

Linking production and comprehension processes: The case of relative clauses

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ABSTRACT

Six studies investigated the relationship between production and comprehension by examining how relative clause production mechanisms influence the probabilistic information used by comprehenders to understand these structures. Two production experiments show that accessibility-based mechanisms that are influenced by noun animacy and verb type shape relative clause production. Two corpus studies confirm these production mechanisms in naturally occurring productions. Two comprehension studies found that nouns and verb types occurring in structures that speakers do not produce are difficult to comprehend. Specifically, the probability of producing a passive structure for a verb type in a given animacy configuration, as measured in the production and corpus studies, predicts comprehension difficulty in active structures. Results suggest that the way in which the verb roles are typically mapped onto syntactic arguments in production plays a role in comprehension. Implications for the relationship between production, comprehension and language learning are discussed.

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1. Introduction

One of the most central questions in cognitive science is the extent to which humans' information processing abilities are shaped by learning from experience. While researchers in every field agree that learning plays a role, there is significant disagreement concerning the extent of this influence. For example, as evidenced by both behavioral and imaging data (Yovel & Kanwisher, 2004), human face recognition processes are distinctly different in character from the processes that recognize natural and manufactured objects, such as trees and cups. One interpretation of these results is that the striking differences between face and object processing reflect the operations of a face-specific processing system that has primarily been shaped by evolutionary forces (Grill-Spector, Knouf, & Kanwisher,

2004; McKone, Kanwisher, & Duchaine, 2007). An alternative explanation is that these results reflect humans' learning from their unique experiences with faces (Gauthier, Curran, Curby, & Collins, 2003; Tarr & Gauthier, 2000). On this view, the face processing data are different in character from other object recognition data because humans have more and different experiences with faces compared to other entities in the world. By virtue of learning from these experiences and unique task demands (such as identifying individuals rather than categorizing them), humans' face processing has a unique character. This view places the burden of the explanation for face processing on learning from experience: the distributional regularities in the input (the range and frequency of faces in the visual world), the special task demands for faces, and the learning abilities of the perceiver to adapt to these experiences and demands.

Similar debates pervade research in language acquisition and processing. Within language acquisition, there are many proposals for a major role of innate grammatical constraints or cognitive primitives, which assign a periph-

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eral role to linguistic experience (Chomsky, 1959; Lust & Foley, 2004), and there are also advocates for ascribing a large role to learning processes (Tomasello, 2003). Similarly, within adult language comprehension, some accounts posit a sentence processing mechanism that operates by fixed parsing principles that navigate the pervasive ambiguities in language (Frazier, 1987), while other traditions have argued that comprehension processes weigh the probability of alternative interpretations based on learning from prior experience (MacDonald, Pearlmutter, & Seidenberg, 1994; Tanenhaus & Trueswell, 1995). These debates in the language domain have an additional level of complexity that is not present in the face processing example, which is that human language users are both potential learners from their linguistic experience and the creators of that experience. That is, the distributional regularities of faces stem from human physiology, not so much human behavior, but the language statistics that comprehenders learn originate in utterances that they and other language users produce.

Whereas researchers in face perception do not feel compelled to explain why faces have the particular distributional characters they have, language researchers can investigate why utterances have certain properties and not others. Indeed, some have argued that an account of language comprehension as emerging from language statistics is incomplete without an account of where the statistics come from, i.e., why languages have particular distributional characteristics and not others (Frazier, 1995; but cf. MacDonald, 1997). Our goal in this article is to take steps in developing a unified framework that explains both the origin of the distributional regularities of language and how learning of those regularities shapes the language comprehension system. The question concerning the origin of linguistic patterns is an important area of research in historical linguistics (Hopper & Traugott, 1993; Keller, 1994; Sweetser, 1990) and to a lesser extent in psycholinguistics (Hawkins, 2004; Wasow, 2002). Although there are multiple reasons why languages tend to have certain properties, our claim is that language production processes are a significant influence on the distributional patterns to which a language user is exposed.

Our approach is called the *Production-Distribution-Comprehension* (PDC) framework because it attempts to link properties of the language production system to particular choices made during utterance production, to link those choices to particular distributional patterns in the input provided to comprehenders, and finally to show that comprehension behavior is modulated by these distributional patterns (MacDonald, 1999; MacDonald & Thornton, unpublished manuscript). At the level of sentence processing, the PDC account essentially argues that structure choices in production, at least some of which are determined by production-specific mechanisms, create robust distributional patterns in the language, which are learned over time by comprehenders who are exposed to this input. These distributional patterns then become the probabilistic constraints that guide the comprehension process in a constraint-based system. On this view, comprehension processes and interpretation preferences can thus be traced to distributional patterns in language use, which

are themselves emergent from *production* mechanisms affecting speakers and writers.

While language producers clearly do make some production choices for the benefit of their audience (e.g., Clark, 1996), it is also clear that some production choices emerge because of the needs of the speaker (Ferreira & Dell, 2000). During planning, choice of word order and syntactic structure is strongly constrained by the *accessibility* of words and phrases (e.g., Bock, 1982; Bock, 1987; Bock & Irwin, 1980; Bock & Levelt, 1994; Bock & Loebell, 1990; Bock & Warren 1985; MacDonald, Bock, & Kelly, 1993). Accessibility can be understood as the degree to which a word or phrase is ready for articulation in the utterance – some elements, by virtue of being long, rare, less frequent or conceptually less salient, etc., may require more planning and retrieval time than others. Given the incremental nature of production in which uttering and planning of upcoming elements occurs simultaneously (Ferreira & Swets, 2002), fluency is maximized by uttering more accessible portions of an utterance early, leaving additional time to plan less accessible components. Our claim is that accessibility-based and other production-driven choices yield distributional patterns in the language that ultimately shape comprehension processes.

Investigating a claim of this sort has several steps, including identifying what production choices speakers make, testing whether the production processes involved give rise to broad distributional patterns, and determining the extent to which the distributional patterns predict comprehension performance. In this article, we follow these steps with reference to the production and comprehension of object relative (or center embedded) clauses such as *the lawyer that the judge criticized*. Dating from Miller and Chomsky's (1963) first discussion of center embedding, an extensive literature has been devoted to explaining why these structures are difficult for children and adults to comprehend (e.g. Kidd, Brandt, Lieven, & Tomasello, 2007; Sheldon, 1974; Wanner & Maratsos, 1978; Caplan & Waters, 1999; Mak, Vonk, & Schriefers, 2002; Mak, Vonk, & Schriefers, 2006). Object relative clauses therefore form a well-studied domain in which to investigate links between production and adult processing, and eventually, links to acquisition. In the present article, we investigate speakers' choices in relative clause production, the resulting distributional regularities in input to comprehenders, and the consequences of these regularities on comprehension processes. We first briefly review the large literature on relative clause comprehension before turning to the much less studied processes of relative clause production.

1.1. Object relative clauses and noun animacy in comprehension

Object relative clauses have been found to be more difficult to comprehend than subject relative clauses (e.g., *the lawyer that criticized the judge*), which contain the same words but a different word order and meaning, or passive relative clauses (e.g., *the lawyer that was criticized by the judge*), which have a similar meaning (Waters & Caplan, 1996; King & Just, 1991; Just & Carpenter, 1992; Gordon,

Hendrick, & Johnson, 2001; Gordon, Hendrick, & Johnson, 2004; Traxler, Morris, & Seely, 2002; Mak et al., 2002; MacWhinney & Pleh, 1988; Gennari & MacDonald, 2008). These findings have often been thought to stem from architectural properties of the sentence comprehension processes, for example that object relatives are harder because they tax working memory more than do subject relatives (see Gennari & MacDonald, 2008, for review). A more recent approach points to the role of learning of probabilistic regularities in explaining comprehension difficulty and rate of acquisition, particularly properties of the nouns in the relative clause (Gennari & MacDonald, 2008; Kidd et al., 2007; Mak et al., 2002; Reali & Christiansen, 2007; Wells, Christiansen, Race, Acheson & MacDonald, 2009). Several studies have pointed out that comprehension difficulty in object relatives varies with the animacy configuration of the nouns involved (Mak et al. 2002; Traxler et al. 2002): Object relatives with inanimate heads such as that in (1a) are easier to process than those with animate heads in (1b).

- (1a) The movie that the director watched received a prize.
 (1b) The director that the movie pleased received a prize.

This animacy effect matches the frequency of the animacy configurations in several corpora: inanimate-head object relative clauses are more frequent than animate-head ones (Roland, Dick, & Elman, 2007; Mak et al., 2002). Gennari and MacDonald (2008) explicitly linked noun animacy to the availability of alternative interpretations in object relatives. They showed that word-by-word reading difficulty in these structures correlates with the availability of the alternative interpretations as the clause unfolds, as measured by sentence completion studies. They argued, along the lines of the constraint satisfaction approach, that semantic indeterminacy plays a role in explaining comprehension difficulty, as noun animacy provides probabilistic information modulating the relative likelihood of the thematic roles assigned to the nouns and the relative likelihood of the alternative events into which the nouns can be integrated.

In the present work, we extend this research to production processes themselves, focusing on the role of animacy and verb properties, such as their associated mappings from event roles to syntactic arguments. Specifically, we argue that constraints during utterance planning give rise to production choices in which certain verbs and noun types co-vary with a particular choice of active or passive structure within the relative clause, resulting in a particular mapping from event roles to syntactic arguments. In active structures, for example, agents or instigators of the event tend to be mapped onto subject position, but this is not the case for passive constructions. The particular conjunctions of verb type and animacy configurations (that is, the animate vs. inanimate status of subject and object nouns) that tend to be produced in passive structures are necessarily rare in active structures. Comprehenders are therefore misled when encountering an active object relative with an animacy configuration and a verb type that signal a passive structure. The unfolding animacy configu-

ration generates great semantic indeterminacy as to the roles that the nouns may play relative to the verb (Gennari & MacDonald, 2008). As proposed by constraint satisfaction approaches, competition between alternative thematic role interpretations of the nouns and their co-varying passive and active structures ensues, as dictated by language experience, giving rise to comprehension difficulty (see, for example, the competition-integration model of McRae, Spivey-Knowlton, & Tanenhaus, 1998).¹ Comprehension difficulty and interpretation preferences in object relatives can thus be traced to frequency-guided interpretation preferences, themselves traced to distributional patterns derived from *production* mechanisms, which promote certain choices among speakers and thus the distributional patterns that drive the comprehension process.

1.2. Animacy and verb type in production

A number of syntactic choices in production have been shown to be strongly influenced by the conceptual accessibility of the noun phrases in the utterance, including choices of active vs. passive voice, and double object vs. prepositional dative forms (e.g., Bock & Warren 1985; Bock & Irwin, 1980; Bock & Loebell, 1990; Ferreira, 1994; McDonald et al., 1993; Bock, 1987). Two aspects of noun phrase accessibility are particularly relevant here because they can be directly linked to comprehension difficulty. One is noun animacy; English speakers have a tendency to locate animate concepts at initial positions in the sentence (Clark 1965; Bates & MacWhinney, 1982; Bock, 1982; Bock, 1987; Bock, Loebell, & Morey, 1992). This observation has often been cast in terms of subjecthood because in English words that are mentioned first are strongly correlated with syntactic subjects (but see Prat-Sala & Branigan, 2000; de Smedt & Kempen, 1987; Kempen & Hoenkamp, 1987; Branigan, Pickering, & Tanaka, 2008). This tendency is particularly noticeable when speakers describe events with an animate and an inanimate participant in which the animate entity is the patient of the action, which results in an unusual preference for passive structures (*The boy was hit by the truck* is preferred over *The truck hit the boy*), even though the patient of an action is otherwise a natural candidate for the object position. Animate nouns are thus mapped onto subject syntactic positions in a way that appears independent of the agent or patient role of the nouns within the sentence (McDonald

¹ In this work, we describe probabilistic constraints as modulating the activation of competing alternative interpretations (e.g., McRae et al., 1998), but there are a number of different ways to conceptualize the effect of experience on new input. One is to view the comprehension process as instantiated in a dynamic computational network that “moves” through a multidimensional space as a function of the input (Tabor and Tanenhaus, 1999). This approach more closely captures the behavior of computational models that do not literally activate alternative interpretations, as comprehension difficulty emerges from the distributional properties of the input (e.g., MacDonald and Christiansen, 2002). This approach is related to computational accounts suggesting that comprehension time is governed by the degree of uncertainty in the input (*entropy*, see Hale, 2006) and the degree to which the encountered input is predicted from prior context and experience (*surprisal*, see Levy, 2008). Our approach is compatible with these views and does not demand any particular computational instantiation of comprehension difficulty.

et al., 1993). This arrangement maximizes production incrementality: The earliest-planned (most accessible) element of the sentence is uttered first, while the speaker plans the less accessible upcoming material (De Smedt & Kempen, 1987; Kempen & Hoenkamp, 1987; Levelt, 1989).

Another aspect of noun phrases that modulates their relative accessibility in production is the thematic roles that nouns bear in the event referred to by the verb. Ferreira (1994) argued that the relative accessibility of the verb's thematic roles influences the rate of active vs. passive sentence production. In production studies in which participants were given two nouns and a verb to make up a sentence, participants were more likely to passivize theme–experiencer verbs than regular agent–theme or experiencer–theme verbs when the nouns had the same or mismatching animacy. Theme–experiencer verbs such as *surprise*, *please*, or *annoy* denote an event in which something or someone causes a change of psychological state in the human animate participant – the experiencer (Belletti & Rizzi, 1988; Grimshaw, 1990; Levin & Rappaport, 1986; Cupples, 2002). Ferreira argued that the affected experiencer role assigned to a noun (e.g., to *the mother* in *The child/gift pleased the mother*) is more prominent than the theme–cause role (e.g., the child or gift), and that passive constructions result from the speakers' preference to locate the most conceptually prominent noun in subject position (e.g., *The mother was pleased by the child/gift*). This preference contrasts with that of ordinary agent–theme verbs in which the agent invariably takes the sentential subject position, thus resulting in an active construction.

Production preferences in the domain of relative clauses have not been extensively investigated (but see Gennari, Mirkovic, & MacDonald, 2005), and little is known about the role of accessibility considerations in the production of these more complex structures. Relative clauses are thought to function like predicates or modifiers of a head noun, e.g., in *the book that I bought*, the relative clause *that I bought* modifies the noun *book* (Chierchia & McConnell-Ginet, 2000). According to some descriptions based on corpus studies, the discourse function of relative clauses is either to ground the head entity with respect to given information in the discourse or to provide a characterization of it (Fox & Thompson, 1990). Unlike main clauses in which passives and actives have different noun orders, the head of the relative clause invariably takes the initial position in the structure by virtue of discourse considerations and language-specific constraints (e.g., English is a head-first language). If the relative clause continues as an active object relative (e.g., *the director that the movie pleased*), the order of nouns (e.g. *director*, *movie*) is the same as in a passive relative (*the director that was pleased by the movie*). These contrasts suggest that some mechanism(s) different from those in main clauses may play a role in relative clause production: because the position of the head noun is fixed, accessibility may (as in main clauses) or may not influence different syntactic function assignment (e.g. subject vs. object) in relative clauses. Thus one goal of the production studies is to investigate the extent to which the accessibility factors that shape main clause structures also act in relative clauses. We address

this question in the first section, which examines relative clause production using a method similar to the one used by Ferreira (1994) with main clauses. In Section 2, we use language corpora to ask whether the patterns identified in the production studies are representative of broad distributional regularities in the language. Finally, in Section 3, we ask about the effects of these distributional regularities on the comprehension of relative clauses.

2. Section 1: animacy and verb type in relative clause production

2.1. Study 1: verb type in active vs. passive production preferences

In this study, we investigated the production preferences associated with theme–experiencer and agent–theme verbs when speakers are constrained to produce a relative clause with one animate and one inanimate noun. Because relative clauses and main clauses differ in several ways, the purpose of this study was to establish whether theme–experiencer verbs show a preference for passives when they occur within relative clauses, as Ferreira (1994) showed for these verbs in main clauses. To this end, we presented speakers with starter words such as *director that* and two additional words (e.g., *pleased*, *movie*) that they had to use in the utterance, in whichever order they wanted. The task thus forced speakers to produce a relative clause while at the same time gave them a choice to continue it with either an active or a passive relative clause (e.g., *that the movie pleased*, *that was pleased by the movie*).

Because we were ultimately interested in linking the production preferences of this experiment with already-established effects in comprehension of object relative clauses, we constructed our materials from those used in Traxler et al. (2002), Experiment 3, and Gennari and MacDonald (2008), Study 3. The word-based production task allowed us to use a method similar to the one used in Ferreira's (1994) investigation of animacy and verb type in main clauses and also to examine production of relative clauses with the same nouns and verbs as participants had read in these previous comprehension studies. Other relative-clause production tasks are not as well suited to these materials. For example, picture description, which we have previously used to investigate some aspects of relative clause production (Gennari et al., 2005), is not suitable because theme–experiencer verbs such as *please* are difficult to convey in a picture. A recall paradigm is another alternative, but our previous work (Race & MacDonald, 2003) showed variation in the extent to which participants included a relative pronoun such as *that*, and we wanted a production task that would come closest to yielding the relative clauses that participants read in Gennari and MacDonald (2008). However, the word-based production task has the disadvantage of not providing reliable measures of onset latencies to assess planning difficulty. The latencies collected in such tasks (the time from the onset of the stimulus to the onset of production) necessarily include the time it takes to complete several other processes:

Table 1
Example of a test item from Production Study 1.

Screen top	Upper word	Lower word	Verb type
director that	movie	pleased	Theme–experiencer
movie that	director	watched	Agent–theme
director that	pleased	movie	Theme–experiencer
movie that	watched	director	Agent–theme

Note: The order of upper and lower words on the screen were counter-balanced across items.

reading the words on the screen, understanding the possible messages they can convey and ordering them in a sequence that may or may not be different from the one on the screen. The time taken to complete these processes not only adds noise to the data but also can vary across conditions; for example, comprehending the message may take different amounts of time in animate and inanimate conditions. Thus here we report only production choices for this task (which are the most essential production data for a test of the PDC) and leave for future research issues concerning production difficulty.²

Two object relative clause conditions were used in this experiment (see Table 1). These conditions contained theme–experiencer and agent–theme verbs respectively and were presented with nouns of varying animacy. Agent–theme verbs were presented with inanimate heads and animate relative clause nouns (e.g., *the movie that the director watched*), whereas theme–experiencer verbs were presented with animate heads and inanimate relative clause nouns (e.g., *the director that the movie pleased*). If structure choice processes in relative clauses are similar to those in main clauses, which have been shown to be strongly affected by animacy (McDonald et al., 1993) and verb type (Ferreira, 1994), then the animacy and verb type manipulations here should result in robust differences in active and passive choices. Specifically, utterances with theme–experiencer verbs should tend to be passive (*the director that was pleased by the movie*) and less likely to be active object relatives (*the director that the movie pleased*) compared to agent–theme verbs, for which active object relatives (*the movie that the director watched*) remains at least as viable a choice as the passive (*the movie that was watched by the director*).

2.1.1. Method

2.1.1.1. Participants. Forty-two undergraduate students from introductory psychology courses at the University of Wisconsin–Madison participated in this experiment. All were native speakers of English and received course credit for participating.

2.1.1.2. Materials and design. Stimuli were 28 items based on those originally developed by Traxler et al. (2002). Each contained two verbs and two nouns that made up the two main conditions (see Table 1). Each of the 28 agent–theme verbs was paired with a theme–experiencer verb (e.g., *watch* was paired with *please*). These verbs were matched for word length and frequency according to the 20 million words English Cobuild corpus (Sinclair, 1995). The mean log frequencies for agent–theme verbs and theme–experiencer verbs were 4.13 and 3.97 respectively ($t < 1$). The mean character per word for these verb types was 5.90 and 6.07, respectively ($t < 1$). The two nouns, one animate and another inanimate, that occurred as arguments of the verbs (e.g., *director*, *movie* were the arguments for both *watch* and *please*), were also matched for frequency. The mean log frequency for animate nouns was 4.19, and for inanimate nouns was 4.26 ($t < 1$). The number of characters per word, however, differed significantly, with animate nouns being longer (7.10 vs. 5.72, $t(27) = 2.95$, $p < .006$).

Thirty-two filler items were also included, and all had four versions each following the pattern of the stimulus items. Two versions of each filler had an animate head noun (e.g. *scientist that – [meeting went]*) and two versions had an inanimate noun (e.g., *package that – [fell truck]*). Of the filler items, half contained intransitive verbs with potential locatives (e.g., *package that – [fell truck]*) or contained no verbs and instead contained a noun and adjective (*student that – [brightest class]*). The other half of the fillers contained materials designed to encourage passive structures, such as past participle verb forms like *stolen* and/or potential locative expressions (e.g., *dictionary that – [stolen museum]* or *player that – [TV interviewed]*). These items were included to counter the overall bias for active forms in English.

The order of presentation of the relative clause noun and verb (e.g., the order of *movie* and *pleased* on the screen below the phrase *director that*) was counterbalanced within and across participants. Each participant saw only one of the versions of each item exemplified in Table 1. There were four lists. Each list contained one of the four possible versions of each test item or filler item and an equal number of items in each presentation order and verb type condition. This guaranteed that participants saw the same number of animate and inanimate head nouns throughout the experiment and the same number of noun–verb or verb–noun presentation orders within the to-be-produced relative clause.

2.1.1.3. Procedure. Participants sat in front of the computer screen next to an experimenter and used the keyboard to move from one trial to the next. The words to be produced in each trial were displayed in different color fonts and locations of the screen. The first two words (e.g., *director that*) were always in black and located at the top of the screen in one line. Underneath this line, there were two vertically arranged words in red (e.g., *movie – pleased* or *pleased – movie*). Participants were instructed to produce a meaningful referential phrase with the words of the screen. They were told that the words in the first line of text had to be produced in the order displayed, whereas the remaining two words in red could be used in any order.

² Testing production difficulty hypotheses requires a different methodology. Ferreira, 1994 found that theme–experiencer verbs in passive structures took longer to produce using a ‘read-produce’ methodology. However, it is possible that initiation times were confounded with comprehension times, as these verbs are difficult to read in active structures (Cupples, 2002). The planning difficulty associated with these structures thus remains an open issue.

Participants were also told that they could include function words or other words not listed on screen in their utterance. There were examples and practice trials to familiarize the participants with the procedure.

Each trial started with the display of the words and stayed on the screen until the participant started speaking. Once the participant had produced a phrase, the experimenter pressed a button on the button box, coding response type (active, passive, other) on-line. When the participant was ready to proceed, he/she pressed a key on the keyboard and the next set of words was displayed. It took between 15 and 25 minutes to complete the 60 trials, and the whole session was recorded on audiotape.

2.1.1.4. Coding. The experimenter's on-line coding of active vs. passive relative clause structure was checked against the transcriptions of the sessions' tapes, carried out by a research assistant unaware of the manipulations of the study. Cases in which producers made the words into a main clause rather than a relative clause were coded as miscellaneous responses.

2.1.2. Results

Fig. 1 displays the proportion of passive relatives as a function of verb type calculated from the total of actives and passives in each verb condition (this way of calculating proportions was used in this and subsequent figures to facilitate comparisons across studies). The proportion of passive productions was much higher for theme–experiencer verbs than for agent–theme verbs. An example of production containing a passive relative clause is *the salesman that was excited about his product*, for a prompt such as *salesman that* – [*excited product*]. An example of active relative clause is *the school that the student attended*, for a prompt like *school that* [*attended student*]. There was a small proportion of miscellaneous responses in this study – e.g., *the salesman was excited to sell the product* – (these were .12 for the theme–experiencer verbs and .04 for the agent–theme verbs calculated over the total number of productions).

Statistics were performed on the frequency of produced structures, collapsing across the counterbalanced word-order presentations and including miscellaneous responses. A Pearson χ^2 test comparing the frequency of structure

choices (passive relative clause, object relative clause or neither) for each verb type indicated that there was a significant association between verb type and structure ($\chi^2(2) = 327.3, p < .0001$). Because a significant χ^2 test does not provide information about the direction or the strength of the effect, we indicate this information with odds ratios, which are the ratio of the probability of an occurrence in one category compared to another (e.g., the probability of passives occurring with one verb type divided the probability of passives occurring with another verb type). An odds ratio of 1 indicates that the probability of a particular occurrence is equal in both categories. In this study, odds ratios indicated that passives were about 7 times more likely to be produced with theme–experiencer verbs than with agent–theme verbs (and conversely, actives were more likely with agent–theme verbs).

Results indicate that theme–experiencer verbs (presented with animate head nouns) are more likely to be produced in passive relative clauses, whereas agent–theme verbs (presented with inanimate head nouns) are more likely to be produced in active structures. Even though in half the cases, participants could have simply read the words aloud in the on-screen order (adding some function words) to make a grammatically correct relative clause, speakers were reluctant to do so, and preferred instead to reverse the order of the words presented to them. This result suggests a strong bias for each verb type (in the current animacy configurations) to occur in a specific relative clause structure.

2.1.3. Discussion

The results of this experiment showed that speakers preferred to produce passive relative clauses with theme–experiencer verbs and animate head nouns but produced active object relatives with agent–theme verbs and inanimate heads. These preferences are consistent with those reported by Ferreira (1994) in simple sentences, in which theme–experiencer verbs were passivized more often than were agent–theme verbs. This indicates that the animate noun bearing the experiencer role of a theme–experiencer verb is often mapped onto the subject position of a passive construction, whereas the animate noun bearing the agent role of an agent–theme verb is mapped onto the subject position of an active construction. Thus even though word order is more fixed in relative clauses than in main clauses (with the head noun always first in English relative clauses), the same verb-based influences on structure choice appear to operate in production of both clause types. Study 2 investigates the extent to which these patterns can be traced to the effects of verb vs. noun animacy.

2.2. Study 2: animacy and verb type in passive vs. active production preferences

In this study, we investigated the potentially separable influences of verb type and animacy on structure choice in relative clauses using the same procedure as in Study 1 but manipulating animacy within a verb type. A fully crossed design is not possible, because all combinations of animacy and verb type do not exist in English. For example, theme–

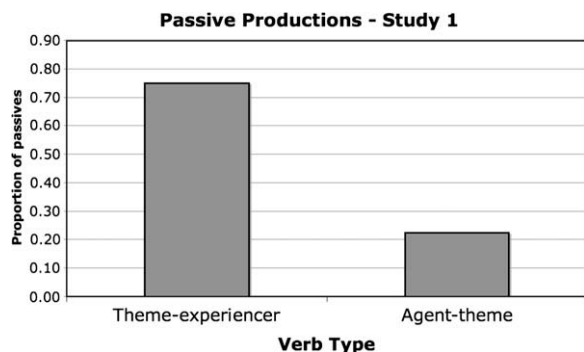


Fig. 1. Proportion of passive relatives from Production Study 1 as a function of verb type.

Table 2
Example of stimulus item from Production Study 2.

Screen top	Upper word	Lower word	Animacy and verb type condition
writer that	critic	angered	Animate–Animate–Theme–experiencer
writer that	review	angered	Animate–Inanimate–Theme–experiencer
writer that	critic	analyzed	Animate–Animate–Agent–theme

Note: The order of upper and lower words on the screen were counter-balanced across items.

experiencer verbs such as *amaze* and *anger* must have an animate entity experiencing the emotion, and so inanimate noun conditions are excluded for this verb type. We therefore tested the three combinations of noun animacy and verb type that yielded sensible phrases, as shown in Table 2. The theme–experiencer verbs occurred with two different animacy configurations: animate head and inanimate relative clause noun – e.g., *the writer that the review angered* – vs. animate head and animate relative clause noun – e.g., *the writer that the critic angered*. These conditions permit comparing active and passive productions for theme–experiencer verbs when they occur in different animacy configurations. In contrast, agent–theme verbs occurred in one condition only, with two animate nouns (*the writer that the critic analyzed*). This arrangement was necessary because agent–theme verbs rarely take inanimate subjects (e.g., *the writer that the review analyzed...*), and such uses may be more difficult to process because of plausibility or conflict with the verbs' semantic requirement of an agent argument. The inclusion of the animate–animate agent–theme condition allows a comparison across verb types (theme–experiencer and agent–theme) within animate–animate items.

2.2.1. Method

2.2.1.1. Participants and procedure. Thirty native English-speaking students at the University of Wisconsin–Madison participated in the experiment for extra credit in an introductory psychology course. The procedure was the same as in Study 1.

2.2.1.2. Materials and design. The nouns and verbs used in this experiment had the form exemplified in Table 2. Thirty-two theme–experiencer verbs (classified in Levin (1993) as *amuse*-type verbs) were paired with ordinary agent–theme verbs of similar frequency and word length. The mean character per word for theme–experiencer verbs was 6.53 and for agent–theme verb was 6.59. The mean log frequency for theme–experiencer verbs according to the Cobuild corpus was 3.78 and for agent–theme was 3.82. The nouns across conditions were also matched for frequency and word length (mean frequency for animate nouns = 4.15 and for inanimate nouns = 4.14; mean character per word for animate nouns = 7 and for inanimate nouns = 7.05). No comparison across these means was significant. The Appendix provides a list of the relative clause items from which the nouns and the verbs of this experiment were taken.

Three lists were constructed. Each list contained one version of each item (either animate–animate–theme–experiencer verb, animate–inanimate–theme–experiencer verb or animate–animate–agent–theme verb). As in Study 1, half the items in each list were presented on the screen in noun–verb (NV) order within the relative clause (e.g., *writer that [critic angered]*), and half the items were in verb–noun (VN) order (e.g., *writer that [angered critic]*). The two presentation orders of each item were counter-balanced across lists. For this, the two presentation orders were systematically assigned across lists in such a way that the three versions of item 1 were presented in NV, VN, NV orders in lists 1, 2 and 3, respectively, item 2 was presented in VN, NV and NV orders across lists, item 3 was presented in NV, VN and VN orders, and so on across items for the six possible combinations of orders and lists. This resulted in each of the three main conditions being presented either 5 or 6 times in each NV and VN orders in each list. Filler items were as in Study 1. The dependent variable in this experiment was the proportion of active object relative and passive productions.

2.2.1.3. Off-line plausibility ratings. To ensure that events described in the materials were equally plausible in all conditions, we asked 32 university students who did not participate in the main experiment to indicate on a scale of 1–7 how likely the events of the materials were. For example, for the item in Table 2, we asked how likely it was for a critic to anger a writer, for a review to anger a writer, or for a critic to analyze a writer. There were three questions per item corresponding to each conditions exemplified in Table 2. The questions were counter-balanced across three lists so that each participant saw one of the three questions for each item. The mean rating for two animate nouns occurring with theme–experiencer verbs (e.g., the critic angering the writer) was 4.7 (SD = .6), the mean rating for an animate and an inanimate noun occurring with theme–experiencer verbs (a review angering the writer) was 4.8 (SD = .6) and the mean rating for animate nouns with agent–theme verbs (an critic analyzing the writer) was 4.9 (SD = .7). The differences across these ratings were not significant ($F(2, 31) = 1.2$, ns).

2.2.1.4. Coding. As in Study 1, responses were coded according to structure (active object relative, active subject relative, passive relative) by a research assistant. Note that in contrast to Study 1, in which subject relatives were implausible (e.g., *the director that pleased the movie*), subject relative clauses were a plausible response option for the Study 2 materials (e.g. *the writer that angered the critic*). In both the passive relative and the active object relative, the head noun plays the experiencer or the patient role, but in the subject relative, the head noun plays the agent or theme–cause argument. Because we were particularly interested in the structures that participants choose when they have to express the same semantic content (i.e., when the head noun bears the experiencer or patient role), we focused our predictions and interpretation on the choices of passive and active object relative clauses across verb types, though rates of subject relatives were included in the statistical tests.

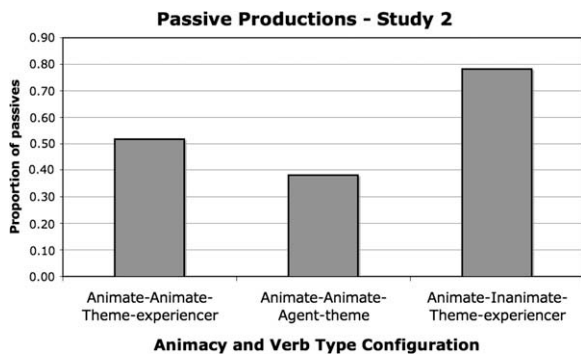


Fig. 2. Proportion of passives relatives in Production Study 2 as a function of animacy and verb type configuration.

2.2.2. Results

Fig. 2 shows the proportion of object and passive relatives across conditions calculated over the total of object and passive relative productions for each verb type, i.e., the total of cases for each verb type in which the meaning conveyed entailed a choice between these structures (e.g., *the writer that the critic angered* vs. *the writer that was angered by the critic*).³ This figure indicates that whereas active object relatives were more frequent with agent–theme verbs (the proportion of passives was only .38), passive relatives were most frequent with theme–experiencer verbs occurring with nouns of mismatching animacy. Examples of relevant productions are *the girl that was frightened by the thunder*, *the economist that the journalist contacted*.

To establish whether there was a significant association between the animacy-verb type conditions and the structures produced, we used a χ^2 test comparing raw frequencies and including all produced structures, as in Study 1. For each verb type and animacy condition (animate–animate–theme–experiencer, animate–animate–agent theme, animate–inanimate–theme–experiencer), we included counts for object relatives, passive relatives and other structures (i.e., subject relative clauses). The test revealed a significant association between animacy-verb type conditions and produced structures ($\chi^2(4) = 194.3, p < .0001$). Odds ratios indicated that passive relatives were more than 6 times more likely to occur with animate–inanimate–theme–experience verbs than in any other animacy and verb type configuration. Object relatives were more than twice as likely to occur with animate–animate–agent–theme verbs than in any other configuration. However, passive relatives and object relatives were equally likely in the animate–animate–theme–experiencer condition. This indicates weak preferences for either object relatives or passive structures in the animate–animate–theme–experiencer conditions when the head noun is perceived as the experiencer of the event. Overall, passive structures were overwhelmingly preferred with theme–experiencer verbs in animate–in-

imate configurations (*the writer that was angered by the review*), whereas active object relatives were more frequent with agent–theme verbs (*the writer that the critic analyzed*).

2.2.3. Discussion

The results indicate that the structural preferences are modulated by verb type and animacy: more active object structures occurred for agent–theme verbs than theme–experiencer verbs, and theme–experiencer verbs were more frequently produced as passives with nouns of mismatching animacy (*the writer that was angered by the review* is more frequent than *the writer that was angered by the critic*). These results are consistent with Ferreira's (1994) results in main clause production, which also indicated that animacy modulated the passivization rates of theme–experiencer verbs. In both Ferreira's study and ours, theme–experiencer verbs in animate–inanimate configurations were more frequently produced as passives than in the animate–animate configuration. This indicates that the animacy of the cause argument plays a role in production choices, modulating the mapping of the experiencer role into subject position.

One intriguing result in this study is the relatively similar production rates of active and passive structures when theme–experiencer verbs occur with two animate nouns. One possibility is that the experiencer head noun of a relative clause competes in accessibility with the noun within the relative clause, which is animate and bears a causal role shared with agents. Both these nouns may therefore be sufficiently prominent to be produced as subject of the relative clause. A similar reason may explain the relatively small differences found in passive rates across verb types when two animate nouns are involved, compared to the large differences of Study 1. In sum, the production studies together showed that animacy and thematic roles exert a powerful influence when the structure being planned contains nouns of mismatching animacy, but thematic roles exert a less powerful influence when animacy is equal.

Beyond the interest for production research, Experiments 1–2 laid the foundation for further exploration of the PDC approach, in that they identified the different distributional patterns that result from different animacy and verb configurations. Before we can ask whether comprehenders are influenced by these production patterns, it is important to establish that these patterns hold more broadly in the language. We investigated this issue in two corpus studies. Study 3 investigates the distributions associated with each verb type independently of animacy configurations, in particular, their tendency to occur in active or passive structures. Study 4 addresses the three configurations used in production Study 2, animate–animate–theme–experiencer, animate–animate–agent–theme, and animate–inanimate–theme–experiencer.

3. Section 2: animacy and verb type in English corpora

3.1. Study 3: verb type in active vs. passive production preferences

Previous corpus analyses of active vs. passive structures (Rohde, 2002) or of relative clause productions (Fox &

³ The proportion of subject relatives is not shown in this figure to facilitate comparisons across studies. Overall, subject relatives were produced in a third of the productions for each verb type, but these tended to occur in the animate–animate conditions, because the animate–inanimate condition did not allow sensible subject relatives (e.g., *the writer that angered the review*).

Thompson, 1990; Roland et al., 2007) have not investigated the effect of verb type on structure within relative clauses. In this study we therefore investigated the tendencies of agent–theme and theme–experiencer verbs to occur in passive constructions within the context of relative clauses in several English corpora. We also investigated the properties of the specific verbs used in the stimulus items from Study 1 in order to relate the spoken production data from that study to patterns in the corpora.

3.1.1. Method

3.1.1.1. Verb type frequency in relative clauses. We extracted 1370 object and 562 unreduced passive relative clauses from the *Wall Street Journal* parsed corpus (Marcus, Santorini, & Marcinkiewicz, 1993). These relative clauses were hand-coded for the type of verb that occurred within the relative clause (agent–theme, theme–experiencer or other verb type). The animacy of the nouns in these relative clauses was not coded. After classification, we calculated for each verb type the proportion of cases occurring in unreduced passive relative clauses and object relative clauses.

3.1.1.2. Coding. Theme–experiencer verbs were defined as those listed in Levin (1993) as psychological change-of-state verbs (*amuse*-type verbs). Agent–theme verbs were those typically involving human actions exerting changes on another event participant, either entities or individuals. This set also included three-argument verbs such as *allow* and encompassed most of Levin's verb types but did not include psychological verbs (*admire*-type verbs also called experiencer–theme verbs), verbs denoting cognitive states (e.g., *believe*), perception verbs (e.g., *hear*) and verbs of existence or appearance (*exist*). We classified the verbs according to their most frequent senses provided by dictionary definitions, irrespective of the particular use in the relative clause. For example, in *the things that stores sell*, we consider *sell* to be an agent–theme–goal verb, although *stores* cannot be taken as a human agent.

3.1.1.3. Stimulus verbs' overall frequency in passive structures. We extracted all the instances of the stimulus verbs of Study 1 from the parsed *Wall Street Journal* corpus and the Brown corpus, and computed the proportion of times in which each verb occurred in passive constructions, in either main or subordinate clauses. Both clause

types were included because a restriction to relative clauses would have yielded too few tokens of many verbs. We searched for the past participle *-ed* forms of the stimulus verbs because this form was presented to participants in Study 1, and the *-ed* form of the verb would be used in passive structures (none of the verbs were irregular, i.e., all had an *-ed* suffix for past and past participle uses). There were 1050 cases for agent–theme verbs and 370 cases for theme–experiencer verbs. Every instance of our stimulus verbs was classified according to whether the verb was used in passive or active constructions by a linguistics student blind to the study. A few verbs in our stimulus set did not occur in these corpora or had only one occurrence and therefore were not included in the analysis (*terrify*, *practice*, *encode*, *covet*, *misplace*, *delight*).

3.1.2. Results

3.1.2.1. Verb type frequency in relative clauses. As shown in Table 3, the analysis of verb type frequency in relative clauses indicated that although theme–experiencer verbs were relatively rare in relative clauses as compared to other verb types (these verbs are less frequent in the corpus in general), to the extent that they occurred in relative clauses at all, they tended to occur in passive relatives. In contrast, agent–theme verbs were often used in active object relative clauses. A χ^2 test comparing the frequency of passive and object relative clauses for each verb type indicated that there was a significant association between verb type and structure ($\chi^2(1) = 44.98$, $p < .0001$). Odds ratios indicated that passive relatives were about eight times more likely to occur with theme–experiencer verbs than agent–theme verbs.

3.1.2.2. Stimulus verbs' frequency in passive structures. The analysis of overall passive occurrences for our Study 1 stimulus verbs revealed that the mean proportion of passive use in main and subordinate clauses across agent–theme verbs was .36, whereas the mean proportion of passives for theme–experiencer verbs was .60. A χ^2 test comparing the frequency of passives and actives for each verb type indicated that there was a significant association between verb type and structure ($\chi^2(1) = 19.14$, $p < .0001$). Odds ratios indicated that passive structures were 3.21 times more likely to occur with our theme–experiencer verbs than our agent–theme verbs.

Table 3

Proportion of verbs occurring in relative clauses from Corpus Study 3.

Verb type	Proportions		Examples		Count
	Object relative	Passive relative	Object relative	Passive relative	
Agent–theme	0.66	0.34	The arguments that Japan will make...	The bakeries (...) that are not regulated by the USDA...	1285
Theme–experiencer	0.17	0.83	The kind of arrangement that the new guidelines would affect...	... soil that was naturally infected with anthrax	48
Other verb types	0.77	0.13	The players who I remember...	the stairs (...) that are located next to the altar	588

Note: Proportions were calculated from the total number of verbs in each verb class.

3.1.3. Discussion

Overall, these corpus analyses suggest that theme–experiencer verbs are often used in passive constructions in both relative clauses and main clauses, whereas agent–theme verbs tend to occur in object relative clauses and other active constructions. In general, producers tend to map the thematic roles of different verb types into distinct syntactic positions and constructions, as they did in our production Study 1. These results therefore link production mechanisms operating in mapping the conceptual representation of the message into sentential syntactic positions to broad distributional patterns in the language. The next study further pursues the corpus analyses, incorporating the role of noun animacy.

3.2. Study 4: Animacy and verb type in passive vs. active production preferences

In this study, we tested whether broad distributional patterns emerge from the production choices revealed in Study 2 by examining production preferences in a large corpus. To facilitate comparison and examine structure choices contingent on animacy, we concentrated on cases that had the animacy distributions of our production Study 2, rather than examining all possible animacy combinations (e.g., inanimate, inanimate). We extracted occurrences of our stimulus verbs in Study 2 from the British National Corpus, a corpus of 100 million words of written text (<http://www.natcorp.ox.ac.uk>), which includes British and some American English texts. We then coded these occurrences according to noun animacy and type of structure (active or passive) and examined the distributional properties of the stimulus verbs.

3.2.1. Methods

3.2.1.1. Data set. From the British National corpus, we extracted 100 random occurrences for each of our stimulus verbs. As in corpus Study 3, searches were conducted using the past tense/past participle *-ed* form of the verbs (e.g., *annoyed*), which was the form presented in the production study (for the one irregular verb of the stimulus set, both past participle and past tense forms were searched). For

cases in which the random searches provided the same example twice, only one case was included in the analyses. A total of 5368 cases (2786 cases for agent–theme verbs, and 2582 for theme–experiencer verbs) were included in the analyses after 429 pre-nominal adjective uses were excluded (e.g., *computer assisted language learning*, *embarrassed silence*). There were only 950 sentences with relative clauses in the sample, about 18% of the total coded data set. This count excludes cases of adverbial clauses in which the relative clause pronoun does not play a subject or object role in the clause (e.g., *the extent to which the Shah had criticized Britain...*), which were treated as ordinary active or passive clauses. 66% of the relative clauses were passive relatives, 26% were subject relatives and 7% were object relatives. Among the passive relative clauses and active object relatives entered into the analysis below, there were 388 relative clause cases for agent–theme verbs and 311 for theme–experiencer verbs.

3.2.1.2. Coding. Each sentence was coded indicating whether it was an active or passive structure, and a main or relative clause. Relative clauses were classified into object relatives, passive relatives, or subject relatives. Only the two phrases that were the arguments of our stimulus verbs were coded for animacy (for *he was pleased that he felt no ill*, for example, we considered *he* and the complement *that*-clause to be arguments of the verb). Table 4 shows examples from the corpus and the coding strategy used.

The verbs in bold indicate the verbs that were searched for and the underlined material indicates the nouns bearing the syntactic subject and object of the verb's arguments (i.e., the theme or the agent/experiencer argument). For the animacy coding, animate nouns were considered to be those referring to living entities or to social institutions such as banks, churches, governments, etc. Inanimate nouns were those referring to other non-living entities. The coding was carried out by two research assistants trained in linguistics and by the authors. Inter-coder reliability was high (95%). Cases of disagreement were re-examined by the coders and changed into the agreed-upon coding.

Table 4

Coded examples from Corpus Study 4.

Example sentences	Animacy Noun 1	Main structure	Relative clause	Animacy Noun 2
From a very early age <u>he assisted his father</u> in his optical workshop, and ...	Animate	Active		Animate
It is a <u>principle</u> that <u>the Palestinian Authority</u> has pursued consistently in time of crisis:...	Inanimate	Active	Object	Animate
Ray Stewart is <u>an experienced athlete</u> , coached by <u>the old master Don Quarrie</u> .	Animate	Passive	Passive	Animate
<u>Those</u> who are enraged by <u>the state of disrepair of Bristol's streets</u> may derive a cold comfort from ...	Animate	Passive	Passive	Inanimate
<u>Political circles</u> were shocked and surprised <u>by the outcome</u> ...	Animate	Passive		Inanimate
Even <u>Dole</u> , who once challenged him for the Presidency, was on verge of tears.	Animate	Active	Subject	Animate
In June <u>town employees</u> were angered because...	Animate	Passive		
<u>She</u> threw the brick over to the bonfire site and attacked with the fork again	Animate	Active		
I once knew an <u>elderly diplomat</u> who had been annoyed as a young man because ...	Animate	Passive	Passive	

Note: Verbs in bold are the verbs searched for. Underlined phrases indicate the syntactic arguments of the corresponding verb bearing its main thematic roles.

3.2.2. Results

To compare the distributional properties in the corpus with the production preferences of Study 2, we computed two sets of analyses on the coded corpus as a function of animacy. The first concerned the distributional properties of the verbs in each verb type, including both main and relative clauses. The second analysis concerned the properties of the verbs when occurring in relative clauses only. In each of these analyses, we examined only the distributions contingent on the animacy configurations that were used in the production experiment of Study 2.

3.2.2.1. Structure preferences in all clause types as a function of animacy and verb type. For each verb type, we computed the proportion of passives and actives in which either both verbal arguments were animate or one was animate and the other inanimate *in any order* (as main and relative clauses may differ in the order of the verbal arguments, see Table 4). Fig. 3 displays the proportions of passives in each condition calculated from the total of active and passive structures produced in each animacy and verb type configuration. Because we restricted our analysis to those configurations used in Study 2, Fig. 3 excludes cases in which agent–theme verbs occur with animate–inanimate configurations (the most frequent configuration for these verbs) and cases in which verbs occurred with only one argument. Thus, Fig. 3 displays only the preferences that are contingent on the specific animacy configurations shown.

A χ^2 test comparing the frequency of active and passive structures for each verb type in each animacy configuration (animate–animate–active, animate–animate–passive, animate–inanimate–passive, animate–inanimate–active or neither) revealed a significant association between verb type and animacy and the structure produced ($\chi^2(4) = 638.4, p < .0001$). Odds ratios indicated that actives were 3.27 times more likely to occur with agent–theme verbs than theme–experiencer verbs. In contrast, passives were more than six times more likely in the animate–inanimate configuration than in any other animacy and verb type configuration. However, when compared to each other, passives and actives structures were equally likely in the animate–animate–theme–experiencer condition. Overall, agent–theme verbs tend to occur in active

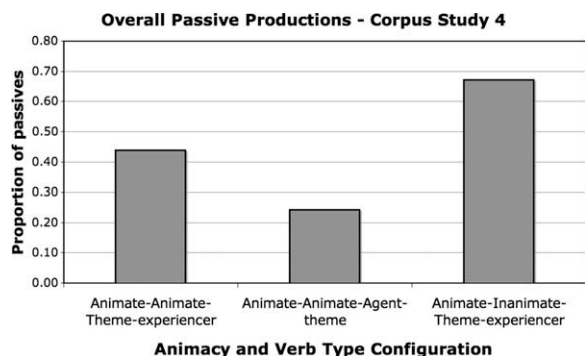


Fig. 3. Proportion of passive structures from Corpus Study 4 as a function of animacy and verb type configuration.

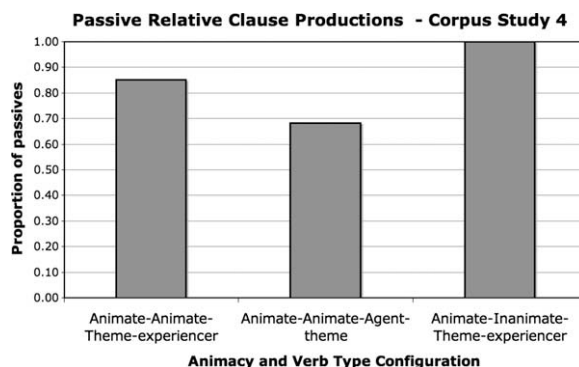


Fig. 4. Proportion of passive relative clauses from Corpus Study 4 as a function of animacy and verb type configuration.

structures and theme–experiencer verbs occur in passive constructions more often with an animate–inanimate noun configuration (*the woman was amazed by the spectacle*) than an animate–animate one (*the woman was amazed by the magician*).

3.2.2.2. Structure preferences in relative clauses as a function of animacy and verb type. For each verb type, we computed the proportion and the raw frequency of passive relatives and active object relatives in which either both verbal arguments were animate or one was animate and the other inanimate *in this order* (proportions were computed from the total cases of passives and object relatives as in Study 2). Fig. 4 displays the proportions of passives computed over the total of active and passive relative clauses in each animacy and verb type configuration. As in Fig. 3, this figure also excludes many cases in which structures occurred with only one argument as in agentless passives. These results thus show preferences between active and passives structures when the meaning expressed and the number of arguments is comparable.

A χ^2 test was conducted comparing relative clause structure frequencies for each verb type in each animacy configuration (animate–animate–object–relative, animate–animate–passive–relative, animate–inanimate–passive–relative or neither; there was no animate–inanimate object relative in the data set–). The test revealed a significant association between verb type and structure–animacy (passive relative (3) = 187.20, $p < .0001$). Odds ratios indicated that active object relatives were about 6 times more likely to occur in the animate–animate–agent–theme configuration than in the animate–animate–theme–experiencer configuration. When the probability of actives is compared to the probability of passives for agent–theme verbs, however, active relatives were 2 times less likely. In contrast, passive relatives were between 5 and 80 times more likely to occur with theme–experiencer verbs compared to agent–theme verbs, with the largest difference obtaining for the animate–inanimate–theme–experiencer configuration. The pattern of results is similar to that of main clauses, but they differ in that active object relatives were small in proportion, compared to main active clauses in similar animacy conditions.

3.2.3. Discussion

Results indicated that the relative proportions of actives vs. passives in the corpus were modulated by animacy configurations and verb types, as in production Study 2. In both corpus counts, agent–theme verbs showed a tendency to occur in active structures compared to theme–experiencer verbs, although in relative clauses, this preference was reduced. Preferences for theme–experiencer verbs were modulated by animacy: with nouns of mismatching animacy, these verbs are overwhelmingly mapped into passive structures, but events with two animate participants are generally less likely to be produced in passives. Interestingly, theme–experiencer verbs in this animacy configuration were produced at similar rates in passive and active main clauses, as they were in Study 2, although in relative clauses, there was an advantage for passives. We will return to the differences between main and relative clause preferences in the general discussion.

Across both corpus studies, despite differences in corpora and range of verbs investigated, the pattern of productions generally reflected the effects of verb type and animacy observed in Studies 1–2. More specifically, the animacy results in Study 4 are broadly similar to those in production Study 2 (see Figs. 2–4), particularly for theme–experiencer verbs, suggesting a strong link between production preferences observed in the laboratory and specific distributional patterns contingent on event types and animacy configurations. This result is significant because natural corpus productions need not agree with those obtained in the laboratory, due to the differences in the message and the task, in that participants in Studies 1–2 were given specific nouns and verbs and were constrained to produce a relative clause of some type, whereas the free productions in the corpora reflect a different set of constraints.

Given this convergence of laboratory and corpus results, we are now in a position to evaluate the effect of verb- and animacy-based production patterns on comprehension difficulty. Studies 5 and 6 of Section 3 examine the comprehension of active object relative clauses and passive relative clauses using the same verbs and nouns as in the production studies. We then directly relate reading times both to the proportions of passives obtained in the laboratory in Studies 1–2 and also to the broader distributional patterns identified in the corpus.

4. Section 3: animacy and verb type in comprehension

4.1. Study 5: verb types' passive vs. active preferences

In our previous investigation of relative clause comprehension, we found that a key source of comprehension difficulty is ambiguity in how to assign thematic roles to the noun phrases that have been encountered (Gennari & MacDonald, 2008). In particular, the thematic roles that participants assigned to the nouns as the relative clause unfolds (as determined by gated completion studies) predicted comprehension difficulty (as indexed by reading times) at subsequent word positions. Infrequent and unexpected semantic roles in a given configuration were difficult to

comprehend in part because of competition with more available roles. Here we aim to tie these results to the production and corpus studies and focus on the contribution of role-to-argument mappings characteristic of active and passive structures. In active structures, the subject noun is typically the agent or instigator of the event, but this is not the case in passives. According to the PDC account, in which interpretation is shaped by experience comprehending past productions, when verbs are encountered, characteristic patterns of role-to-argument mappings are activated and may compete with those suggested by the unfolding input. This view predicts that the degree to which role-to-argument mappings take the form of a passive configuration in production will be a good predictor of comprehension difficulty when verbs occur in active object relative clauses.

We tested this prediction by regressing the verbs' passivization rates from Study 1 and 3 onto the reading times of the stimulus items occurring in active object relatives. These reading times were taken from Study 2 of Gennari and MacDonald (2008) as reported (no additional manipulation of reading times were conducted). This study used single-word self-paced reading (“moving window”), and analyzed only those reading times for which comprehenders subsequently answered a comprehension question correctly. The materials of this study were used to create the items of the present production Study 1. Thus, for the items exemplified in Table 1 (*the director that* – [movie, pleased], *the movie that* – [watched, director]), we used in our regression analyses the reading times of the corresponding sentences *The director that the movie pleased had received a prize* and *The movie that the director watched had received a prize*. The results of this reading study are reported in detail elsewhere (Gennari & MacDonald, 2008) and are summarized in Fig. 5.

4.1.1. Regression analyses

To test our prediction, we picked the word position in the comprehension results that showed the most difficulty as a function of animacy and verb type. We thus used as the dependent variable in our regressions the residual reading times at the main auxiliary verb position in Fig. 5 (e.g., at *had* in *The director that the movie pleased had received a prize*

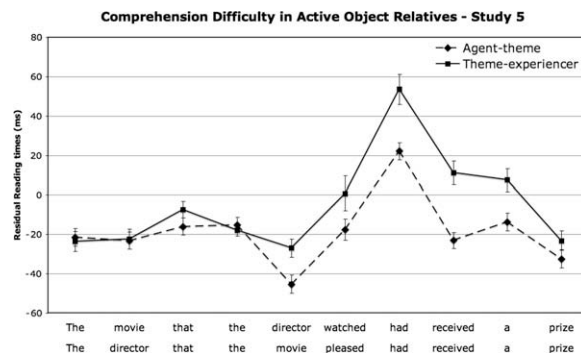


Fig. 5. Mean residual reading times per word position for active object relative clauses as a function of verb type. Data reported in Gennari and MacDonald (2008). Error bars indicate standard error.

ceived a prize). This position has been claimed to be an integration point, where the thematic roles are assigned to the nouns (cf. King & Just, 1991; Gordon et al., 2001; Grodner & Gibson, 2005), although arguably, some of this processing already starts at the relative clause verb (Gennari & MacDonald, 2008). The predictors in these regressions were the passive proportions across items from production Study 1 and from corpus Study 3. Passivization rates from Study 1 significantly predicted the reading times at the main auxiliary verb ($F(1, 54) = 7.35, p = .009, R = .35$). Passivization rates from the corpus Study 3 also significantly predicted the reading times of the main auxiliary verb ($F(1, 47) = 4.83, p = .03, R = .31$); one outlier was removed from this analysis using case diagnostics procedures described in Field (2005). Scatter plots are shown in Fig. 6. The more a verb tended to occur in a passive structure, the more difficult it was to process when occurring in an active object relative clause. The rates from the production study are better predictors than the corpus counts, most likely because the production study specifically examined production of relative clauses alone, and with exactly the same nouns as in the comprehension stimuli.

4.1.2. Discussion

Gennari and MacDonald (2008) showed that relative clause comprehension difficulty was linked to comprehenders' expectations of how the structure and thematic roles would be resolved as the sentence unfolds. The present study goes further and shows that comprehension difficulty is specifically linked to production-based distributional regularities in comprehenders' experiences. For example, consider the relative clauses with theme-experiencer verbs in the present study, such as *The director that the movie pleased had received a prize*. Fig. 5 shows that sentences of this sort are difficult for comprehenders. Studies 1 and 3 show why: speakers almost never convey this sort of message, with this type of verb and animacy configuration, as an object relative clause. Instead, they utter a passive, as in *The director that was pleased by the movie*,

because this structure allows a preferred mapping of roles to sentence positions, as discussed in the production studies here. Thus comprehenders who encounter *The director that the movie...* do not strongly activate the ultimately "correct" interpretation and instead strongly activate alternative structures with different thematic roles for the sentence entities. When the relative clause verb (e.g. *pleased*) and main clause verb (*had*) are encountered, they disconfirm these alternative interpretations, which results in more competition between alternative thematic roles and role-to-argument mappings characteristic of active and passive structures, giving rise to comprehension difficulty. The comprehension difficulty can be traced to the distributional regularities in the language, which can themselves be traced to production preferences owing to certain role-structure mappings.

Our final question is whether verb type and animacy configuration exert separate and/or interacting influences on comprehension. The materials in Study 5, in which animacy and verb type were confounded, create a very robust contrast between configurations that very frequently occur as object relatives and those that very rarely occur in this form. Study 6 examines the potentially more subtle effects of individual animacy and verb type manipulations in a comprehension study.

4.2. Study 6: Animacy and verb type in reading comprehension

Several previous studies of relative clause comprehension have emphasized the importance of animacy in comprehension difficulty (e.g., Mak et al., 2002; Traxler et al., 2002). Our own view, bolstered by the production results in Study 2, is that animacy and verb type are both important in creating the distributional patterns that were observed in corpus Study 4. If animacy is the sole factor governing comprehension difficulty, then there should be no effect of verb type in object relative clauses containing two animate nouns. If the comprehension patterns follow

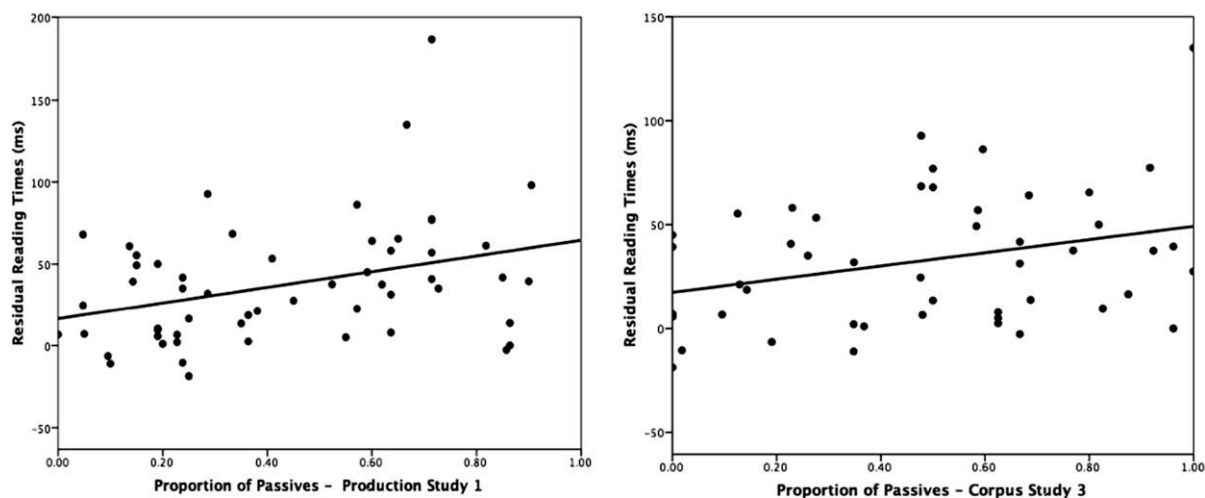


Fig. 6. Scatter plots from Study 5 showing the relationship between production preferences and reading comprehension.

the distributional regularities showing that animacy and verb type are both important, then a more complicated pattern of results should obtain. First, for theme–experiencer verbs, passive structures are more likely with nouns of mismatching animacy. Thus object relatives with these verbs should be more difficult to comprehend in the context of mismatching nouns than in the context of two animate nouns. This follows from the claim that the activation strength of a given pattern of role-to-argument mapping depends on its contingent probability. Second, theme–experiencer verbs in any configuration should be more difficult than agent–theme verbs, because the relative likelihood of active object relative clauses is higher for agent–theme verbs than for theme–experiencer verbs, generating less competition between alternative structures. Finally, the likelihood of a verb type occurring in passive structures, given one or another animacy configuration, should account for some variance in comprehension difficulty, because less frequent role-to-argument mappings take longer to activate. In reading theme–experiencer verbs, readers activate their associated passive configurations, so that competition or conflict may arise when the unfolding structure is incompatible with the verbs' typical role-to-argument mappings.

4.2.1. Methods

4.2.1.1. Participants. A total of seventy native English-speaking students at the University of Wisconsin-Madison participated in this experiment for extra credit in an introductory psychology course. Participants scoring below 75% correct performance throughout the experiment were excluded from the analyses reported below, resulting in seven participants being removed and a total of 63 subjects included. Compared to the other participants, the excluded participants had both a low overall comprehension accuracy rate for the generally easier filler items. These participants appeared to have read the sentences superficially and therefore, their reading times may not reflect full understanding of the sentence meaning. Note that the pattern of results did not change when fewer participants were excluded.

4.2.1.2. Materials and design. The materials of this study were developed from those used in the production experiment of Study 2 and are listed in the appendix. The same 32 pairs of matched verbs and their accompanying nouns were presented in an object relative clause structure. There were three conditions as exemplified in Table 5, Animate–Animate–Theme–experiencer verb, Animate–Animate–

Agent–theme–verb and Animate–Inanimate–Theme–experiencer verb. Three lists were constructed, each containing one version of each item. Each participant saw an equal number of items in each condition and one version of each item.

4.2.1.3. Procedure. A moving window word-by-word self-paced reading paradigm was used (Just, Carpenter, & Woolley, 1982) in which only one word at a time was visible on the screen and all other non-space characters of the sentence were replaced by dashes. Participants advanced through each word of the sentence by pressing a computer key. Reading times to each word were recorded. Participants read the stimulus sentences and immediately after answered a comprehension question about the content of the sentence. For the stimulus sentences, the questions referred to the content of the relative clause about 70% of the time (e.g., *did the writer anger the critic?*). The 32 stimulus items were intermixed with 64 filler sentences containing a variety of structures such as sentential complements, coordinate structures, etc. Residual reading times were used as dependent variable. These were obtained by regressing word length onto each subjects' reading times per word and then subtracting the expected reading time from the actual reading time. Reading times higher than 2.5 standard deviation of the mean per word position were replaced by the cutoff value within this range.

4.2.2. Results

4.2.2.1. Comprehension responses. Overall, readers responded to about 80% of questions correctly. Among the experimental items, the Animate–Animate–Theme–experiencer condition was the most difficult, with a proportion correct of .70, whereas the Animate–Inanimate–Theme–experiencer condition and the Animate–animate–Agent–theme condition had .81 and .83 proportion correct, respectively. A one-way repeated measures ANOVA with these conditions as the main factor and proportion correct as the dependent variable revealed a significant main effect of condition ($F(2,124)=11.54, p<.0001$; $F(2, 62)=7.92, p=.001$). Planned contrasts indicated that the Animate–Animate–Theme–experiencer condition was significantly different from the remaining two conditions, all $p's < .05$. These results suggest that when answering comprehension questions, the thematic roles of the two animate nouns were more difficult to retrieve for theme–experiencer verbs. This may be due to the fact that the thematic roles assigned by the verb could have potentially applied to either animate noun (e.g., critics and writers can anger each other). The thematic roles of agent–theme verbs in contrast, were better supported by world knowledge (e.g., typically critics analyze writers), making them easier to retrieve.

4.2.2.2. Reading times. Only reading times on trials with correct question responses were included in the analyses (analyses including all trials were also conducted, and an identical pattern of results was obtained). To perform overall statistics across several word positions, we analyzed a region containing the relative clause verb, the main auxiliary verb of the sentence, and the following verb. A mixed

Table 5
Example stimulus item from Comprehension Study 6.

Example sentence	Animacy and verb type condition
The writer that the critic angered had written novels...	Animate–Animate–Theme–experiencer
The writer that the critic analyzed had written novels...	Animate–Animate–Agent–theme
The writer that the review angered had written novels...	Animate–Inanimate–Theme–experiencer

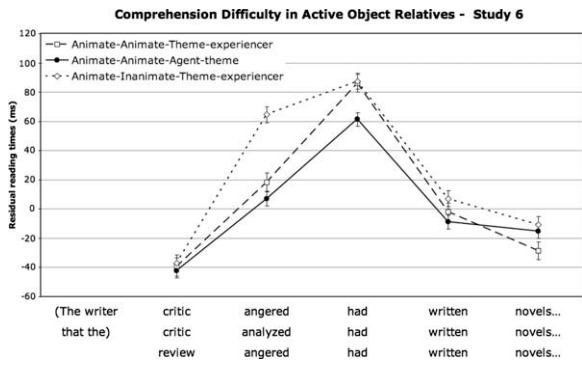


Fig. 7. Mean residual reading times per word position for active object relative clauses as a function of verb type and animacy configuration in Study 6. Error bars indicate standard error.

3 × 3 design with residual RT as dependent variable and the Animacy-Verb Type conditions (Animate-Animate-Theme-experiencer, Animate-Animate-Agent-theme and the Animate-Inanimate-Theme-experiencer) and Word Position as factors revealed a main effect of Animacy-Verb Type condition ($F(2, 370) = 11.62$, $MSE = 41882.51$, $p < .0001$; $F(2, 186) = 7.86$, $MSE = 16494.08$, $p = .0005$), a main effect of Word Position ($F(1, 185) = 27.52$, $MSE = 273099.15$, $p < .0001$; $F(2, 93) = 71.46$, $MSE = 163711.54$, $p < .0001$) and an interaction ($F(4, 370) = 2.59$, $MSE = 9339.14$, $p = .03$; $F(4, 186) = 2.89$, $MSE = 6079$, $p = .02$). Residual RTs are shown in Fig. 7 and

averaged raw reading times per word position are given in Table 6. Further one-way comparisons at the relative clause verb position revealed a significant main effect of condition ($F(2, 124) = 7.69$, $MSE = 44147$, $p = .0007$; $F(2, 62) = 8.07$, $MSE = 18787.01$, $p = .0008$), with the Animate-Inanimate-Theme-Experiencer condition taking significantly longer than the other two conditions in both by-items ($p < .01$) and by-subjects analyses ($p < .005$). At the main auxiliary verb position, there was a main effect of condition ($F(2, 124) = 3.04$, $MSE = 10538.58$, $p = .05$; $F(2, 62) = 3.21$, $MSE = 8517.99$, $p = .05$) with the Animate-animate Agent-theme condition being faster than the other two conditions in the by-subjects ($p < .04$) and the by-items analyses ($p = .02$ and $p = .06$). Overall, the Animate-Inanimate-Theme-experiencer condition was more difficult at the relative clause verb position, but the Agent-theme condition was easier than the two Theme-experiencer conditions at the main auxiliary verb. No other effects were found in the verb region. The results suggest that animacy considerations were relevant at the relative clause verb position, whereas differences across verb types were found at the main auxiliary verb. This result is consistent with previous results showing early semantic effects associated with animacy at the relative clause verb (Gennari & MacDonald, 2008).

4.2.2.3. *Regression analyses.* To test whether the degree to which comprehension difficulty correlated with the rate of role-to-argument mappings in passives in different animacy configurations, we regressed the proportion of pas-

Table 6
Raw mean reading times for each word position in Study 6.

Condition	Word position within relative clauses and main verb phrases				
	Noun	Verb	Auxiliary	Main verb	Next
Animate-Animate-Theme-experiencer	315.96	387.50	407.37	346.15	315.79
Animate-Animate-Agent-theme	316.75	380.92	384.35	335.39	327.02
Animate-Inanimate-Theme-experiencer	324.07	429.49	405.83	356.70	329.78

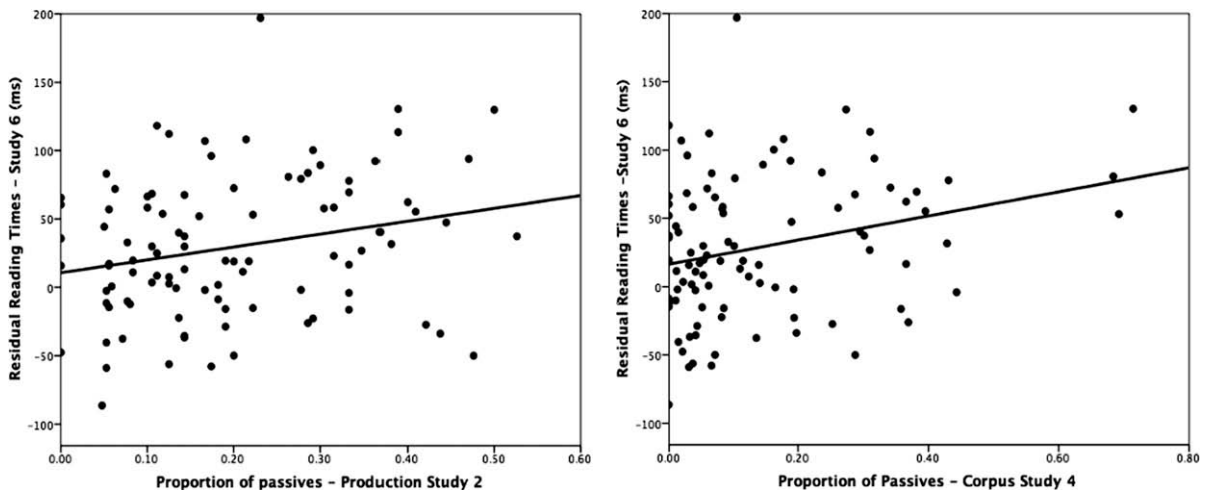


Fig. 8. Scatter plots from Study 6 showing the relationship between production preferences and reading comprehension at the relative clause verb.

sives for each verb in each animacy configuration obtained from corpus Study 4 and production Study 2 onto the residual reading times of the relative clause verb of the current study. We picked this position for the same reason as in Study 5: the largest difficulty effect (and thus substantial variance that production measures could potentially account for) was found here. Example scatter plots are shown in Fig. 8. The proportion of passive productions for each verb in each animacy configuration from Study 2 (calculated from the total of passives and object relative productions for each verb) significantly predicted residual reading times ($F(1, 94) = 5.80, p = .02, R = .24$), indicating the comprehension difficulty was partially explained by production preferences. From corpus Study 4, we used two measures contingent on animacy configurations, one obtained from the overall proportions, including main and relative clauses, and another including the proportions found only in relative clause structures (again calculated from the total of passives and object relative productions for each verb). These regressors also accounted for significant amount of variance in reading times ($F(1, 94) = 7.63, p = .007, R = .27; F(1, 92) = 4.40, p = .04, R = .22$), indicating that comprehension difficulty was partially explained by distributional patterns.

4.2.3. Discussion

The results showed that theme–experiencer verbs were more difficult to comprehend when occurring with nouns of mismatching animacy, and they were in general more difficult than agent–theme verbs in object relative clauses. Verb type and animacy configuration interacted in determining comprehension difficulty, as their role differed across word positions in the sentence: At the relative clause verb, integration into the current representation is costly if an inanimate participant has been processed. In contrast, at the main auxiliary verb, theme–experiencer verbs are more difficult than agent–theme verbs irrespective of the animacy configuration. This result suggests that different sources of information (noun animacy and verb semantics) play a role at different positions, consistent with previous results showing both early sensitivity to noun animacy within object relative clauses (Gennari & MacDonald, 2008) and semantic effects at the relative clause verb, particularly in the context of two animate nouns (Grodner & Gibson, 2005; Gordon et al., 2001). Semantic integration between the relative clause verbs and nouns thus starts taking place at this position, typically continuing over the next word. Our current results in addition suggest that the fit between the animacy configuration and the typical role-to-argument mapping of the verbs plays a part in this integration process, hence the correlation with the verbs' preferences in each configuration. Overall, the results are consistent with the predictions of the PDC approach in that production preferences and distributional patterns in the language explain comprehension difficulty.

5. General discussion

In several studies, we have shown how production preferences within object relative clauses are modulated

by verb type and noun animacy, how production results in the laboratory are mirrored in broad language corpora, and how the production preferences were linked to comprehension difficulty. In Section 1, Study 1 found that theme–experiencer verbs are more likely to be produced in passive constructions than agent–theme verbs. In Study 2, the choice of passive structures varied with both verb type (agent–theme verbs were more often produced in active structures) and animacy (more passives were produced with nouns of mismatching animacy than with nouns of the same animacy). The corpus studies in Section 2 showed similar preferences. The comprehension studies of Section 3 then related production preferences and comprehension difficulty. Specifically, Study 5 showed that verb types' passivization rates in Study 1 and corpus Study 3 significantly predicted reading times in comprehension of object relative clauses. Finally, Study 6 showed that in reading object relatives, difficulty was also modulated by both the animacy configuration and the verb type within the relative clause. Critically, comprehension difficulty was predicted by the likelihood of a verb occurring in passive structures, given an animacy configuration, which was obtained from production Study 2 and corpus Study 4.

This work has had two foci, first to explore structure choices in production and second to examine the consequences of those choices on comprehension. In the following sections, we consider each of these points in turn.

5.1. Production mechanisms and distributional patterns

Previous research has shown that relatively more salient or accessible nouns are often mapped onto subject position in the sentence because they are easier to retrieve from memory (Clark 1965; Bock, 1982; Bock, 1987; Bock, 1986; Bock & Loebell, 1990; Bock & Warren, 1985; Bock et al., 1992; Ferreira, 1994). With ordinary agent–theme verbs, both the animacy and the conceptual salience of the agent role cause the animate agent participant to be positioned in subject position, resulting in an active construction. With theme–experiencer verbs, however, animacy and thematic role accessibility forces interact, particularly when the theme–cause–argument is animate, as more actives are produced in such cases (Ferreira, 1994). The studies reported here indicate that even with the greater restrictions on word order in relative clauses, there are still substantial effects of animacy and verb type on relative clause structure, similar to those in main clauses. Our results are thus consistent with relative accessibility considerations: the animate noun bearing the most prominent semantic role relative to other nouns in the message is mapped onto the subject position of the relative clause, resulting in actives (agent–theme verbs) or passive structures (theme–experiencer verbs), provided that discourse constraints are satisfied.

The most interesting case for accessibility-based production mechanisms is found in structures with two animate nouns, where the strong influence of animacy is balanced out. Theme–experiencer verbs in these structures show a reduction in passive preferences compared to cases of mismatching animacy: in Study 2, there were as many

passive structures as active object structures for theme–experiencer verbs. The same pattern was found in main clauses for theme–experiencer verbs in corpus Study 4. This reduction suggests a degree of competition between the information coming from each of the nouns. The animacy of the theme–cause argument may compete with the experiencer argument for the subject position and modulate its relative accessibility, resulting in an unstable preference. Although the precise mechanism operating in relative clause production needs further study, the accessibility considerations put forward here can go some way towards explaining the production preferences in the current production studies.

Accessibility-based mechanisms also appear to operate in corpus productions across numerous speakers and discourse contexts, as both laboratory preferences and corpus distributions were similarly modulated by verb type and animacy. Of course discourse information structure can exert additional influences on accessibility, e.g., entities that are presupposed/given in the context are typically more accessible and therefore occur in prominent positions (Prat-Sala & Branigan, 2000; Fox & Thompson, 1990; Bock & Irwin, 1980). But these additional influences in natural discourse productions do not seem to oppose animacy and verb type influences; in fact, they often are convergent with these influences (Prat-Sala & Branigan, 2000). One reason for this is that animacy, event role prominence (agent or experiencer) and discourse salience often correlate with one other, resulting in converging production preferences: The things talked about and presupposed in the discourse are often animate participants in prominent semantic roles (Bock et al., 1992), thus resulting in broadly similar structure preferences as those in laboratory productions.

One place where animacy and verb type did not have identical repercussions across our production and corpus studies was in active object relatives. These relatives generally showed a reduced pattern in the animate–animate configuration, compared to the overall corpus pattern in main active clauses and the pattern in production Study 2 (cf. Figs. 2–4). This is likely because object relative clauses occur in more specific discourse contexts than those in Study 2 and than in active main clauses in general. Object relative clauses are felicitous when the head noun is the topic (the thing talked about), the subject of the relative clause is presupposed in the discourse and the relative clause is used to relate these two discourse entities (cf. Fox & Thompson, 1990). This explains why object relatives tend to occur with inanimate heads, which are rarely presupposed in discourse, and pronominal subjects such as *I* or *you*, which typically are presupposed (Real & Christiansen, 2007). Thus, felicitous discourse conditions for producing object relatives with two animate nouns are rare in our and others' corpus studies (Mak et al., 2002; Fox & Thompson, 1990; Roland et al., 2007). These observations suggest that the relatively large preference for object relatives in our production Study 2 compared to the corpus distributions likely reflects the influence of lexical conceptual salience (derived from animacy and role prominence) due to the nature of the task, but is less representative of relative clause productions in discourse contexts. Interest-

ingly, the results of Study 2 match those found in main clauses in the corpus, suggesting that though the task might have affected the overall rate of object relatives, it still revealed the same sort of lexical influences operating in main clauses.

5.2. Distributional patterns and comprehension mechanisms

The finding that comprehension difficulty in object relatives was modulated by animacy and verb type and was correlated with the likelihood of producing a passive structure is consistent with the PDC approach advocated here. The different animacy configurations in relative clauses affect the viability of alternative interpretations, e.g., potential thematic roles for the nouns being read (see Gennari & MacDonald 2008), and critically, the distributional properties of the verbs activate specific patterns of mapping thematic roles to arguments (e.g., experiencers mapped onto subjects of passives). The partial interpretations (or expectations) elicited by animacy configurations such as *the director that the critic...* fit the mapping patterns of agent–theme verbs but not those of theme–experiencer verbs. When a theme–experiencer verb is eventually encountered, frequent role-to-argument mappings associated with the verb are activated and conflict with the unfolding input. Competition between alternative interpretations (thematic roles) thus takes place until one is adopted. The differences in comprehension difficulty across animacy configurations and verb types can thus be explained by the contingent probabilities of the alternatives in each case as derived from linguistic experience.

These results, and the PDC approach, are consistent with the constraint satisfaction accounts of sentence processing. Whereas constraint satisfaction accounts have typically been applied to other more obvious syntactic ambiguities (see MacDonald & Seidenberg, 2006, for review), it has recently been extended to account for comprehension difficulty in object relative clauses (Gennari & MacDonald, 2008; Kidd et al., 2007; Real & Christiansen, 2007). Our results indicate that animacy and the frequent role-to-argument mappings associated with verbs provide probabilistic information modulating the relative likelihood of an interpretation. Verbs that tend to assign specific roles to the subject position of passive constructions are difficult to read when occurring in active structures (see Cupples, 2002 for similar results). As in constraint satisfaction approaches, the probabilistic information derived from distributional patterns does not always have the same effect if other additional factors also play a role (MacDonald et al., 1994). The activation strength of a low-frequency interpretation, for example, can be boosted if that interpretation is primed from the discourse context, thus resulting in less difficult comprehension (for networks modeling interactions between frequency and contexts, see Kawamoto (1993) and McRae et al. (1998).

From the constraint satisfaction perspective, there is no single source of comprehension difficulty in object relative clauses such as the temporary ambiguity at the pronoun *that* (Traxler et al., 2002), the distance between noun–verb relations (Gibson, 1998; Grodner, Gibson, & Tunstall, 2002;

Grodner & Gibson, 2005) or the similarity-based retrieval at verb positions (Lewis & Vasishth, 2005; Van Dyke & Lewis, 2003; Van Dyke, 2007; Lewis, Vasishth, & Van Dyke, 2006; Gordon et al., 2001; Gordon et al., 2004). Instead, our results suggest that comprehension difficulty depends on the degree to which the viability of alternative interpretations vary as a function of the particular distributional properties of the words being read, including noun animacy, verb meaning, and thematic fit between nouns and verbs. Returning to the question raised in the introduction concerning the relative role of experiential vs. innate architectural properties in explaining sentence comprehension, we see the PDC as offering an argument for a central role for experience, but not for the abandonment of all architectural constraints on comprehension. That is, it must be the case that there are computational limitations that are taxed by difficult sentences, and in this sense all parsing approaches have some basis for agreement that the architecture of the sentence processing system must affect comprehension behavior. On the other hand, our account emphasizes the role of experience with the distributional patterns of the language in the comprehension process, including experience with specific lexical/structure pairings, while the memory-based accounts have generally (though not entirely) emphasized the general difficulty of certain syntactic structures independent of specific lexical items and comprehenders' experiences. An important role for future research is an improved specification of the interaction between the comprehension architecture and the information gleaned from learning about distributional regularities.

5.3. Relation between production and comprehension through learning

The PDC emphasizes the role of learning distributional patterns in comprehension, but production mechanisms are themselves sensitive to distributional properties of words in sentence types (Stallings, MacDonald, & O'Seaghdha, 1998; Kidd et al. 2007). Moreover, structure choice in production is influenced by prior utterances (often called structural persistence or syntactic priming), both when these experiences stem from the speaker's prior productions and when the experiences stem from comprehension (Bock, Dell, Chang, & Onishi, 2007). These results suggest that both production and comprehension processes are shaped by prior experiences. This line of argument has been supported by Chang, Dell, and Bock (2006) and Bock et al. (2007), who argued that language learning and production performance stem from the same processing mechanisms, and that the same abstract structural knowledge supports both types of processes. We view this as an attractive framework for investigating the mutual influences on comprehension and production, but the existence of these mutual influences identifies a potential circularity in the PDC approach: How can production constraints play a causal role in comprehension behavior if those production constraints are themselves shaped by experience, including comprehension experience?

Though this question is clearly an important topic for future research, our initial hypothesis is that production

constraints tend to have a greater effect on comprehension (the PDC) than in reverse, for two broad reasons. First, unlike comprehension, production continually involves making (unconscious) choices about what to utter – what structure, lexical items, etc. to convey a message. Comprehenders may occasionally modulate these choices, e.g., by asking for clarifications or repetitions, but on balance, production has the most direct effect on the distributional regularities in the input. Second, language production is a more difficult process than comprehension, as evidenced by numerous differences between these skills. Production skills are acquired later than comprehension skills in childhood (Fenson, Dale, Reznick, Bates, et al., 1994; Bates et al., 1988) and the type of speech errors that abound in language production do not seem to have correlates in comprehension. Lexical substitution errors for example, (e.g., *we forgot to add the list to the roof*) arise from linearization processes that are specific to production. Production also requires the retrieval of words and meaning from memory, a process that tends to easily break down (as attested by tip of the tongue phenomena), whereas the difficulty of accessing meaning, given a percept, is rarely experienced. Moreover, production skills are somewhat more limited in scope than comprehension skills: most people are able to understand languages and dialects other than their own but do not necessarily produce them.

This processing difficulty, plus the availability of choices of what to utter to convey a message, creates a situation in which production choices are often made to ease production demands, not the audience's comprehension, and are thus strongly affected by the accessibility of concepts, words, and phrases during planning. Phrases, word orders and role-to-argument mappings that go against those favored by accessibility and other production mechanisms are more likely to fall out of use or not to come into use at all. This tendency explains, for example, the virtual non-existence of object relative clauses in which the subject of the relative clause is an inanimate noun (e.g., *the director that the movie pleased*), even though such cases can be comprehended and certain verbs clearly co-occur with such arguments. On this view, production constraints remain a strong determinant of production choices, and from there, comprehension constraints. The fact that production itself is also subject to significant learning does not change the nature of these relationships, and thus we view the PDC as a viable hypothesis even though learning occurs throughout production and comprehension. Indeed, we see the potential to pursue research on learning mechanisms, potentially linking to research in acquisition, as an exciting avenue for sentence comprehension and production research.

In this context, the present work suggests that ways of mapping event participants into syntactic structures (role-to-argument mappings) operate in comprehension through sensitivity to language-specific distributional patterns coming from production. Sensitivity to how event roles are mapped into sentence positions is evident at a very early age, even when only a few words can be spoken (e.g., Gertner, Fisher, & Eisengart, 2006; Fisher, 2002), and this knowledge in turn feeds and shapes the learning of production skills (Clark & Hecht, 1983; Chang et al., 2006). This early comprehension-based learning in the

pre-linguistic child is nonetheless consistent with the PDC, in that the distributional regularities that the child is learning stem from the productions (and we hypothesize, largely from production constraints) of speakers who are providing the child's input (Gennari & MacDonald, 2006). Sensitivity to distributional regularities associated with relative clauses has also been demonstrated in child and adult research. Kidd et al. (2007) showed that young children's processing of relative clauses reflects the distributional regularities of their experience and that the rate of acquisition differs for English and German according to the properties of the input. Wells et al. (2009) manipulated adults' experiences with relative clauses over the course of a month and found that the nature of the experience affected interpretation of object relative clauses (see also Wonnacott, Newport, & Tanenhaus, 2008). This research therefore goes beyond correlations between the environment (such as corpus counts) and sentence comprehension and shows that linguistic experience have direct effects on linguistic performance, supporting a significant role for learning in guiding sentence processing.

One important issue for the present approach concerns the computational implementation of the relationship between production and comprehension. Some researchers have recently argued for a common system of shared resources or common processing mechanisms in production, comprehension and acquisition (Seidenberg & MacDonald, 2001; Bock et al., 2007; Chang et al., 2006; MacDonald, 1999; Plaut & Kello, 1999; Rohde, 2002; St. John & McClelland, 1990). For example, Chang et al., proposed a computational model that can learn abstract syntactic generalizations by using error-based learning as the model makes predictions to each input. In this model, linguistic experience shapes the acquisition of production skills and both learning and production share the same architecture. This approach contrasts with proposals arguing that the production and the comprehension systems are separable, although they may interact during comprehension or acquisition (Clark & Hecht, 1983; Pickering & Garrod, 2007). Our data are in principle consistent with either of these approaches, as long as both comprehension and production processes are learned from the same distributional properties of the language. Yet, the role of language-specific role-to-argument mappings in child and adult performance (Tomasello, 2003) and in priming across diverse domains, including production, comprehension and non-linguistic event conceptualizations (Chang et al., 2006; Bock et al., 2007; Gennari, Sloman, Malt, & Fitch, 2002) strongly suggest that the same mappings established through learning are recruited for both production and comprehension, rather than replicating the same knowledge in separate systems.

In sum, we have provided a framework that links comprehension performance with production mechanisms via learned distributional patterns. The structural regularities in the experience, which are shaped in part by production mechanisms, are shown to be an invaluable source of information influencing comprehension processes. This result has implications for language acquisition, theories of adult processing and other domain of cognition such as face perception in that it attributes to experience a

substantial rather than peripheral role and does not necessitate pre-specified domain specific processing mechanisms. Additional attention to learning mechanisms and the nature of production constraints, including computational modeling of both comprehension and production learning, will be crucial for future work in the PDC, and for an understanding of comprehension and production processes more generally.

Appendix

- | | | |
|---|---|--|
| 1 | a | The teacher that the headmaster annoyed has decided to retire next year |
| | b | The teacher that the headmaster oversaw has decided to retire next year |
| | c | The teacher that the evaluations annoyed has decided to retire next year |
| 2 | a | The doctor that the nurse pleased had asked to be considered for the new position |
| | b | The doctor that the nurse dated had asked to be considered for the new position |
| | c | The doctor that the analyses pleased had asked to be considered for the new position |
| 3 | a | The lawyer that the colleague confused has appealed the state court's decision |
| | b | The lawyer that the colleague criticized has appealed the state court's decision |
| | c | The lawyer that the legislation confused has appealed the state court's decision |
| 4 | a | The diplomat that the official scared has resigned because of some personal reasons |
| | b | The diplomat that the official consulted has resigned because of some personal reasons |
| | c | The diplomat that the treaty scared has resigned because of some personal reasons |
| 5 | a | The detective that the suspect injured had been tracking ex-convicts for a long time |
| | b | The detective that the suspect attacked had been tracking ex-convicts for a long time |
| | c | The detective that the explosion injured had been tracking ex-convicts for a long time |
| 6 | a | The coach that the player impressed has decided to make changes in his team |
| | b | The coach that the player greeted has decided to make changes in his team |
| | c | The coach that the game impressed has decided to make changes in his team |
| 7 | a | The writer that the critic angered had written novels since he was young |
| | b | The writer that the critic analyzed had written novels since he was young |
| | c | The writer that the review angered had written novels since he was young |
| 8 | a | The child that the babysitter dazzled was adopted when he was a new-born baby |
| | b | The child that the babysitter fetched was adopted when he was a new-born baby |
| | c | The child that the fireworks dazzled was adopted when he was a new-born baby |

(continued on next page)

Appendix (continued)

- 9 a The assistant that the boss upset had worked in a law firm for several years
 b The assistant that the boss hired had worked in a law firm for several years
 c The assistant that the fee upset had worked in a law firm for several years
- 10 a The visitor that the woman attracted had come from France the week before
 b The visitor that the woman introduced had come from France the week before
 c The visitors that the museum attracted had come from France every year
- 11 a The candidate that the governor infuriated had been trying to get approval from the media
 b The candidate that the governor championed had been trying to get approval from the media
 c The candidate that the debate infuriated had been trying to get approval from the media
- 12 a The goalkeeper that the referee embarrassed was regarded as extremely irritable
 b The goalkeeper that the referee suspended was regarded as extremely irritable
 c The goalkeeper that the scandal embarrassed was regarded as extremely irritable
- 13 a The soldier that the captain frustrated had been very obedient and efficient
 b The soldier that the captain enlisted had been very obedient and efficient
 c The soldier that the training frustrated had been very obedient and efficient
- 14 a The accountant that the chairman irritated had arrived at the company years ago
 b The accountant that the chairman lectured had arrived at the company years ago
 c The accountant that the budget irritated had arrived at the company years ago
- 15 a The politician that the analyst shocked has argued intensely against his views
 b The politician that the analyst advised has argued intensely for his views
 c The politician that the incident shocked has argued intensely to explain what happened
- 16 a The girl that the clown frightened had been crying a lot at the party
 b The girl that the clown approached had been crying a lot at the party
 c The girl that the thunder frightened had been crying a lot at the party
- 17 a The journalist that the economist impressed had been writing about the economy for years
 b The journalist that the economist contacted had been writing about the economy for years
 c The journalist that the allegations impressed had been writing about the economy for years
- 18 a The prisoner that the guard enraged had been sentenced to life in prison
 b The prisoner that the guard subdued had been sentenced to life in prison

Appendix (continued)

- c The prisoner that the abuse enraged had been sentenced to life in prison
- 19 a The secretary that the employee embarrassed has been complaining about her co-workers
 b The secretary that the employee telephoned has been complaining about her co-workers
 c The secretary that the affair embarrassed has been complaining about her co-workers
- 20 a The customer that the shopkeeper bothered had received discounts on several items
 b The customer that the shopkeeper assisted had received discounts on several items
 c The customer that the helpline bothered had received discounts on several items
- 21 a The applicant that the manager puzzled has decided to withdraw his application
 b The applicant that the manager evaluated has decided to withdraw his application
 c The applicant that the interview puzzled has decided to withdraw his application
- 22 a The recruits that the commander comforted had been training hard in the south
 b The recruits that the commander mobilized had been training hard in the south
 c The recruits that the transfer comforted had been training hard in the south
- 23 a The administrator that the novice amused was considered a nice person
 b The administrator that the novice obeyed was considered a nice person
 c The administrator that the gossip amused was considered a nice person
- 24 a The boy that the girl charmed had been in love with her for a while
 b The boy that the girl shoved had been in love with her for a while
 c The boy that the story charmed had been in love with a girl for a while
- 25 a The screenwriter that the singer inspired had written two masterpieces before
 b The screenwriter that the singer pursued had written two masterpieces before
 c The screenwriter that the journey inspired had written two masterpieces before
- 26 a The mayor that the reporter outraged had been accused of embezzlement in the past
 b The mayor that the reporter acquitted had been accused of embezzlement in the past
 c The mayor that the inquiry outraged had been accused of embezzlement in the past
- 27 a The team that the athlete amazed was regarded as extremely experienced
 b The team that the athlete initiated was regarded as extremely experienced
 c The team that the Olympics amazed was regarded as extremely experienced
- 28 a The schoolmaster that the pupil concerned had left the school for another job

Appendix (continued)

- b The schoolmaster that the pupil described had left the school for another job
- c The schoolmaster that the remark concerned had left the school for another job
- 29 a The policeman that the teenager alarmed had received several phone calls that night
- b The policeman that the teenager stabbed had received several phone calls that night
- c The policeman that the fighting alarmed had received several phone calls that night
- 30 a The skater that the trainer delighted has been preparing for a major competition
- b The skater that the trainer monitored has been preparing for a major competition
- c The skater that the medal delighted has been preparing for a major competition
- 31 a The trader that the banker disappointed has started a new business abroad
- b The trader that the banker questioned has started a new business abroad
- c The trader that the imports disappointed has started a new business abroad
- 32 a The agent that the major alerted had been working for the CIA
- b The agent that the major ousted had been working for the CIA
- c The agent that the message alerted had been working for the CIA

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