi.org/10.1016/j.jml.2003.09.003

Jackson, C. N. (2017). Second language structural priming: A critical review and directions for future research. *Second Language Research*, 026765831774620. https://doi.org/10.1177/0267658317746207

Jaeger, T. F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language*, *59*(4), 434–446. https://doi.org/https://doi.org/10.1016/j.jml.2007.11.007

Jaeger, T. F., & Snider, N. E. (2008). Implicit learning and syntactic persistence: Surprisal and cumulativity. In *Proceedings of the 29th annual Cognitive Science Society (CogSci09)* (pp. 1061–1066). Austin, TX: Cognitive Science Society.

Jaeger, T. F., & Snider, N. E. (2013). Alignment as a consequence of expectation adaptation: Syntactic priming is affected by the prime's prediction error given both prior and recent experience. *Cognition*, *127*(1), 57–83. https://doi.org/https://doi.org/10.1016/j.cognition.2012.10.013

Kaan, E., & Chun, E. (2018). Priming and adaptation in native speakers and second-language learners. *Bilingualism*, *21*(2), 228–242. https://doi.org/10.1017/S1366728916001231

Kaschak, M. P. (2007). Long-term structural priming affects subsequent patterns of language production. *Memory & Cognition*, *35*(5), 925–937. https://doi.org/10.3758/BF03193466

Kaschak, M. P., Kutta, T. J., & Schatschneider, C. (2011). Long-term cumulative structural priming persists for (at least) one week. *Memory and Cognition*, *39*(3), 381–388.

https://doi.org/10.3758/s13421-010-0042-3

Kaschak, M. P., Loney, R. A., & Borreggine, K. L. (2006). Recent experience affects the strength of structural priming. *Cognition*, *99*(3). https://doi.org/10.1016/j.cognition.2005.07.002

Kidd, E. (2012a). Implicit statistical learning is directly associated with the acquisition of syntax. *Developmental Psychology*, *48*(1), 171–184. https://doi.org/10.1037/a0025405

Kidd, E. (2012b). Individual differences in syntactic priming in language acquisition. *Applied Psycholinguistics*, *33*(02), 393–418. https://doi.org/10.1017/S0142716411000415

Leonard, L. B. (2011). The primacy of priming in grammatical learning and intervention: A tutorial. *Journal of Speech Language and Hearing Research*, *54*(2), 608. https://doi.org/10.1044/1092-4388(2010/10-0122)

Lew-Williams, C., & Fernald, A. (2007). Young children learning Spanish make rapid use of grammatical gender in spoken word recognition. *Psychological Science*, *18*(3), 193–198. https://doi.org/10.1111/j.1467-9280.2007.01871.x

Lukyanenko, C., & Fisher, C. (2016). Where are the cookies? Two- and three-year-olds use number-marked verbs to anticipate upcoming nouns. *Cognition*, *146*, 349–370. https://doi.org/https://doi.org/10.1016/j.cognition.2015.10.012

Mahowald, K., James, A., Futrell, R., & Gibson, E. (2016). A meta-analysis of syntactic priming in language production. *Journal of Memory and Language*, *91*, 5–27. https://doi.org/https://doi.org/10.1016/j.jml.2016.03.009

Malhotra, G., Pickering, M. J., Branigan, H. P., & Bednar, J. A. (2008). On the persistence of structural priming: Mechanisms of decay and influence of word-forms. In B. C. Love, K. McRae, & V. M. Sloutsky (Eds.), *Proceedings of the 30th annual conference of the cognitive science society, Cognitive Science Society,* (pp. 657–662). Austin, TX.

Messenger, K., Branigan, H. P., & McLean, J. F. (2011). Evidence for (shared) abstract structure underlying children's short and full passives. *Cognition*, *121*(2), 268–274. https://doi.org/10.1016/j.cognition.2011.07.003

Messenger, K., Branigan, H. P., & McLean, J. F. (2012). Is children's acquisition of the passive a staged process? Evidence from six-and nine-year-olds' production of passives. *Journal of Child Language*, *39*(5), 991–1016. https://doi.org/10.1017/S0305000911000377

Messenger, K., Branigan, H. P., McLean, J. F., & Sorace, A. (2012). Is young children's passive syntax semantically constrained? Evidence from syntactic priming. *Journal of Memory and Language*, *66*(4), 568–587. https://doi.org/10.1016/j.jml.2012.03.008

Messenger, K., & Fisher, C. (2018). Mistakes weren't made: Three-year-olds' comprehension of novel-verb passives provides evidence for early abstract syntax. *Cognition*, *178*, 118–132. https://doi.org/10.1016/J.COGNITION.2018.05.002

Nitschke, S., Kidd, E., & Serratrice, L. (2010). First language transfer and long-term structural priming in comprehension. *Language and Cognitive Processes*, *25*(1), 94–114. https://doi.org/10.1080/01690960902872793

Peter, M., Chang, F., Pine, J. M., Blything, R., & Rowland, C. F. (2015). When and how do children develop knowledge of verb argument structure? Evidence from verb bias effects in a structural priming task. *Journal of Memory and Language*, *81*, 1–15. https://doi.org/https://doi.org/10.1016/j.jml.2014.12.002

Peter, M., & Rowland, C. F. (2018). Aligning developmental and processing accounts of implicit and statistical learning. *Topics in Cognitive Science*, *0*(0). https://doi.org/10.1111/tops.12396

Pickering, M. J., & Branigan, H. P. (1998). The representation of verbs: Evidence from syntactic priming in language production. *Journal of Memory and Language*, *39*(4), 633–651. https://doi.org/https://doi.org/10.1006/jmla.1998.2592

Pickering, M. J., & Ferreira, V. S. (2008). Structural priming: A critical review. *Psychological Bulletin*, *134*(3), 427–459.

R Core Team. (2015). *A language and enviroment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Reitter, D., Keller, F., & Moore, J. D. (2011). A Computational cognitive model of syntactic priming. *Cognitive Science*, *35*(4), 587–637. https://doi.org/10.1111/j.1551-6709.2010.01165.x

Rowland, C. F., Chang, F., Ambridge, B., Pine, J. M., & Lieven, E. V. M. (2012). The development of abstract syntax: Evidence from structural priming and the lexical boost. *Cognition*, *125*(1), 49–63. https://doi.org/https://doi.org/10.1016/j.cognition.2012.06.008

Savage, C., Lieven, E., Theakston, A., & Tomasello, M. (2006). Structural priming as implicit learning in language acquisition: The persistence of lexical and structural priming in 4-

year-olds. *Language Learning and Development*, *2*(1), 27–49. https://doi.org/10.1207/s15473341lld0201_2

Seeff-Gabriel, B., Chiat, S., & Roy, P. (2008). *Early Repetition Battery*. London, UK: Pearson Assessment.

Shimpi, P. M., Gámez, P. B., Huttenlocher, J., & Vasilyeva, M. (2007). Syntactic priming in 3- and 4-Year-old children: Evidence for abstract representations of transitive and dative forms. *Developmental Psychology*, *43*(6), 1334–1346.

Shin, J. A., & Christianson, K. (2012). Structural priming and second language learning. *Language Learning*, *62*(3), 931–964. https://doi.org/10.1111/j.1467-9922.2011.00657.x

Thothathiri, M., & Snedeker, J. (2008a). Give and take: Syntactic priming during spoken language comprehension. *Cognition*, *108*(1), 51–68. https://doi.org/10.1016/J.COGNITION.2007.12.012

Thothathiri, M., & Snedeker, J. (2008b). Syntactic priming during language comprehension in three- and four-year-old children. *Journal of Memory and Language*, *58*(2), 188–213. https://doi.org/https://doi.org/10.1016/j.jml.2007.06.012

Vasilyeva, M., Huttenlocher, J., & Waterfall, H. (2006). Effects of language intervention on syntactic skill levels in preschoolers. *Developmental Psychology*, *42*(1), 164–174. https://doi.org/10.1037/0012-1649.42.1.164

Wiig, E. H., Secord, W. A., & Semel, E. (2006). Clinical Evaluations of Language Fundamentals (CELF) Preschool 2-UK. London, UK: Pearson Assessment.

Zimmerman, F. J., Gilkerson, J., Richards, J. A., Christakis, D. A., Xu, D., Gray, S., & Yapanel, U. (2009). Teaching by listening: The importance of adult-child conversations to language development. *Pediatrics*, *124*(1), 342 LP – 349. Retrieved from http://pediatrics.aappublications.org/content/124/1/342.abstract

Appendix: Prime and Target Items (see https://osf.io/tfjh2/ for a full item list)

Prime items for exposure phase

1. the bear is washing the clown / the clown is getting washed by the bear
2. the pig is washing the girl / the girl is getting washed by the pig
3. the rabbit is feeding the witch / the witch is getting fed by the rabbit
4. the lion is feeding the boy / the boy is getting fed by the lion

5. the sheep is knocking over the girl / the girl is getting knocked over by the sheep
6. the lion is knocking over the fireman / the fireman is getting knocked over by the lion
7. the tiger is shaking the doctor / the doctor is getting shaken by the tiger
8. the elephant is shaking the witch / the witch is getting shaken by the elephant
9. the cat is poking the queen / the queen is getting poked by the cat
10. the frog is poking the clown / the clown is getting poked by the frog
11. the frog is pinching the robber / the robber is getting pinched by the frog
12. the cat is pinching the nurse / the nurse is getting pinched by the cat

Target items counterbalanced across exposure and test phases

	Set A	Set B
1.	pig kissing policeman	policeman patting goat
2.	sheep kissing cat	king patting rabbit
3.	dog biting robber	sheep squashing ballerina
4.	monkey biting doctor	elephant squashing girl
5.	lion scratching nurse	pirate carrying mouse
6.	tiger scratching king	builder carrying cow
7.	postman pushing witch	dog chasing queen
8.	prince pushing rabbit	cat chasing boy
9.	turtle licking fairy	fairy pulling tiger
10.	duck licking baby	witch pulling lion
11.	horse kicking clown	bear tickling nurse
12.	cow kicking fireman	robber tickling frog