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The interplay between syntactic and non-syntactic structure in language production

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ABSTRACT

Speakers frequently reuse earlier encountered structures. A long-standing view in language production research is that this *structural priming* is driven by the persistence of abstract syntax, independent from unordered, conceptual representations. However, evidence has been building that non-syntactic information can also influence structural choice. Here we examined whether and how the syntactic priming of relative clause structures might interact with the priming of the conceptual category order of adjectives in noun phrase production. Study 1 found that speakers are more likely to produce relative clause structures (*spotted bow that's green*) after having heard relative clause structures (*striped lock that's blue*) as opposed to an alternative structure (*striped blue lock*), and they also tended to repeat the conceptual order of the prime, with more pattern-first orders after pattern-first primes than after color-first primes. Critically, we found larger syntactic priming when the conceptual order of the prime persisted more in the target and larger conceptual order priming when the syntactic structure of the prime persisted more in the target. Studies 2 and 3 found that conceptual category order priming can be enhanced by adjective overlap as well as noun overlap between prime and target, whereas syntactic priming can only be enhanced by noun overlap. These results supported the interactive priming account: Although the syntactic structure and the conceptual order are represented at different levels and hence can be activated independently, the link between them is also primed, which enhances priming at both levels.

Introduction

Much evidence indicates that speakers tend to reuse previously encountered structures. One of the earliest experimental demonstrations of this tendency, often referred to as *structural priming,* is found in Bock (1986a), who reported that speakers are more likely to produce passive forms such as *The church is struck by lightning* (as opposed to active alternatives like *Lightning strikes the church*) after having heard passive forms than after having heard active forms in the preceding trial. In the same study, Bock also provided evidence for the priming of so called *dative* or *ditransitive* structures, which in English can alternate between double object constructions (*A rock star sold an undercover agent some cocaine*) and prepositional object constructions (*A rock star sold some cocaine to an undercover agent*). Since this demonstration, structural priming has been observed for many other constructions (e.g., V.Ferreira, 2003; Hartsuiker & Westenberg, 2000; Konopka & Bock, 2009), in and across different languages (e.g., Hartsuiker et al., 2004; Kantola & Van Gompel, 2011; Loebell & Bock, 2003) or modalities (e.g., Branigan et al., 2000; Segaert et al., 2012) (see Branigan & Pickering, 2017; Mahowald et al., 2016; Pickering & Ferreira, 2008, for reviews and meta-analysis).

A controversial issue concerns the nature of the representation that is primed. Language production proceeds in stages, involving different levels of representation (Bock & Levelt, 1994; Dell, 1986; DeSmedt, 1990; Garrett, 1975; Kempen & Hoenkamp, 1987; Levelt et al., 1999; Levelt, 1989). According to the sentence production model proposed by Bock and Levelt (1994), speakers activate their intended message during *conceptualisation*, which serves as input to *grammatical encoding*, during which speakers assign syntactic roles and surface positions to the lexical items retrieved from the mental lexicon. Subsequent processes include *phonological encoding*, whereby speakers plan the phonological structure of the sentence prior to articulation. Earlier studies tended to focus on the role of *autonomous syntax* during grammatical encoding (Garrett, 1975; 1980), postulating that structural priming is driven by the perseverance of syntactic structure, abstracted from non-syntactic features of the utterance (Bock, 1986a; Bock et al., 1992; Pickering & Branigan, 1998). On this view, structural priming is primarily driven by *syntactic priming*.

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Indeed, speakers persevere with the syntactic structure of the prime, despite differences in tense, aspect, and number between the *prime* (or the utterance encountered earlier) and the *target* (or the to-be-produced utterance) (Bock, 1986a; Pickering & Branigan, 1998). Similarly, structural priming has been found without repetition of closed-class words (e.g., *The secretary baked a cake for her friend* primes *The girl handed a paintbrush to the boy* as much as *The secretary took a cake to her friend* does, Bock, 1989; Fox Tree & Meijer, 1999) or open-class words (Bock, 1986a; Pickering & Branigan, 1998), suggesting that it is the surface syntax, not the identity of the prepositions, that is primed. The effect does not appear to be dependent on prosodic similarity, either: *Susan brought a book to Stella,* but not *Susan brought a book to study,* primes prepositional object structures (Bock & Loebell, 1990).

Moreover, findings suggest that syntactic structure is repeated despite differences in event or thematic roles (Bock & Loebell, 1990; Messenger et al., 2012; but see Ziegler et al., 2019). For example, Bock and Loebell (1990) found that sentences with prepositional-locatives such as *The woman drove her Mercedes to the churches* prime sentences with prepositional-dative structures such as *The woman gave her Mercedes to the churches*, where the prepositional object denotes a *recipient* rather than a *location*. Similarly, Messenger et al. (2012) reported that passives with agent-patient verbs such as *The king is being scratched by the tiger* are elicited as much following passive primes with theme-experiencer verbs such as *The girl is being shocked by the sheep* as following passive primes with agent-patient verbs such as *The girl is being hit by the sheep* in children. This might be because the thematic roles contrasted in these studies are similar (e.g., both *recipients* and *locations* are the *goals* of transfer of possession, e.g., Jackendoff, 1983). However, Bock and Loebell reported that passive forms were primed by intransitive-locative primes such as *The 747 was landing by the control tower* as much as passive primes such as *The 747 was alerted by the control tower*. The *by*-phrases in locatives and passives denote clearly different meanings (locations vs agents). These findings strongly supported the view that it must be the surface syntactic forms, rather than meanings, which drive structural priming.

Meanwhile, evidence has been building that structural priming can also be driven by non-syntactic information (Bernolet et al., 2009; Bock et al., 1992; Cai et al., 2012; Chang et al., 2003; Fleischer et al., 2012; Griffin & Weinstein-Tull, 2003; Heydel & Murray, 2000; Köhne et al., 2014; Pappert & Pechmann, 2014; Scheepers et al., 2011; Salamoura & Williams, 2007; Vernice et al., 2012; Ziegler & Snedeker, 2018). For instance, using so-called *spray/load* verbs, Chang et al. (2003) showed that sentences with location-theme orders such as *the farmer heaped the wagon with straw* occurred more frequently after sentences with location-theme orders such as *the girl rubbed the table with polish* than after sentences with theme-location orders such as *the girl rubbed polish onto the table*. Since both orders share the same syntactic structure (NP-V-NP-PP), the effect cannot be due to syntactic priming. Moreover, thematic role orders are primed even between sentences that differ in syntax (Cai et al., 2012; Fleischer et al., 2012; Hare & Goldberg, 1999; Salamoura & Williams, 2007). Hare and Goldberg (1999) showed that sentences such as *The officers provided the soldiers with guns* prime double-object dative forms (e.g., *The man gave the child a present*) rather than prepositional dative forms (e.g., *The man gave a present to the child*). *Provide-with* sentences have the same phrasal structure (VP NP PP) as prepositional object dative forms, but they have different thematic role orders (recipient-theme vs theme-recipient). On the other hand, *provide-with* sentences have the same thematic role orders as double object dative forms, but they differ in syntactic structure (VP NP PP vs VP NP NP). Hence, the fact that *provide-with* sentences prime double object structures rather than prepositional object structures indicates that thematic role order priming can override syntactic priming. Furthermore, Ziegler et al. (2019) reported that whilst *by*-phrase locatives such as *The 747 was landing by the control tower* prime passives, the use of other locatives such as in *The 747 was landing next to the control* do not prime passives. Hence, abstract syntax alone may not be sufficient to cause structural priming.

The current study

The overarching aim of the current study was to investigate whether and how syntactic priming might be related to the priming of non-syntactic information. One reason for postulating the independence of syntactic priming from non-syntactic priming lies in findings that syntactic priming does not interact with the mapping of animacy features (Bock et al., 1992; Bock & Loebell, 1990; Chen et al., 2020; Huang et al., 2016; though see Gámez & Vasilyeva, 2015). For instance, in Bock et al. (1992), participants heard and repeated either an active (1 & 2) or passive (3 & 4) prime sentence. They then described a target picture using an active (5) or passive (6) structure.

Prime
(1) The boat carried five people.
(2) Five people carried the boat.
(3) The boat was carried by five people.
(4) Five people were carried by the boat.
Target
(5) The alarm awakened the boy.
(6) The boy was awakened by the alarm.

Participants were more likely to choose an inanimate-first active target response (5), assigning an inanimate entity to the first-mentioned subject, when the prime sentence had an inanimate first-mentioned subject (1 & 3) rather than an animate first-mentioned subject (2 & 4). This was the case regardless of whether the prime and the target had the same structure (both active) or different structures (the prime was a passive). This result was incompatible with predictions from transformational grammar about function assignment (Chomsky, 1981), which are irrelevant for our current concerns. Critical to our concern, Bock et al. took this finding as evidence for a separation between the priming of the concept-to-syntax mapping and the processes underpinning structural choice; passive primes (3 & 4) elicited passive responses (6) more often than active primes did (1 & 2), regardless of the animacy match between the subject of the prime and the subject of the target. However, active–passive alterations are critically dependent on the thematic role-to-syntax mapping. Hence, when an inanimate-subject passive sentence such as (3) primes a passive structure in the target (6) via syntactic priming, it is not possible to persevere with the animacy feature, because the inanimate entity in the target is the agent, which cannot be the subject of a passive sentence. Conversely, an animate-subject active prime (2) might elicit an animate-subject passive target (6) via animacy feature mapping, but when this happens, the syntactic structure cannot persist in the target, because the animate subject in the target is the patient, which cannot be the subject of an active sentence.[1] Hence, because active–passive alternations are constrained by thematic roles, and the thematic role and the animacy feature are confounded in the target (the agent was always inanimate, and the patient was always animate), animacy feature priming and syntactic priming can only independently influence structural choice (*unless* speakers are free to alter the thematic roles, which would change the meaning of the sentence). Thus, the findings from Bock et al. (1992) do not inform whether

[1] Neither the animacy feature nor the syntax of the inanimate-subject active prime (1) can elicit the animate-subject passive target in (6). An animate-subject active prime (2) can elicit the animate-subject passive in (6) via animacy feature mapping, but not via syntactic priming (the prime and target differ in syntax). An inanimate-subject passive prime (3) can elicit (6) via syntactic priming only, but not via animacy feature mapping (the prime and target differ in animacy feature mapping). An animate-subject passive prime (4) can elicit (6) via both animacy feature mapping and syntactic priming. Hence, assuming that these effects are additive, animacy feature mapping and syntactic priming can show main effects. But no existing theory, other than transformational grammar, would predict an interaction.

syntactic priming interacts with the conceptual-level processing. In the current study, we therefore focused on noun phrase production. As explained below, this allowed us to examine the relationship between syntactic priming and non-syntactic priming, without confounding them.

Syntactic priming in noun phrases

Cleland and Pickering (2003) demonstrated syntactic priming in noun phrases. Participants were more likely to use relative-clause descriptions such as *square that's red* after the confederate had produced relative clause descriptions such as *diamond that's green* as opposed to adjective noun descriptions such as *green diamond*. The effect was stronger when the prime and the target had the same noun (i.e., *square that's green* was the prime for the target, *square that's red*) than when they had different nouns, whilst whether prime and target had the same adjective or not did not clearly influence priming (i.e., non-significant by subject analyses but significant by item analyses). Note that the noun boost effect was *not* due to an enhanced lexical availability of the repeated noun, leading to a general increase in the relative clause responses, where the noun occurs first. If this had been the case, noun repetition after *green square* should also have increased relative clause responses. But this is not what was found. In fact, Cleland and Pickering found that semantic similarity between the prime and target nouns also enhances syntactic priming; the likelihood of the primed relative clause structure being reused was higher when the prime noun and the target noun had the same semantic categories (e.g., *sheep* vs *goat*) than when they had different semantic categories, though the interaction was weaker compared to when the same noun was repeated.

Cleland and Pickering (2003) interpreted their results in terms of the *residual activation model* (Pickering & Branigan, 1998). In this model, syntactic structures are represented as *combinatorial nodes,* in association with the lexical properties, *lemmas*, of the head noun. This is illustrated in the diagram in Fig. 1. The *N,RC* node represents relative clause structures, and the *A,N* node represents adjective-noun structures. Both nodes are linked to the noun lemma, *square*. The probability of a particular structure being selected depends on the level of activation of the node that represents it. Priming increases this probability by increasing the activation of the node. The processing of *square that's green* activates not only the lemma, *square,* but also the *N,RC* node, and importantly, the link that binds them. The assumption is that the activation of these nodes and the binding link remains active, at least temporarily, and this will bias future selection. That is, the residual activation of the *N,RC* node increases the probability of this node being selected again in future, causing *syntactic priming*. This probability is enhanced further if the same noun is repeated in the target, because the *N,RC* node receives additional activation from the residual activation of the link between *square* and the *N,RC* node, causing a *noun boost effect*. The boost effect should be weaker when the target noun is a semantic associate to the prime than when the prime noun is repeated in the target because a semantic associate to the prime noun is less activated than the prime noun itself. As a result, the link between the semantic associate and the primed syntactic node should also be less strongly activated. That is, the strength of syntactic priming is modulated by the level of activation of the associated nodes.

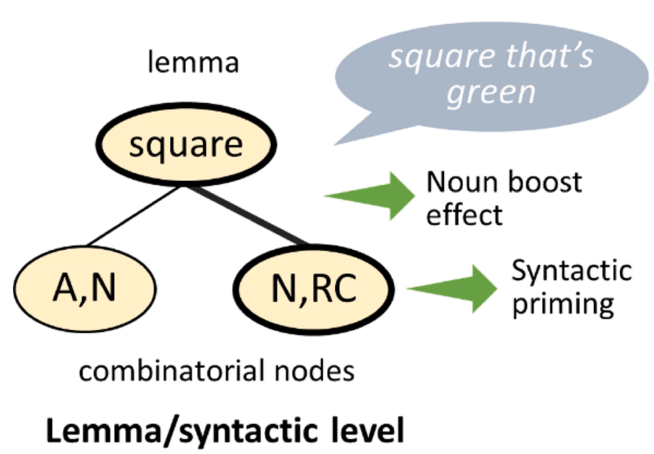

Fig. 1. Residual activation model (adapted from Cleland & Pickering, 2003).

Conceptual (category) order priming in noun phrase

Critically, descriptions such as *square that's red* and *red square* differ not only in the phrasal structure, but also in the order of the conceptual attributes; color is mentioned first in *red square,* whereas it is mentioned last in *square that's red.* Studies have shown that the order of attributes mentioned in noun phrases can be primed (e.g., Goudbeek & Krahmer, 2012; Fukumura, 2018). Specifically, when a noun phrase contains multiple adjectives, the ordering of the adjectives is guided by their conceptual categories (e.g., Culbertson et al., 2020; Dixon, 1982; Hetzron, 1978; Scott, 2002). For instance, in a language with prenominal modification, size-before-color order (*small red car*) is favored over color-before-size order (*red small car*), whereas this can be reversed in a language with postnominal modification. The idea is that adjectives that denote more *absolute* (Martin, 1969), *intrinsic* or *inherent* (Danks & Glucksberg, 1971; Quirk et al., 1985; Whorf, 1945) or *less subjective* (Hetzron, 1978; Scontras et al., 2017) concepts such as color or pattern tend to occur closer to the noun that they modify. Although these preferences, especially those involving scalar or relative adjectives such as size, are relatively fixed (e.g., Danks & Schwenk, 1972), other preferences are more flexible and can be attenuated by different factors including priming (Fukumura, 2018).

Specifically, speakers tend to favor color-before-pattern orders (e.g., *green spotty bow*) rather than the reverse order (*spotty green bow*), not only in languages with prenominal modification (Fukumura, 2018; Tarenskeen et al., 2015) but also in a language with postnominal modification such as Basque (Fukumura & Santesteban, 2017). Color tends to be more salient and over-specified more often than pattern (i.e., *green spotted bow* when *spotted bow* was sufficient for identification) (Fukumura, 2018; Haywood et al., 2003; Tarenskeen et al., 2015), so these preferences can be explained in terms of accessibility-based production models that claim that speakers preferentially place the more salient or accessible information earlier to enable incremental production processes (e.g., Bock, 1986b; Bock & Irwin, 1980; Bock & Warren, 1985; Fukumura, 2018; Ferreira & Yoshita, 2003; McDonald et al., 1993; Prat-Sala & Branigan, 2000; Tanaka et al., 2011). Crucial to the current study, such color-first preferences can be overridden by priming. In a dialogue task, Fukumura (2018) reported that participants were more likely to produce a pattern-before-color order (e.g., *spotted blue bow*) when their conversational partner had produced a pattern-before-color order (e.g., *striped green bow*) rather than a color-before-pattern order (e.g., *green striped bow*). The syntactic structure of the prime was always the same (Adjective-Adjective-Noun), so syntactic priming cannot be the cause of the effect. Although the prime and target always had the same noun, the adjectives were always different. The findings thus demonstrated the priming of abstract conceptual category orders shared by different adjective concepts, or *conceptual (category) order priming.*

Interactive priming account

In the current study, we asked whether and how the syntactic priming of the use of relative clause structures might interact with conceptual order priming for adjective ordering. Suppose you hear a complex description with a relative clause such as *spotted bow that's green,* as opposed to an alternative description with a simpler structure such as *spotted green bow.* If syntactic priming plays a role, then having heard *spotted bow that's green* should increase the likelihood with which you will use a relative clause in the next occasion. If you were primed with the conceptual category order of the adjectives, you would be more likely to repeat the pattern-color order of this description. To consider how these two effects might interact, see the diagram in Fig. 2, which illustrates what we call the **interactive priming account**. Unlike Cleland and Pickering's (2003) residual activation account, this account assumes that speakers represent abstract conceptual category orders at the conceptual level, separate from syntactic structures at the lemma/syntactic level. Hence, in the diagram, the *CP* node represents color-pattern orders, and the *PC* node represents pattern-color orders. At the lemma/syntactic level, the *ANRC* node represents Adjective (A)-Noun (N)-Relative Clause (RC) structures, and the *AAN* node represents Adjective (A)-Adjective (A)-Noun (N) structures.

The key assumption of this interactive priming account is that the same conceptual orders are shared across different syntactic structures. Hence, in Fig. 2, the CP node and PC node at the conceptual level and the AAN and ANRC node at the lemma/syntactic level are orthogonally linked. This means that the processing of *spotted bow that's green* should activate the PC node at the conceptual level, the ANRC node at the syntactic level, and importantly, the link that binds the PC node and the ANRC node. The residual activation of the PC node will cause *conceptual order priming*, increasing the rates of PC orders relative to cases where the prime involved CP order. Likewise, the residual activation of the ANRC node will cause *syntactic priming*, increasing the rates of ANRC structures, relative to cases where the prime had an AAN structure. Critically, the residual activation of the PC-ANRC link should enhance the persistence of the PC-ANRC mapping in the target, leading to *cross-level interactive priming*. That is, when the PC order is activated for in the target, the residual activation of the PC-ANRC link will *boost* the activation of the ANRC node relative to the AAN node at the lemma level, increasing ANRC responses further. Likewise, when the ANRC structure gets activated again in the target, the PC-ANRC link will boost the activation of the PC node relative to the CP node, increasing PC order responses.

Note interactive priming is contingent on whether one of the primed elements, the conceptual order or syntactic structure of the prime, gets selected in the target. Some orders or structures are more likely to be selected than others. Specifically, speakers generally prefer the CP order to the PC order, presumably because color is more salient than pattern and speakers preferentially place more salient information earlier (e.g., Fukumura, 2018). Likewise, AAN structures should be more favored than ANRC structures (cf. Cleland & Pickering, 2003) because AAN structures are simpler and speakers may favor simpler structures. Hence, the baseline activation of the nodes representing the CP order and the AAN structure must be higher than that of their alternatives, and this should put the CP order and the AAN structure at an advantage in subsequent selection. Thus, the likelihood of the CP order being selected after a CP prime in the target should be higher than the likelihood of the PC order being selected after a PC prime in the target. Similarly, the likelihood of the AAN structure being selected in the target after an AAN prime should be higher than the likelihood of the ANRC structure being selected in the target after an ANRC prime. That is, the CP order and the AAN structure are more likely to *persist* from the prime to the target than the PC order and the ANRC structure, respectively. Hence, the interactive priming account predicts the following. We should observe larger syntactic priming if the syntactic structure is primed in association with the CP order than with the PC order. Likewise, conceptual order priming should be larger if the conceptual order is primed in associated with the AAN structure than with the ANRC structure. This is because the higher likelihood of persistence of the CP order or the AAN structure in the target increases the likelihood of interactive priming, which should in turn enhance syntactic priming or conceptual order priming, respectively.

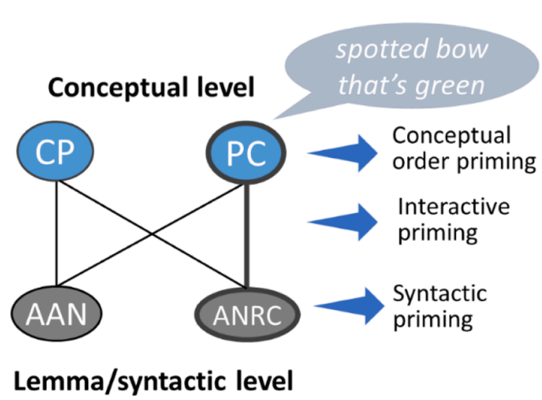

Fig. 2. Underlying representations for interactive priming. CP = Color-Pattern order; PC = Pattern-Color order; AAN = Adjective-Adjective-Noun; ANRC = Adjective-Noun-Relative Clause.

Alternative accounts

We contrasted the interactive priming account with two alternatives accounts. Unlike the interactive priming account, these alternative accounts assume that conceptual representations are "unordered", so there is no abstract conceptual structure that can be associated with syntactic structures. Under these accounts, adjective ordering is determined during *grammatical encoding*, driven by representations that are semantically as well as syntactically specified. Consistent with this, the size-before-color order preference tends to vary, depending on the direction of the head noun determined by the grammar, that is, whether the noun precedes or follows the modifiers (e.g., Hetzron, 1978). Findings also suggest that the violation of such preferences disrupts comprehension similarly to grammatical violations (Kemmerer et al., 2007).

According to the first account, which we call the **two-stage syntactic priming account**, the syntactic structure of a noun phrase must be selected before the adjective order can be determined. This is motivated by the so-called *two-stage* model of grammatical encoding (Bock & Levelt, 1994; Garrett, 1980; Hartsuiker et al., 1999), according to which speakers first compute a linearly unspecified functional structure before assembling the words and phrases linearly. On this account, the production of *striped bow that's blue* entails the activation of an *A,N,RC* node, which specifies the occurrence of adjectives (A), a noun (N), and a relative clause (RC) without demanding a particular order. This is then followed by the activation of an A_PNRC_C node, which elaborates the A,N, RC node by specifying the assembly order, including the adjective category order of pattern (P) before color (C). As illustrated in Fig. 3 (left), the processing of a pattern-first relative clause structure such as *spotted bow that's green* will activate the A,N,RC node, the A_PNRC_C node, and the link that binds them. The activation of the A,N,RC node will increase relative clause responses, and the activation of the A_PNRC_C node will increase PC orders for ANRC structures. The priming of the link between them will further boost the activation of the A_PNRC_C node when the A,N,RC node gets activated again in the target, increasing the rates of PC orders for the ANRC structure further. Critically, the activation of the A_PNRC_C prime node should increase A_PNRC_C responses (*striped bow that's blue*) only; the rate of A_PA_CN (*striped blue bow*) responses, which differ in syntactic structure, should not be affected by the A_PNRC_C prime. This is because the two-stage syntactic priming account assumes that syntactic priming precedes adjective order priming. Hence, syntactic priming (i.e., the higher rate of A,N,RC responses after A,N,RC primes than after A,A,N primes) should *not* be affected by whether speakers choose the same conceptual order as the prime in the target. By contrast, the conceptual order of the prime can only influence adjective ordering when the same syntactic structure is selected in the target.

The second alternative account assumes that syntactic choice will be made in 'one go'. This **one-stage syntactic priming account** is motivated by the one-stage model of constituent structure priming proposed

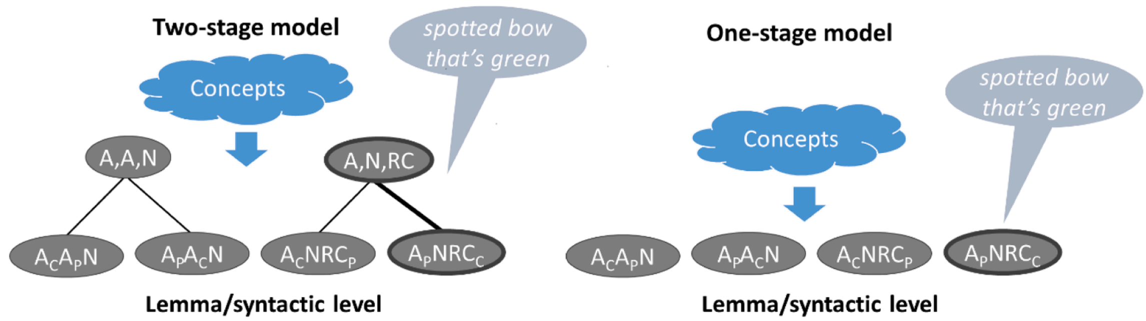

Fig. 3. Two-stage and one-stage syntactic priming accounts. C = Color adjective; P = Pattern adjective, AAN = Adjective-Adjective-Noun; ANRC = Adjective-Noun-Relative Clause; A,A,N = Adjective, Adjective, Noun (with no sequencing information); A,N,RC = Adjective, Adjective, Relative clause (no sequencing information).

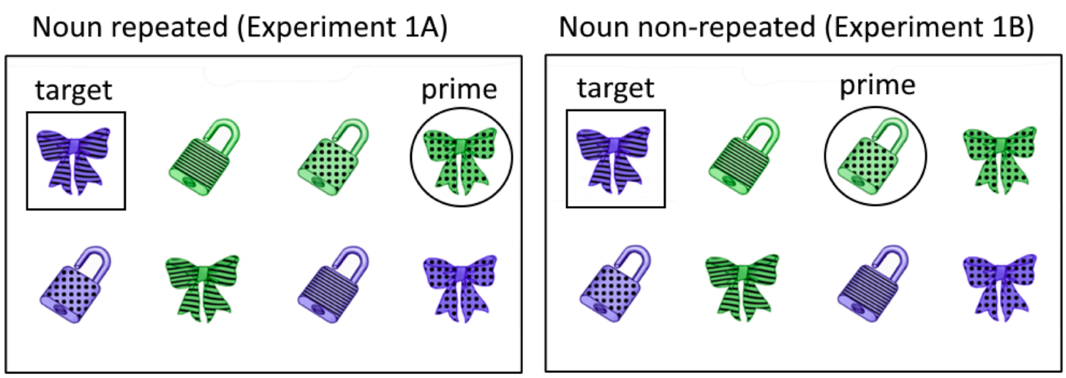

Fig. 4. Example displays of Study 1.

by Pickering et al. (2002), according to which linearly-specified syntactic structures can be generated without involvement of intermediate representations. On this view, both adjective order priming and syntactic priming are driven by the syntactic representations that specify adjective category order. That is, as shown in Fig. 3 (right), primes such as *spotted bow that's green* will activate the A_PNRC_C node directly, increasing A_PNRC_C responses in the target (relative to other primes). A_PNRC_C primes should not elicit A_CNRC_P responses such as *blue bow that's striped*, however, because these structures are represented by different nodes. Likewise, A_PA_CN primes such as *spotted green bow* can only elicit A_PA_CN responses such as *striped blue bow*, but not A_CA_PN responses such as *blue striped bow*. Hence, neither syntactic priming nor conceptual priming can occur in the absence of its counterpart.

To summarize, the current study aimed to examine whether and the extent to which syntactic priming is independent from the priming of non-syntactic representations. Study 1 pitched the interactive priming account against the above-mentioned two alternative accounts, investigating whether and how the syntactic structure of the prime interacts with the conceptual order of the prime on syntactic choice and conceptual order choice. As a preview, the results of Study 1 provided support for the interactive priming account, ruling out the two alternative accounts. Studies 2 and 3 further evaluated the key assumption of the interactive priming account, which is that conceptual order and syntactic structure are represented separately and hence can be differentially boosted.

Study 1

Study 1 examined the relationship between syntactic priming and conceptual order priming, investigating cross-level interactive priming predicted by the **interactive priming account**. In all experiments we used a web-based referential communication task, where participants first heard a *prime* description (e.g., *spotted bow that's green*) in the presence of a visual display such as the one in Fig. 4, in which the objects enclosed in the circle represent the prime objects. Participants then described the target object marked by a square. We varied the syntactic structure of the prime, which had either an Adjective-Adjective-Noun (AAN) or Adjective-Noun-Relative Clause (ANRC) structure. We also manipulated the conceptual category order of the adjectives mentioned in the prime description, which had either a Color-Pattern (CP) or Pattern-Color (PC) order (see Table 1). To maximize the chance of observing syntactic priming (Cleland & Pickering, 2003), in Experiment 1A (Fig. 4 left), prime and target always had the same nouns. In Experiment 1B (Fig. 4 right), prime and target always had different nouns. In both experiments, the prime and target always had different adjectives.

If the prime conceptual order affects adjective ordering choice (*conceptual order priming*), participants should produce more PC orders

Table 1
Example prime descriptions by prime syntax and prime conceptual order in Study 1.

Prime syntax	Prime conceptual order	Experiment 1A: Noun repeated	Experiment 1B: Noun non-repeated
AAN	Color-Pattern (CP)	*Green spotted bow*	*Green spotted lock*
	Pattern-Color (PC)	*Spotted green bow*	*Spotted green lock*
ANRC	Color-Pattern (CP)	*Green bow that's spotted*	*Green lock that's spotted*
	Pattern-Color (PC)	*Spotted bow that's green*	*Spotted lock that's green*

Note. AAN = Adjective-Adjective-Noun; ANRC = Adjective-Noun-Relative Clause.

after PC primes than after CP primes (Fukumura, 2018). If the prime syntax affects syntactic choice (*syntactic priming*), participants should produce more ANRC responses after ANRC primes than after AAN primes (cf. Cleland & Pickering, 2003). According to the **interactive priming account**, these two priming effects interact, leading to larger syntactic priming when speakers repeat the conceptual order of the prime in the target than when they do not and to larger conceptual order priming when speakers repeat the same syntactic structure of the prime than when they do not. Because speakers are more likely to repeat CP orders than PC orders and the AAN structure than the ANRC structure, CP order primes and AAN structure primes should be more likely to cause interactive priming than their counterparts, leading to larger syntactic priming and conceptual order priming respectively. These predictions contrast with the **two-stage syntactic priming account**, according to which the likelihood of syntactic priming should be unaffected by whether speakers adopt the same conceptual order as in the prime or a different conceptual order from the prime, whereas the reverse should not hold: Conceptual order priming should only occur when speakers adopt the same syntactic structure as in the prime. Finally, the **one-stage syntactic priming account** predicts that adjective ordering and syntactic structure are primed in one step, driven by the syntactic structure that specifies adjective ordering. On this view, there should be no syntactic priming when speakers do not adopt the same conceptual order as the prime and no conceptual order priming should be expected when speakers adopt a different conceptual order from the prime.

Data availability

Data, materials, and R scripts are available via: https://osf.io/cs58z/?view_only=1b2db5eb27c74ddb81546f0a9414c3c2.

Method

Participants

We recruited 96 native speakers of British English (48 each for Experiment 1A and 1B) from Prolific (www.prolific.co) in exchange for cash. All participants reported to be university students based in the UK, aged between 18 and 30, and to have no difficulty with processing color and pattern. Data from eight participants were replaced (five for Experiment 1A, and three for Experiment 1B) due to complete recording failure or poor recording quality ($n = 7$) or high error rates in the prime trials (over 25 %) ($n = 1$). The sample size was based on Mahowald et al.'s (2016) power analyses, which indicated that 48 participants and 24 items per experiment should achieve 97 % power to detect a priming effect with lexical overlap.

Materials

Thirty-six experimental items were created. Each item comprised a 4 × 2 display of 8 objects and auditory prime descriptions. Fig. 4 shows example displays, where the objects enclosed in the circle represents the *prime* object that participants had to identify, and the object in the square represents the *target* object that participants had to describe. The pictures in the display were taken from shaded images in Rossion and Pourtois (2004) and applied one of three different colors (red, blue, green) and patterns (striped, spotted, chequered) (Fukumura, 2018; Fukumura & Carminati, 2021). Each display contained pictures of two different object categories, two different colors and two different patterns, such that the combination of these three properties identified the prime and target referents uniquely. In Experiment 1A, the primes and targets always had the same nominal categories (e.g., both were bows), whereas in Experiment 1B they had different nominal categories (e.g., the prime had a lock and target had a bow). In the display, the objects were positioned randomly, subject to the constraint that overall, the prime and target objects should occur in all the positions as equally often as possible (i.e., at least four times but no more than five times).

We manipulated the conceptual order and the syntactic structure of the prime descriptions. See Table 1 for example prime descriptions. In the *CP* (Color-Pattern) order condition, color preceded pattern, whereas in the *PC* (Pattern-Color) order condition, pattern preceded color. In the *AAN* condition, the prime description had an Adjective-Adjective-Noun sequence (e.g., *green spotted bow/spotted green bow*). In the *ANRC* condition, the description had an Adjective-Noun-Relative Clause sequence (e.g., *green bow that's spotted/spotted bow that's green*). This resulted in the four prime conditions (CP-AAN, CP-ANRC, PC-AAN, PC-ANRC). Audio descriptions were generated using ttsmp3.com and we used a male British voice profile ("Brian") with the speech rate set to "slow". In addition, we created 48 filler trials, where the objects were contrasted in size, orientation, and type, but not in color or pattern. To ensure that participants produced enough relative clauses, 25 filler trials had prime descriptions with relative clauses, where the objects' orientation was mentioned (e.g., *the bat that's upside down*; *the large cannon that's facing right*).

Procedure

Following informed consent, participants were given instructions. They were asked to take turns with a hypothetical partner to describe a picture. That is, in each trial, participants listened to an audio recording of an object description 2000 ms after the presentation of the visual display (Fig. 4) and then selected the referent of the description using a mouse key. This triggered the presentation of a square around the target object, which participants had to describe, so that the object could be identified uniquely in the display. Once participants produced a description, they pressed a key to proceed to a new trial. In the instructions, participants were shown example modifiers that could be used to describe different attributes. Participants were also shown different example constructions including those with relative clauses and told that they were free to use different word orders, though they were advised to avoid using locational descriptions (e.g., *the fork on the bottom row*). The whole session lasted for about 25 min (on average) and participants were offered to take a 1–2 mins break halfway through. The experiment was presented using PennController for IBEX (Zehr & Schwarz. 2018), a web-based experiment software. The participants were required to use the Google Chrome or Mozilla Firefox browser on a laptop/desktop. The project was approved by the University of Stirling General University Ethics Panel.

Design

In Experiment 1A, the prime and target objects had the same nominal categories and in Experiment 1B they always had different nominal categories. We used a 2 (prime conceptual order: CP vs PC) × 2 (prime syntactic structure: AAN vs ANRC) repeated measures design for each experiment, leading to the creation of four lists. Together with 48 filler items, 36 experimental items were randomly distributed across each list, each containing one version (condition) of each experimental item and nine items per condition. There was at least one filler item occurring between the experimental trials. In each experiment, 12 participants were randomly assigned to each list.

Scoring

We scored whether participants used an Adjective-Adjective-Noun structure (*AAN*) (e.g., *striped blue bow / blue striped bow*) or an Adjective-Noun-Relative Clause structure (*ANRC*) (e.g., *striped bow that's blue / blue bow that's striped*), and whether color was mentioned first (Color-Pattern, *CP*) or pattern was mentioned first (Pattern-Color, *PC*). This led to four target responses: (1) CP AAN (e.g., *the blue striped bow*); (2) CP ANRC (e.g., *the blue bow that's striped*); (3) PC AAN (e.g., *the striped blue bow*); (4) PC ANRC (e.g., *the striped bow that's blue*). Descriptions were scored as *Others* and excluded from analyses if participants did not produce two adjectives (i.e., the descriptions were underspecified) ($n = 16$) and/or included additional information such as size and orientation (e.g., *the green train that is striped, facing left*; *the large red* *spotted box*) ($n = 3$); participants produced both adjectives in the relative clause ($n = 17$); participants did not use adjectives for pattern (e.g., *the red shirt with stripes*; *the blue pipe that's got spots on*) ($n = 40$) or used a wrong adjective (e.g., *chequered* instead of *striped; blue* for *red*) ($n = 2$); participants altered their response (e.g., *the chequered pram, the red chequered pram*) or used non-target word orders (e.g., *the chequered jumper blue; the green clock and its chequered*) ($n = 17$); participants did not name the object ($n = 4$) or skipped the response ($n = 1$). Cases where participants produced and corrected a naming error (e.g., *the spotted blue circle, sorry, the spotted red circle*) were included, provided that corrected descriptions did not alter the initial word order choice. In total, 100 trials (2.9 %) (Experiment 1A = 26, 1.5 %; Experiment 1B = 74, 4.3 %) were excluded from analyses. The average rate of errors in identifying the prime objects was 1.2 %, indicating that participants were paying attention and understood the prime descriptions.

Results

Fig. 5 reports the percentages of four target responses (i.e., CP-AAN, CP-ANRC, PC-AAN, PC-ANRC) by each prime condition (see Appendix A for response frequencies and standard errors) for **Experiment 1A** (left), where the head noun was always repeated from the prime to the target, and for **Experiment 1B** (right), where the prime and the target always had different nouns. As shown in the figure, each target response occurred most frequently following the prime with the same conceptual order and syntax as the target in both experiments (e.g., CP ANRC responses occurred more often after CP ANRC primes than after other primes). This was confirmed by logit mixed effect analyses (Baayen et al., 2008), implemented in R (version 4.1.1., R Core Team, 2021), on the rates of each target response relative to all other target responses; each target type occurred most frequently after primes with the same conceptual order and the same syntactic structure (all *ps* $\leq$.01, Appendix B). Fig. 5, however, also indicates that participants did not always repeat the syntactic structure and conceptual order from the prime; they produced other combinations than those used in the primes. In the following, we thus examined whether and how prime syntax and prime conceptual order interacted on the binary choice of syntactic structure (AAN vs ANRC) or conceptual order (CP vs PC) in the target.

Analysis overview

To recap our predictions, if *syntactic priming* has an effect, there should be more ANRC responses after an ANRC prime than after an AAN prime. If *conceptual order priming* has an effect, there should be more PC order responses after a PC prime than after a CP prime. Critically, the **interactive priming account** predicts larger syntactic priming with CP order primes than with PC order primes and larger conceptual order priming with AAN structure primes than with ANRC structure primes. These predictions motivated the first set of analyses, which examined whether the effect of prime syntactic structure (AAN vs ANRC) on syntactic choice (AAN vs ANRC) or the effect of prime conceptual order (CP vs PC) on adjective ordering (CP vs PC) interacted with prime conceptual order (CP vs PC order) or prime syntax (AAN vs ANRC), respectively. The second set of analyses then examined whether syntactic priming or conceptual order priming interacted with whether prime and target had the same conceptual order (*conceptual order congruence*) or the same syntactic structure (*syntactic congruence*). The analyses offered a more direct test for the general prediction of the interactive priming account, which is that priming should be stronger when one of the primed elements is repeated in the target than when it is not. The results underpinned the interpretation of the first analyses and the analyses were also motivated by the predictions from the two alternative accounts. The **two-stage syntactic priming account** predicts that the magnitude of syntactic priming should not be affected by whether participants repeat the prime conceptual order in the target, whereas conceptual order priming should only occur when participants choose the same syntactic structure as the prime in the target. By contrast, the **one-stage syntactic priming account** predicts that there should be no syntactic priming when participants adopt a different conceptual order from the prime and no conceptual order priming when participants adopt a different syntactic structure from the prime.

For all analyses, initial models adopted the maximal random effect structure justified by the design (Barr et al., 2013), including all the fixed effects and by-participants and by-items random slopes and random intercepts, whilst supressing correlations between the random effects (Bates et al., 2015a; 2015b; Kliegl, 2014; Singmann, & Kellen, 2020). We then removed any random effect with zero or close-to-zero variances to address potential singularity, though this procedure had little numerical impacts and did not alter the results of the initial models. The fixed effects were mean-centred and standardized to reduce collinearity between the fixed effects (Baayen et al., 2008); like sum coding, centering allows us to interpret the results in terms of main effects and interactions (Baayen et al., 2008) and facilitates convergence in R (Gelman & Hill, 2007).

Syntactic choice

As above, the first analyses examined whether the effect of prime syntax (AAN vs ANRC, coded as 0 and 1, respectively) on syntactic choice (AAN vs ANRC, coded as 0 and 1) (*syntactic priming*) interacted with prime conceptual order (CP vs PC, coded as 0 and 1). The second analyses then examined whether the effect of prime syntax on syntactic choice interacted with a new variable, *conceptual order congruence*, which coded whether participants adopted the same conceptual order as the prime (coded as 1) or a different conceptual order from the prime (coded as 0). Tables 2 and 3 report the frequencies, means and standard

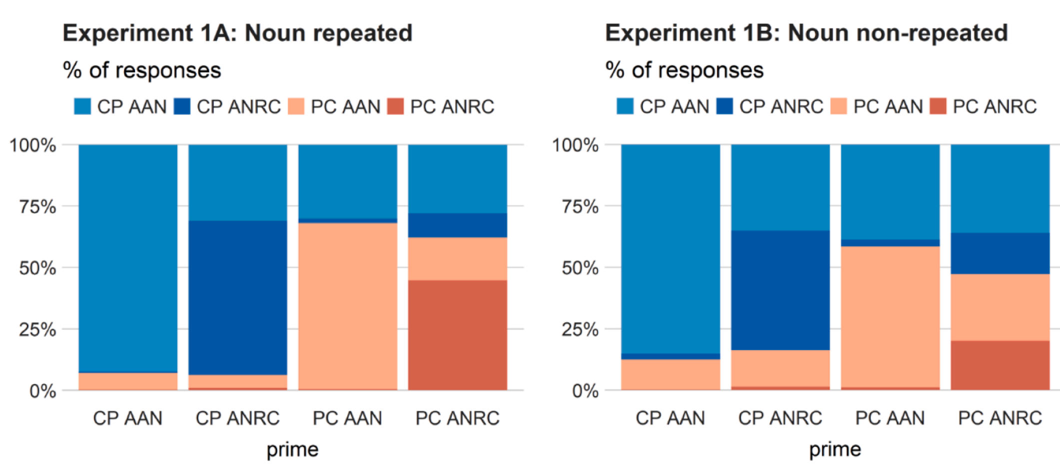

Fig. 5. Percentages of target responses by prime in Study 1 (see Appendix F for response frequencies and standard errors).

Table 2
Frequencies of AAN and ANRC structure responses, collapsed over target conceptual order, by prime conceptual order and syntax.

Prime		Target response			
Conceptual order	Syntax	AAN	ANRC	% of ANRC	*SE*
Experiment 1A: Noun repeated					
CP prime	AAN prime	426	4	0.9 %	0.5 %
	ANRC prime	152	267	63.7 %	2.4 %
PC prime	AAN prime	418	10	2.3 %	0.7 %
	ANRC prime	193	232	54.6 %	2.4 %
Experiment 1B: Noun non-repeated					
CP prime	AAN prime	414	11	2.6 %	0.8 %
	ANRC prime	202	203	50.1 %	2.5 %
PC prime	AAN prime	404	17	4.0 %	1.0 %
	ANRC prime	254	149	37.0 %	2.4 %

Table 3
Frequencies of AAN and ANRC structure responses, collapsed over target conceptual order, by conceptual order congruence and prime syntax.

Prime		Target response			
Conceptual order congruence	Syntax	AAN	ANRC	% of ANRC	*SE*
Experiment 1A: Noun repeated					
Same order	AAN prime	686	5	0.7 %	0.3 %
	ANRC prime	204	453	68.9 %	1.8 %
Different order	AAN prime	158	9	5.4 %	1.8 %
	ANRC prime	141	46	24.6 %	3.2 %
Experiment 1B: Noun non-repeated					
Same order	AAN prime	603	15	2.4 %	0.6 %
	ANRC prime	251	278	52.6 %	2.2 %
Different order	AAN prime	215	13	5.7 %	1.5 %
	ANRC prime	205	74	26.5 %	2.6 %

errors (*SE*s) of AAN and ANRC responses, collapsed over target conceptual order, for the first and second analyses, respectively. We report the analyses for each experiment first before combined analyses.

Experiment 1A. Table 4 summarizes the results for both the first and second analyses. The first analysis (1) revealed a main effect of syntax, which indicated that overall, there were more ANRC responses following ANRC primes (59.1 %, *SE* = 1.7 %) than following AAN primes (1.6 %, *SE* = 0.4 %). The non-significant main effect of prime conceptual order indicated that the overall rates of relative clause responses did not differ between CP primes and PC primes. Importantly, a significant prime syntax × prime conceptual order interaction showed a larger effect of prime syntax with CP primes (62.8 %) than with PC primes (52.3 %). The simple effects were significant with both orders. In the second analysis (2), a significant prime syntax × conceptual order congruence interaction indicated that participants were more likely to repeat the prime syntax when prime and target had the same conceptual order (68.2 %) than when they had different orders (19.2 %). The simple effects of prime syntax were significant with both cases.

Experiment 1B. Table 5 summarizes the results. The first analysis (1) revealed a main effect of prime syntax, indicating more ANRC responses following ANRC primes (43.6 %, *SE* = 1.7 %) than following AAN primes (3.3 %, *SE* = 0.6 %). As in Experiment 1A, the analysis also found a significant prime syntax × prime conceptual order interaction, which indicated a larger syntactic priming with CP primes (47.5 %) than with PC primes (32.9 %), though the simple effects were significant with both primes. The second analysis (2) found a significant interaction between prime syntax and conceptual order congruence, showing a larger effect of syntactic priming with the same conceptual order (50.2 %) than with different conceptual orders (20.8 %). The simple effects of prime syntax were significant for both orders.

Cross-experiment comparison. The comparison between Experiments 1A (noun repeated) and 1B (noun not repeated), including prime syntax, prime conceptual order, and experiment (noun repeated vs noun non-repeated, coded as 1 and 0 respectively) as fixed effects (all mean centred) revealed a larger syntactic priming in Experiment 1A (57.5 %) than in Experiment 1B (40.3 %), *Estimate* = 0.66, *SE* = 0.22, z = 2.98, p =.003. No other effect interacted with experiment, and there was no main effect of experiment (see Appendix C for a full summary). In both experiments AAN structures (Experiment 1A: 69.9 %; Experiment 1B: 77.0 %) were generally selected more often than ANRC structures (as indicated by the negative intercepts) and AAN structures were repeated more often from the prime to the target than ANRC structures, with a higher rate of syntactic congruence after AAN primes than after ANRC primes (Experiment 1A: 98.4 % vs 59.1 %, *Estimate* = − 3.33, *SE* = 0.47, z = -7.11, p <.001; Experiment 1B: 96.7 % vs 43.6 %, *Estimate* = -2.70, *SE* = 0.31, z = -8.81, p <.001, see Appendix D).

Table 4
Analysis of syntactic priming in Experiment 1A.

Fixed effects	*Estimate*	*SE*	*z*	*p*
(1) Prime syntax × conceptual order				
(Intercept)	−3.36	0.47	−7.16	<.001
Prime syntax	4.29	0.51	8.44	<.001
Prime conceptual order	0.06	0.22	0.27	.787
Prime syntax × conceptual order	−0.55	0.24	−2.28	.022
CP prime				
(Intercept)	−3.29	0.60	−5.54	<.001
Prime syntax	4.92	0.79	6.22	<.001
PC prime				
(Intercept)	−3.21	0.47	−6.83	<.001
Prime syntax	3.63	0.52	6.97	<.001
(2) Prime syntax × conceptual order congruence				
(Intercept)	−3.36	0.48	−7.08	<.001
Prime syntax	4.22	0.50	8.50	<.001
Conceptual order congruence	0.21	0.23	0.89	.373
Prime syntax × conceptual order congruence	0.83	0.19	4.42	<.001
Same conceptual order				
(Intercept)	−3.16	0.47	−6.67	<.001
Prime syntax	4.47	0.55	8.11	<.001
Different conceptual order				
(Intercept)	−4.98	1.33	−3.75	<.001
Prime syntax	2.59	0.70	3.70	<.001

Table 5
Analysis of syntactic priming in Experiment 1B.

Fixed effects	*Estimate*	*SE*	*z*	*p*
(1) Prime syntax × prime conceptual order				
(Intercept)	−2.77	0.31	−8.91	<.001
Prime syntax	2.23	0.24	9.14	<.001
Prime conceptual order	−0.09	0.12	−0.70	.486
Prime syntax × conceptual order	−0.36	0.12	−3.04	.002
CP prime				
(Intercept)	−2.87	0.43	−6.73	<.001
Prime syntax	2.76	0.33	8.45	<.001
PC prime				
(Intercept)	−2.59	0.29	−8.81	<.001
Prime syntax	1.73	0.25	6.89	<.001
(2) Prime syntax × conceptual order congruence				
(Intercept)	−2.65	0.29	−8.95	<.001
Prime syntax	2.19	0.23	9.52	<.001
Conceptual order congruence	0.06	0.12	0.53	.596
Prime syntax × conceptual order congruence	0.51	0.11	4.44	<.001
Same conceptual order				
(Intercept)	−2.60	0.30	−8.66	<.001
Prime syntax	2.36	0.24	9.73	<.001
Different conceptual order				
(Intercept)	−2.76	0.40	−6.86	<.001
Prime syntax	1.46	0.33	4.46	<.001

Conceptual order choice

As was done for syntactic choice, the first analyses examined whether the effect of prime conceptual order (CP vs PC, coded as 0 and 1) on adjective ordering (CP vs PC, coded as 0 and 1) (*conceptual order priming*) interacted with prime syntax (AAN vs ANRC structure, coded as 0 and 1). The second set of analyses examined whether conceptual order priming was affected by a new variable, *syntactic congruence,* which coded whether participants adopted the same syntactic structure as the prime or a different syntactic structure from the prime (coded as 1 and 0, respectively). Tables 6 and 7 reports the frequencies, means and standard errors (*SEs*) of CP and PC order responses, collapsed over target structure, for the first and second analyses, respectively.

Experiment 1A. Table 8 summarizes the results. The first analysis (1) revealed a main effect of prime conceptual order showed more PC responses after PC primes (65.1 %, $SE = 1.6$ %) than after CP primes (6.6 %, $SE = 0.9$ %), showing an effect of conceptual order priming. There was no main effect of prime syntax nor an interaction. The second analysis (2) revealed a significant prime conceptual order × syntactic congruence interaction, indicating a larger effect of prime conceptual order when prime and target had the same structures (68.9 %) than when they had different structures (22.7 %). The simple effects of prime conceptual order were significant in both cases.

Experiment 1B. Table 9 summarizes the results. The first analysis (1) revealed a main effect of prime conceptual order, indicating more PC responses after PC primes (52.9 %z, $SE = 1.7$ %) than after CP primes (14.3 %, $SE = 1.2$ %). The prime conceptual order × syntax interaction indicated larger conceptual order priming following AAN primes (45.9 %) than following ANRC primes (30.8 %), though the simple effects were significant with both primes. In the second analysis (2), the prime conceptual order × syntactic congruence interaction confirmed a larger effect of prime conceptual order when prime and target had the same syntactic structure (48.8 %) than when they had different syntactic structures (13.5 %). The simple effects of prime conceptual order were significant for both cases.

Cross experiment comparison. The analysis including prime conceptual order, prime syntax, and experiment as fixed effects showed found a larger conceptual order priming in Experiment 1A (58.5 %) than in Experiment 1B (38.6 %), $Estimate = 0.41$, $SE = 0.11$, $z = 3.68$, $p < .001$. Again, no other variable interacted with experiment (see Appendix C for a full summary). As we have seen, the effects of syntactic priming and conceptual order priming were all significant within each experiment, however. Overall, participants chose CP orders (Experiment 1A: 64.1 %; Experiment 1B: 66.4 %) more often than PC orders (as indicated by the negative intercepts) and they repeated CP orders more often than PC orders from the prime to the target, with a higher rate of conceptual congruence after CP primes than after PC primes (Experiment 1A: 93.4 % vs 65.1 %, $Estimate = -1.31$, $SE = 0.19$, $z = -7.03$, $p < .001$; Experiment 1B: 85.7 % vs 52.9 %, $Estimate = -1.11$, $SE = 0.19$, $z = -5.76$, $p < .001$, see Appendix D for full analyses).

Table 6
Frequencies of CP and PC responses, collapsed over target structure, by prime conceptual order and syntax in Study 1.

Prime		Target response			
Syntax	Conceptual Order	CP	PC	% of PC	*SE*
Experiment 1A: Noun repeated					
AAN prime	CP prime	400	30	7.0 %	1.2 %
	PC prime	137	291	68.0 %	2.3 %
ANRC prime	CP prime	393	26	6.2 %	1.2 %
	PC prime	161	264	62.1 %	2.4 %
Experiment 1B: Noun non-repeated					
AAN prime	CP prime	372	53	12.5 %	1.6 %
	PC prime	175	246	58.4 %	2.4 %
ANRC prime	CP prime	339	66	16.3 %	1.8 %
	PC prime	213	190	47.1 %	2.5 %

Table 7
Frequencies of CP and PC responses, collapsed over target structure, by prime conceptual order and syntactic congruence in Study 1.

Prime		Target response			
Syntactic congruence	Conceptual order	CP	PC	% of PC	*SE*
Experiment 1A: Noun repeated					
Congruent	CP prime	660	33	4.8 %	0.8 %
	PC prime	171	479	73.7 %	1.7 %
Incongruent	CP prime	133	23	14.7 %	2.8 %
	PC prime	127	76	37.4 %	3.4 %
Experiment 1B: Noun non-repeated					
Congruent	CP prime	559	58	9.4 %	1.2 %
	PC prime	231	322	58.2 %	2.1 %
Incongruent	CP prime	152	61	28.6 %	3.1 %
	PC prime	157	114	42.1 %	3.0 %

Table 8
Analysis of conceptual order priming in Experiment 1A.

Fixed effects	*Estimate*	*SE*	*z*	*p*
(1) Prime conceptual order × syntax				
(Intercept)	−1.31	0.19	−7.00	<.001
Prime conceptual order	2.22	0.21	10.55	<.001
Prime syntax	−0.15	0.11	−1.36	.174
Prime conceptual order × syntax	−0.06	0.09	−0.66	.508
(2) Prime conceptual order × syntactic congruence				
(Intercept)	−1.23	0.18	−6.75	<.001
Prime conceptual order	2.15	0.18	12.15	<.001
Syntactic congruence	0.09	0.09	1.07	.285
Prime conceptual order × syntactic congruence	0.49	0.08	5.78	<.001
Same syntax				
(Intercept)	−1.28	0.18	−7.00	<.001
Prime conceptual order	2.42	0.21	11.34	<.001
Different syntax				
(Intercept)	−1.26	0.25	−5.00	<.001
Prime conceptual order	0.75	0.17	4.32	<.001

Table 9
Analysis of conceptual order priming in Experiment 1B.

Fixed effects	*Estimate*	*SE*	*z*	*p*
(1) Prime conceptual order × syntax				
(Intercept)	−1.11	0.19	−5.79	<.001
Prime conceptual order	1.30	0.13	9.73	<.001
Prime syntax	−0.05	0.07	−0.76	.449
Prime conceptual order × syntax	−0.25	0.07	−3.64	<.001
AAN prime				
(Intercept)	−1.05	0.21	−4.96	<.001
Prime conceptual order	1.54	0.17	9.20	<.001
ANRC prime				
(Intercept)	−1.20	0.22	−5.56	<.001
Prime conceptual order	1.05	0.15	6.93	<.001
(2) Prime conceptual order × syntactic congruence				
(Intercept)	−1.12	0.19	−5.80	<.001
Prime conceptual order	1.32	0.13	10.34	<.001
Syntactic congruence	−0.17	0.07	−2.36	.018
Prime conceptual order × syntactic congruence	0.47	0.07	6.46	<.001
Same syntax				
(Intercept)	−1.30	0.20	−6.55	<.001
Prime conceptual order	1.62	0.16	10.03	<.001
Different syntax				
(Intercept)	−0.76	0.22	−3.54	<.001
Prime conceptual order	0.46	0.14	3.20	.001

Discussion

As we anticipated, participants produced more ANRC structures following ANRC primes than following AAN primes, demonstrating syntactic priming, and more PC orders after PC primes than after CP primes, demonstrating conceptual order priming. The magnitudes of these effects were substantial, in line with other priming studies in a dialogue (e.g., Branigan et al., 2000; Cleland & Pickering, 2003; Fukumura, 2018). Critically, in both experiments, syntactic priming was larger when speakers adopted the same conceptual order as in the prime rather than a different conceptual order from the prime. Likewise, conceptual order priming was larger when speakers adopted the same syntactic structure as in the prime as opposed to a different syntactic structure from the prime. These results provided support for the interactive priming account: When the primed conceptual order gets repeated, the primed syntactic structure receives a boost from the residual activation of its link to that conceptual order, which enhances the likelihood of syntactic persistence. Likewise, when the primed syntactic structure gets repeated, the primed conceptual order receives an additional boost from the residual activation of its link to that primed syntactic structure, enhancing the likelihood of conceptual order persistence. Consistent with these, both experiments showed larger syntactic priming with the CP order prime than with the PC order prime and Experiment 1B found larger conceptual order priming with the AAN structure prime than with the ANRC structure prime: Compared to their counterpart, the CP order and the AAN structure were more likely to persist from the prime to the target and hence trigger interactive priming, thereby enhancing syntactic priming and conceptual order priming, respectively.

Although there were fewer incongruent responses than congruent responses (see Table 3 and Table 7), both experiments also showed evidence for *independent priming*: The prime syntactic structure had an effect even when participants selected a different conceptual order from the prime. Likewise, the prime conceptual order affected adjective ordering even when participants selected a different syntactic structure from the prime. These results were incompatible with the two alternative accounts. The two-stage syntactic priming account assumes that the choice of a syntactic structure precedes the ordering of adjectives, driven by the syntactic structure that carries no specification of adjective ordering, whereas adjective ordering is driven by the syntactic structure that specifies adjective ordering. Hence, whilst syntactic priming should be independent of whether speakers selected the same adjective order as the prime or a different adjective order from the prime, the reverse should not hold. According to the one-stage syntactic priming account, structural choice is made in 'one go', directly driven by the syntactic structure that specifies adjective ordering; hence, neither syntactic priming nor conceptual order priming should occur independently. However, as we have just discussed, we found conceptual order priming even when speakers adopted different syntactic structures from the prime, and syntactic priming occurred even when speakers selected different conceptual orders from the prime.

Study 2

Study 1 provided support for the **interactive priming account**, by demonstrating evidence for cross-level interactive priming. The aim of Studies 2 and 3 was to develop this account further, focusing on its key assumption, which is that conceptual order and the syntactic structure are represented at different levels. Unlike the two alternative accounts discussed earlier, the interactive priming account assumes that adjective ordering is chosen at the conceptual level, whereas syntactic structures are selected at the syntactic level; hence, although conceptual order priming and syntactic priming interact, conceptual orders and syntactic structures are activated separately. Studies 2 and 3 assessed this assumption, investigating whether conceptual order priming and syntactic priming can be boosted independently. If the conceptual order and the syntactic structure are represented separately and at different levels, they could be boosted independently.

Specifically, the cross-experiment comparison in Study 1 indicated larger syntactic priming when the prime and target had the same noun rather than different nouns. Whilst this was in line with the noun boost effect on syntactic priming observed in Cleland and Pickering (2003), it was not just syntactic priming that was boosted: Conceptual order priming was also larger (20 %) in the experiment where the prime and target had the same noun. Hence the question is whether adjective repetition, as well as noun repetition, boosts both conceptual order priming and syntactic priming or whether adjective repetition differentially boosts conceptual order priming and syntactic priming. The residual activation model (Branigan & Pickering, 2017; Carminati et al., 2019; Cleland & Pickering, 2003; Pickering & Branigan, 1998) assumes that noun repetition enhances syntactic priming because nouns are the syntactic heads of noun phrases, and syntactic structures are primed in association with syntactic heads. On this view, adjective repetition is unlikely to boost syntactic priming because adjectives are not the heads of noun phrases. However, the model is primarily concerned with syntactic priming; it provides no prediction as to whether adjective repetition, as well as noun repetition, boosts conceptual order priming.

The head/non-head distinction is a syntactic distinction, based on syntactic categories. Such a distinction may not apply at the conceptual level; noun repetition may boost conceptual order priming, *not* because the noun is the syntactic head, but because the noun *concept* is associated with the relative orders of color and pattern concepts. If so, conceptual order priming could be boosted by non-heads. To consider how adjective repetition might interact with conceptual order priming, see the diagram in Fig. 6. In the diagram, the adjective concepts, SPOTTED and GREEN, are linked to the two ordering nodes, the CP node and the PC node, because these ordering nodes can only be activated based on the conceptual categories of the adjective concepts: Following *spotted bow that's green* as a prime, the PC node gets activated because speakers activate the concepts, SPOTTED and GREEN, along with their conceptual categories such as *Pattern* and *Color*, just like syntactic categories such as *Noun* are activated along with lemmas (Roelofs, 1992; Pickering & Branigan, 1998). If the links between the concepts and the PC node remain active, the repetition of SPOTTED or GREEN should boost conceptual order priming because the conceptual node should receive a boost via its link to the repeated concept, which should increase PC responses (relative to when the concept is not repeated).

Note that adjective repetition may interact with conceptual order priming via different mechanisms, however. Repeated adjectives might generally occur early because repetition priming make the repeated adjective both conceptually and linguistically more accessible than a non-repeated adjective, and more accessible adjectives tend to be placed earlier via accessibility-based adjective ordering. In this scenario, only the first adjective repetition should enhance the rates of conceptual order persistence. When the first adjective of the prime is repeated, both repetition priming and conceptual order priming should promote its earlier occurrence in the target. When the second adjective of the prime is repeated, repetition priming should counteract conceptual order priming; repetition priming will influence the earlier placing of the second adjective in the target, whilst conceptual order priming would bias the earlier placing of the first-mentioned conceptual category. Hence the repetition of the second adjective should reduce the rates of conceptual order persistence.

Thus, Study 2 examined whether adjective repetition, as well as noun repetition, can enhance conceptual order priming. We varied the prime adjective order, which had either CP or PC order. The repetition of noun, color and pattern was manipulated in Experiment 2A, Experiment 2B and Experiment 2C, respectively. The prime descriptions always had an AAN structure, since we were only interested in conceptual order priming in Study 2.

Method

Participants

We recruited 144 participants (48 per experiment) from the University of Stirling undergraduate student community. Participants reported to be native speakers of British English (only English spoken at home where they were raised) and aged between 17 and 30 and with no

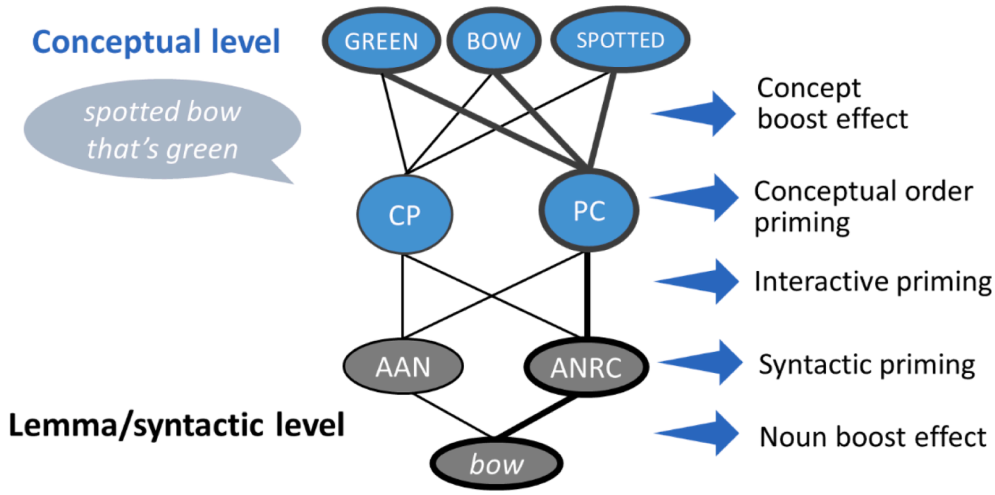

Fig. 6. Representations of conceptual orders and syntactic structures. CP = Color-Pattern; PC = Pattern-Color; AAN = Adjective- Adjective-Noun; ANRC = Adjective-Noun-Relative Clause.

visual impairments. Data from 28 participants were replaced due to recording failures or technical issues ($n = 18$), high identification errors in the prime trials (over 25 %) ($n = 8$) or many excluded trials (over 30 %) ($n = 2$).

Materials and procedure

The displays were the same as those in Experiment 1, except that there were two *prime* objects, one *repeated prime* and one *non-repeated prime*. Fig. 7 shows as an example display. In Experiment 2A, the repeated primes shared the same object category with the target (*noun repeated primes*). In Experiments 2B and 2C, the repeated primes had the same color (*color repeated primes*) or pattern (*pattern repeated primes*) as the targets, respectively. The non-repeated primes did not share any property with the target. The prime descriptions had either Color-before-Pattern (CP) vs Pattern-before-Pattern (PC) orders and the same audio descriptions used in the Adjective-Adjective-Noun conditions in Experiment 1 were used. There were 48 filler items, similar to those used in Experiment 1, though to discourage relative clause responses, we removed the relativizer *that*, which was included in some filler prime descriptions in Study 1. The procedure was the same as in Experiment 1. The average error rate of identifying the prime objects was 2.4 %.

Design

Within each experiment, prime conceptual order had either a color-before-pattern (CP) order or a pattern-before-color (PC) order. Experiments 2A, 2B, and 2C varied the repetition of noun, color, and pattern (repeated vs non-repeated), respectively. This resulted in a 2 (prime conceptual order: CP vs PC) × 2 (prime attribute repetition: repeated vs non-repeated) repeated measures design for each experiment. The 36 experimental items and 48 filler items were distributed as before, and 12 participants were assigned to each list in each experiment.

Scoring

We scored whether participants produced color-pattern (CP) orders or pattern-color (PC) orders. Cases were excluded from analyses when the responses contained only one adjective ($n = 17$) or failed to include nouns ($n = 11$) or included additional information such as size or orientation ($n = 15$); participants changed their responses or word order (e.g., *spotted circle, spotted red circle*) ($n = 45$), they used coordination (*the green and black striped train*) ($n = 5$) or an erroneous word order (*circle dark blue saucepan*) or relative clauses (*the green shoe that's chequered*) ($n = 3$). We also excluded cases where participants used a wrong color, pattern, or noun ($n = 22$); they did not repeat the noun, color, or pattern of the prime in the repeated condition ($n = 12$); or they used a prepositional phrase for pattern (e.g., *with stripes*) ($n = 5$); there was a recording failure ($n = 6$) or other technical error ($n = 20$). Thus, in total, 162 cases (3.1 %) (Experiment 2A = 47, 2.7 %; Experiment 2B = 67, 3.9 %; Experiment 2C = 48, 2.8 %) were excluded from analyses.

Results

Table 10 reports the response frequencies, means and standard errors (*SEs*) of CP and PC orders by prime conceptual order and noun (Experiment 2A), color (Experiment 2B) or pattern (Experiment 2C) repetition. Before combined analyses, we report the results for each experiment separately. Each analysis included prime conceptual order (CP vs PC, coded as 0 and 1) and noun, color, or patter repetition (repeated vs not repeated, coded as 1 and 0) as fixed effects. Table 11 summarizes the results for each experiment.

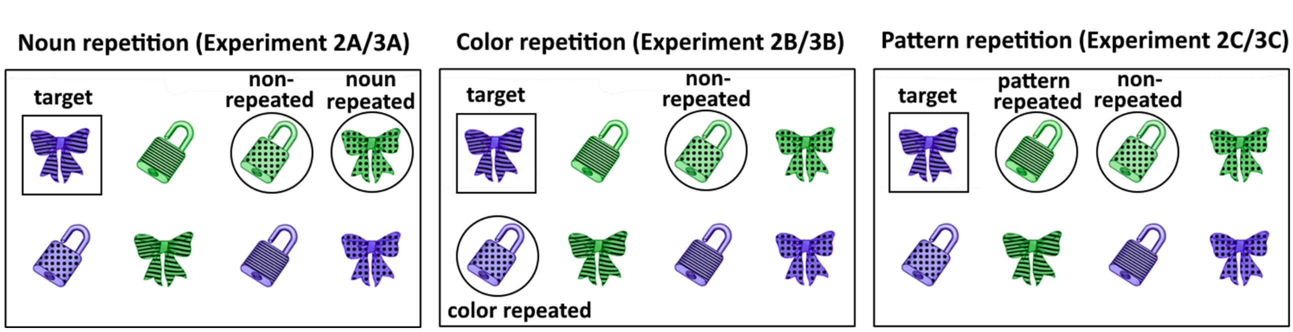

Fig. 7. Example display for Studies 2 and 3.

Table 10
Frequencies of CP and PC order responses by condition in Study 2.

Prime		Target response			
Repetition	Order	CP	PC	% of PC	*SE*
Experiment 2A: Noun repetition					
Noun repeated	CP	397	32	7.5 %	1.3 %
	PC	201	224	52.7 %	2.4 %
Non-repeated	CP	364	56	13.3 %	1.7 %
	PC	220	187	45.9 %	2.5 %
Experiment 2B: Color repetition					
Color repeated	CP	346	64	15.6 %	1.8 %
	PC	140	273	66.1 %	2.3 %
Non-repeated	CP	358	62	14.8 %	1.7 %
	PC	226	192	45.9 %	2.4 %
Experiment 2C: Pattern repetition					
Pattern repeated	CP	395	29	6.8 %	1.2 %
	PC	124	293	70.3 %	2.2 %
Non-repeated	CP	354	68	16.1 %	1.8 %
	PC	172	245	58.8 %	2.4 %

Table 11
Analysis of conceptual ordering in Study 2.

Fixed effects	*Estimate*	*SE*	*z*	*p*
(1) Experiment 2A (Noun repetition)				
(Intercept)	−1.62	0.25	−6.35	<.001
Prime conceptual order	1.57	0.14	11.07	<.001
Noun repetition	−0.14	0.08	−1.67	.094
Prime conceptual order × noun repetition	0.31	0.08	3.83	<.001
Noun repeated prime				
(Intercept)	−1.82	0.30	−6.10	<.001
Prime conceptual order	1.99	0.24	8.41	<.001
Non-repeated prime				
(Intercept)	−1.36	0.23	−5.90	<.001
Prime conceptual order	1.16	0.13	8.61	<.001
(2) Experiment 2B (Color repetition)				
(Intercept)	−0.98	0.19	−5.04	<.001
Prime conceptual order	1.30	0.12	10.48	<.001
Color repetition	0.29	0.07	4.12	<.001
Prime conceptual order × color repetition	0.25	0.07	3.55	<.001
Color repeated prime				
(Intercept)	−0.67	0.20	−3.40	.001
Prime conceptual order	1.55	0.17	9.29	<.001
Non-repeated prime				
(Intercept)	−1.22	0.21	−5.85	<.001
Prime conceptual order	1.01	0.12	8.65	<.001
(3) Experiment 2C (Pattern repetition)				
(Intercept)	−1.12	0.22	−5.00	<.001
Prime conceptual order	1.95	0.16	12.02	<.001
Pattern repetition	−0.15	0.10	−1.58	.114
Prime conceptual order × pattern repetition	0.50	0.09	5.68	<.001
Pattern-repeated				
(Intercept)	−1.23	0.27	−4.57	<.001
Prime conceptual order	2.52	0.25	9.99	<.001
Non-repeated				
(Intercept)	−0.91	0.23	−3.96	<.001
Prime conceptual order	1.40	0.15	9.39	<.001

Experiment 2A: Noun repetition

Table 11 (1) summarizes the results. A significant main effect of prime conceptual order showed more PC orders after PC order primes (49.4 %, $SE = 1.7$ %) than after CP order primes (10.4 %, $SE = 1.0$ %). A significant conceptual order × noun repetition interaction indicated a larger conceptual order priming when the prime and the target had the same noun (45.2 %) than when they had different nouns (32.6 %), though the simple effects were significant in both conditions.

Experiment 2B: Color repetition

Table 11 (2) summarizes the results. A main effect of prime conceptual order showed more PC orders following PC primes (56.0 %, $SE = 1.7$ %) than following CP primes (15.2 %, $SE = 1.2$ %), and a significant prime × color repetition interaction indicated a larger effect of prime conceptual order when color was repeated (50.5 %) than when color was not repeated (31.1 %), though the simple effects were reliable in both conditions.

Experiment 2C: Pattern repetition

Table 11 (3) summarizes the results. A main effect of prime revealed more PC orders following PC primes (64.5 %, $SE = 1.7$ %) than CP primes (11.5 %, $SE = 1.1$ %), and a significant conceptual order × pattern repetition interaction indicated larger conceptual order priming when pattern was repeated (63.5 %) than when pattern was not repeated (42.7 %). Again, the simple effects were significant in both conditions.

Cross-experiment comparisons

Two cross-experiment comparisons examined (1) whether noun repetition boosted conceptual order priming more strongly than adjective repetition and (2) whether the repetition of color or pattern adjective differentially boosted conceptual order priming. The comparison between Experiment 2A (noun repetition) and Experiments 2B/2C (adjective repetition) included prime adjective order, repetition, and experiment (noun repetition vs adjective repetition, coded as 1 and 0), as fixed effects, which were mean-centred and standardized in line with other analyses.[2] The analyses found no significant conceptual order × repetition × experiment interaction, $Estimate = -0.02$, $SE = 0.05$, $z = -0.47$, $p = .636$, providing no evidence that noun repetition boosts conceptual order priming differently from adjective repetition (see Appendix E for a full summary). The comparison between Experiments 2B and 2C (color repetition, coded as 0, vs pattern repetition, coded as 1), however, revealed a significant conceptual order × repetition × experiment interaction, $Estimate = 0.12$, $SE = 0.05$, $z = 2.28$, $p = .023$, though the magnitude of the boost effect was numerically similar in these experiments (19.3 % for color repetition and 20.8 % for pattern repetition) (see Appendix E for a full summary). Pattern repetition in Experiment 2C increased CP responses after CP primes, $Estimate = -0.69$, $SE = 0.16$, $z = -4.21$, $p < .001$, as well as PC responses after PC primes, $Estimate = 0.34$, $SE = 0.09$, $z = 3.75$, $p < .001$. By contrast, color repetition in Experiment 2B boosted PC responses after PC primes, $Estimate = 0.53$, $SE = 0.08$, $z = 6.44$, $p < .001$, but not CP responses after CP primes, $Estimate = 0.04$, $SE = 0.11$, $z = 0.37$, $p = .710$.

Discussion

Study 2 showed that not only noun repetition but also color or pattern repetition enhances conceptual order priming, and there was no evidence that adjective repetition is less effective in boosting conceptual order priming than noun repetition is. It was not the case that adjective repetition interacted with prime adjective order because repeated adjectives generally occurred earlier. If so, only the repetition of the first-mentioned adjective should have enhanced conceptual order persistence, and this was not what we found. After PC primes, not only the repetition of pattern (the first adjective) but also the repetition of color (the second adjective) enhanced the perseverance of PC responses (relative to non-repeated adjective conditions). After CP primes, the repetition of pattern (the second adjective) boosted CP responses; in fact, it was the repetition of color (the first adjective) that failed to boost CP responses (we will return to this finding in Study 3). Conceptual order priming was enhanced by noun repetition, even though the position of the noun was constant in all conditions. Hence, both noun repetition and adjective repetition enhanced the priming of conceptual category orders because it increased the tendency to persevere with the relative order of the conceptual categories of the prime.

In sum, Study 2 found that adjective repetition, as well as noun repetition, interacts with conceptual order priming. Speakers are more likely to persevere with the relative order of the conceptual categories of

[2] The results remain the same with Helmert coding.

the adjectives when one of the adjectives is repeated in the target than when there is no such repetition. The findings thus provide support for the interactive priming account that claims that conceptual order priming can be enhanced by the repetition of non-heads.

Study 3

Study 3 examined whether syntactic priming can be boosted by color or pattern repetition as well as noun repetition. The **interactive priming account** assumes that for interactive priming to arise, the repeated element must be associated with the syntactic structure of the prime. One possibility is that, as assumed by the residual activation model, noun repetition enhances syntactic priming because the syntactic structure is associated with the head noun of a noun phrase (cf. Branigan & Pickering, 2017; Carminati et al., 2019; Cleland & Pickering, 2003; Pickering & Branigan, 1998). That is, syntactic nodes representing noun phrase structures (i.e., the AAN node or the ANRC node) specify how the head noun combines with other words, not how a non-head combines with other words. Hence, following a prime such as *spotted bow that's green*, the ANRC node may get activated in combination with the activation of the lemma of the head noun (*bow*) and its syntactic category (*Noun*). This will establish a link between the ANRC node and the lemma, *bow*. Critically, adjectives are not the heads of noun phrases. Hence, the activation of the ANRC node does not involve the activation of the individual adjective lemmas, *spotted* and *green*. Thus, the ANRC node is not linked to the adjective lemmas. As a result, the repetition of neither *spotted* nor *green* should interact with syntactic priming.

Some researchers have argued that syntactic structures can be associated with non-heads at least temporarily (Reitter et al., 2011), however. Consistent with this, Scheepers et al. (2017) reported that with ditransitive verbs (e.g., *send, give*), syntactic priming is enhanced not only by verb repetition but also by repetition of event participants (such as agents and recipients), though Carminati et al. (2019) more recently found that syntactic priming can only be boosted by verb repetition and failed to replicate Scheepers et al.'s findings. Hence, if syntactic structures can be primed in association with non-heads (Reitter et al., 2011; Scheepers et al., 2017), adjective repetition could also enhance syntactic priming, given that the repetition of color or pattern reliably enhanced conceptual order priming in Study 2. Thus, in Study 3, we varied the prime syntax (AAN vs ANRC) and prime conceptual order (CP vs PC) as in Study 1, and noun (Experiment 3A), color (Experiment 3B) and pattern (Experiment 3C) repetition as in Study 2.

Method

Participants

We recruited 144 participants (48 participants each for Experiments 3A, 3B, 3C) who had the same profile as those in Experiments 1 and 2 in exchange for cash or course credits. Data from additional seven participants were excluded from analyses because of recording failures or poor recording qualities ($n = 5$) or high rates of exclusion in the target trials (over 30 %) ($n = 2$).

Materials, design, and procedure

There were 40 experimental trials in total, with four experimental items in additional to those used in Studies 1 and 2. We used 48 filler trials similar to those used in Experiments 1 and 2. Audio descriptions were generated using the Google Cloud Text-to-Speech API, with a British English male voice profile. The speaking rate and pitch were set to 0.85 and + 0.4, respectively. As in Experiment 1, we manipulated the syntactic structure (AAN vs ANRC) and conceptual order (CP vs PC) of the prime. In addition, repetition of noun (Experiment 3A), color (Experiment 3B) and pattern (Experiment 3C) was also varied, as in Experiment 2. This led to a 2 (prime syntax) × 2 (prime conceptual order) × 2 (prime attribute repetition) repeated measured design. Forty experimental items and 48 filler items were randomly distributed across eight lists. The procedure was the same as before. The average error rate in the prime trials was 1.51 %.

Scoring

As in Experiment 1, we scored whether participants produced CP or PC orders and whether they used AAN or ANRC structures. As before, cases were excluded if the referring expressions contained one adjective only ($n = 21$) or involved additional information such as size or orientation ($n = 32$) or failed to include nouns ($n = 2$); participants altered word order or response type ($n = 26$), participants coordinated the two modifiers ($n = 3$) or both adjectives were mentioned in the relative clauses ($n = 46$). We also excluded cases where participants used a wrong color, pattern, or noun ($n = 26$) or did not repeat the given color or pattern in the repeated prime condition ($n = 7$) or they did not use an adjective to refer to pattern (e.g., *with stripes*) ($n = 39$). Together with cases with a recording failure or incomplete response ($n = 10$), 212 cases were excluded from analyses (3.7 % of total responses) (Experiment 3A = 58, 3.0 %; Experiment 3B = 71, 3.7 %; Experiment 3C = 83, 4.3 %).

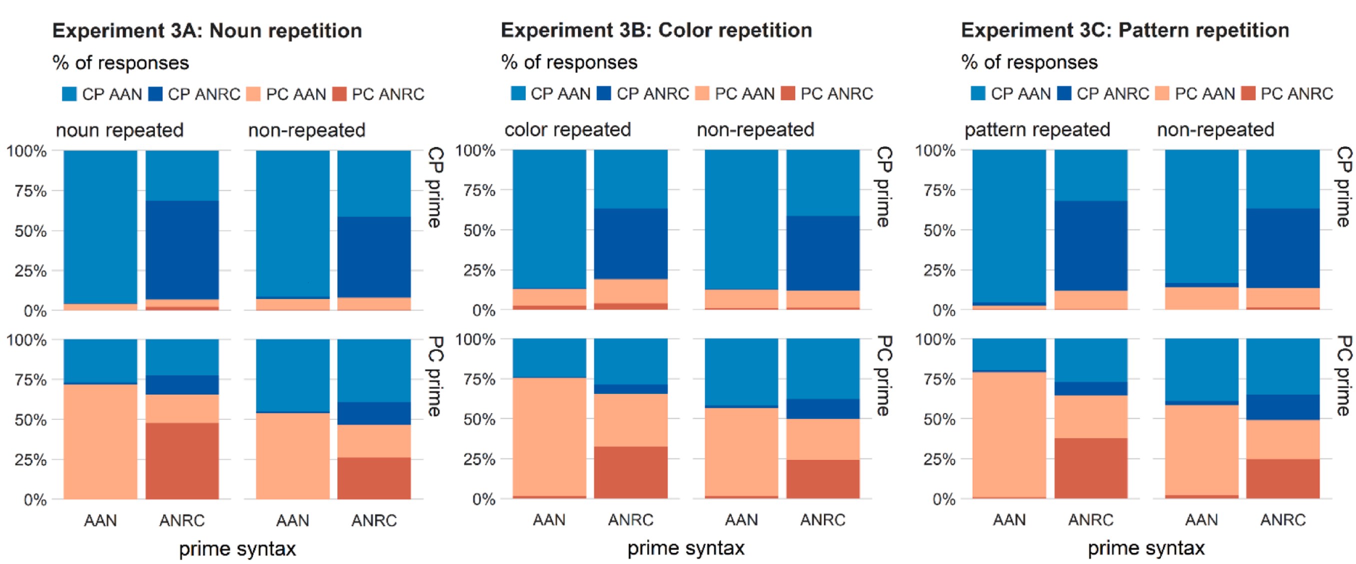

Fig. 8. Percentages of target responses by prime syntax, prime conceptual order and repetition (see Appendix F for frequencies and standard errors) in Study 3.

Table 12
Frequencies of AAN and ANRC structure responses, collapsed over target conceptual order, by condition in Study 3.

Prime			Target response			
Order	Repetition	Syntax	AAN	ANRC	% of ANRC	*SE*
(1) Experiment 3A: Noun repetition						
CP	Noun repeated	AAN	237	1	0.4 %	0.4 %
		ANRC	84	148	63.8 %	3.2 %
	Non-repeated	AAN	231	4	1.7 %	0.8 %
		ANRC	111	116	51.1 %	3.3 %
PC	Noun repeated	AAN	234	3	1.3 %	0.7 %
		ANRC	95	139	59.4 %	3.2 %
	Non-repeated	AAN	229	3	1.3 %	0.7 %
		ANRC	136	91	40.1 %	3.3 %
(2) Experiment 3B: Color repetition						
CP	Color repeated	AAN	226	7	3.0 %	1.1 %
		ANRC	119	111	48.3 %	3.3 %
	Non-repeated	AAN	229	3	1.3 %	0.7 %
		ANRC	121	112	48.1 %	3.3 %
PC	Color repeated	AAN	229	6	2.6 %	1.0 %
		ANRC	140	87	38.3 %	3.2 %
	Non-repeated	AAN	224	7	3.0 %	1.1 %
		ANRC	145	83	36.4 %	3.2 %
(3) Experiment 3C: Pattern repetition						
CP	Pattern repeated	AAN	231	6	2.5 %	1.0 %
		ANRC	99	128	56.4 %	3.3 %
	Non-repeated	AAN	227	6	2.6 %	1.0 %
		ANRC	111	115	50.9 %	3.3 %
PC	Pattern repeated	AAN	228	5	2.1 %	1.0 %
		ANRC	123	105	46.1 %	3.3 %
	Non-repeated	AAN	220	11	4.8 %	1.4 %
		ANRC	132	90	40.5 %	3.3 %

Results

Fig. 8 reports the distribution of all target responses for each experiment (see Appendix F for response frequencies and standard errors).

Syntactic choice

Table 12 reports the frequencies, means and standard errors (*SE*s) of AAN and ANRC responses, collapsed over target conceptual order. The goal of Study 3 was to determine whether the effect of prime syntax on syntactic choice (AAN vs ANRC responses) interacts with noun (Experiment 3A), color (Experiment 3B) or pattern (Experiment 3C) repetition. Hence, here we examined the binary choice of AAN and ANRC (coded as 0 and 1, respectively) responses. Before reporting combined analyses, we first report the results for each experiment. The analyses included prime syntax (ANRC vs AAN, coded as 1 and 0, respectively), prime conceptual order (PC vs CP, coded as 1 and 0, respectively) and noun, color, or pattern repetition (repeated vs non-repeated, coded as 1 and 0, respectively) as fixed effects. Table 13 summarizes the results for each experiment.

Experiment 3A: Noun repetition. Table 13 (1) summarizes the results. There was no significant main effect of noun repetition, showing no evidence that noun repetition itself increased the rates of relative clause responses. A significant main effect of prime syntax indicated more ANRC responses following ANRC primes (53.7 %, *SE* = 1.6 %) than AAN primes (1.2 %, *SE* = 0.4 %). The prime syntax × noun repetition interaction was also significant, with a larger effect of prime syntax when the prime noun was repeated (60.8 %) than when it was not repeated (44.1 %). The effects of prime syntax were significant in both cases.

Experiment 3B: Color repetition. Table 13 (2) summarizes the results. The main effect of prime syntax indicated more ANRC responses following ANRC primes (42.8 %, *SE* = 1.6 %) than following AAN primes (2.5 %, *SE* = 0.5 %). Critically, there was no prime syntax × color repetition interaction nor prime syntax × conceptual order × color repetition interaction, showing no evidence that color repetition enhances syntactic priming. By contrast, as in Study 1, the prime syntax × conceptual order interaction revealed a larger effect of prime syntax with CP primes (46.0 %) than with PC primes (34.6 %), but the effects were significant with both primes.

Table 13
Analyses of syntactic priming in Study 3.

Fixed effects	*Estimate*	*SE*	*z*	*p*
(1) Experiment 3A (Noun repetition)				
(Intercept)	−3.19	0.40	−7.91	<.001
Prime syntax	3.42	0.30	11.56	<.001
Prime conceptual order	−0.05	0.19	−0.26	.792
Noun repetition	0.10	0.19	0.54	.589
Prime syntax × conceptual order	−0.25	0.20	−1.27	.205
Prime syntax × noun repetition	0.46	0.19	2.46	.014
Prime conceptual order × noun repetition	0.24	0.19	1.31	.191
Prime conceptual order × syntax × repetition	−0.13	0.18	−0.68	.496
Noun repeated prime				
(Intercept)	−2.87	0.42	−6.77	<.001
Prime syntax	3.61	0.39	9.26	<.001
Non-repeated prime				
(Intercept)	−3.15	0.42	−7.43	<.001
Prime syntax	2.89	0.33	8.84	<.001
(2) Experiment 3B (Color repetition)				
(Intercept)	−3.34	0.40	−8.37	<.001
Prime syntax	2.77	0.29	9.42	<.001
Prime conceptual order	−0.11	0.15	−0.74	.460
Color repetition	0.16	0.14	1.16	.247
Prime syntax × conceptual order	−0.33	0.17	−1.99	.047
Prime syntax × color repetition	−0.10	0.14	−0.74	.462
Prime conceptual order × color repetition	−0.12	0.14	−0.82	.410
Prime conceptual order × syntax × repetition	0.18	0.14	1.30	.192
CP prime				
(Intercept)	−3.11	0.42	−7.34	<.001
Prime syntax	3.03	0.39	7.68	<.001
PC prime				
(Intercept)	−3.35	0.46	−7.31	<.001
Prime syntax	2.33	0.29	7.92	<.001
(3) Experiment 3C (Pattern repetition)				
(Intercept)	−2.65	0.32	−8.18	<.001
Prime syntax	2.53	0.23	10.95	<.001
Prime conceptual order	−0.09	0.13	−0.65	.516
Pattern repetition	−0.03	0.12	−0.25	.802
Prime syntax × conceptual order	−0.29	0.14	−2.02	.043
Prime syntax × pattern repetition	0.19	0.12	1.63	.103
Prime conceptual order × pattern repetition	−0.14	0.13	−1.08	.278
Prime conceptual order × syntax × repetition	0.11	0.12	0.87	.384
CP prime				
(Intercept)	−2.60	0.37	−7.10	<.001
Prime syntax	2.82	0.32	8.74	<.001
PC prime				
(Intercept)	−2.56	0.33	−7.79	<.001
Prime syntax	2.10	0.25	8.48	<.001

Experiment 3C: Pattern Repetition. Table 13 (3) summarizes the results. The main effect of prime syntax confirmed more ANRC responses following ANRC primes (48.5 %, *SE* = 1.7 %) than with AAN primes (3.0 %, *SE* = 0.1 %). Importantly, there was no significant syntax × pattern repetition priming nor conceptual order × syntax × pattern repetition priming, providing no evidence that pattern repetition reliably enhances syntactic priming. As in Study 1, the prime syntax × conceptual order interaction was significant, indicating stronger syntactic priming with CP primes (51.0 %) than with PC primes (39.9 %), but the simple effects of prime syntax were significant with both primes.

Cross-experiment comparison. A cross-experiment comparison examined whether noun repetition enhanced syntactic priming differently from adjective repetition. The comparison between Experiment 3A and Experiment 3B/3C included prime syntax (AAN vs ANRC), prime

Table 14
Frequencies of CP and PC order responses, collapsed over target structure, by condition in Study 3.

Prime			Target response			
Syntax	Repetition	Conceptual Order	CP	PC	% of PC	*SE*
		Experiment 3A: Noun repetition				
AAN	Noun repeated	CP	228	10	4.2 %	1.3 %
		PC	67	170	71.7 %	2.9 %
	Non-repeated	CP	218	17	7.2 %	1.7 %
		PC	107	125	53.9 %	3.3 %
ANRC	Noun repeated	CP	216	16	6.9 %	1.7 %
		PC	81	153	65.4 %	3.1 %
	Non-repeated	CP	209	18	7.9 %	1.8 %
		PC	121	106	46.7 %	3.3 %
		Experiment 3B: Color repetition				
AAN	Color repeated	CP	203	30	12.9 %	2.2 %
		PC	58	177	75.3 %	2.8 %
	Non-repeated	CP	203	29	12.5 %	2.2 %
		PC	100	131	56.7 %	3.3 %
ANRC	Color repeated	CP	186	44	19.1 %	2.6 %
		PC	78	149	65.6 %	3.2 %
	Non-repeated	CP	205	28	12.0 %	2.1 %
		PC	114	114	50.0 %	3.3 %
		Experiment 3C: Pattern repetition				
AAN	Pattern repeated	CP	231	6	2.5 %	1.0 %
		PC	49	184	79.0 %	2.7 %
	Non-repeated	CP	200	33	14.2 %	2.3 %
		PC	96	135	58.4 %	3.2 %
ANRC	Pattern repeated	CP	200	27	11.9 %	2.2 %
		PC	81	147	64.5 %	3.2 %
	Non-repeated	CP	195	31	13.7 %	2.3 %
		PC	113	109	49.1 %	3.4 %

conceptual order (CP vs PC), repetition (repeated vs non-repeated) and experiment (noun repetition vs adjective repetition, coded as 1 and 0)[3] as fixed effects. The analysis revealed a prime syntax × repetition × experiment interaction, *Estimate* = 0.20, *SE* = 0.10, *z* = 2.06, *p* =.039, confirming that noun repetition boosted syntactic priming more strongly than adjective repetition (see Appendix G for a full summary).

Conceptual order choice

The analyses of syntactic choice showed that only noun repetition enhances syntactic priming. Here we examined whether conceptual order priming was enhanced by adjective repetition as well as noun repetition, as was the case in Study 2. The binary choice of CP and PC (coded as 0 and 1, respectively) responses was analyzed as a function of prime conceptual order (CP vs PC), prime syntax (AAN vs ANRC) and noun, color, or pattern repetition (repeated vs non-repeated). Table 14 reports the frequencies, means and standard errors (*SE*s) of CP and PC order responses, collapsed over target syntactic structure, by condition. Table 15 summarizes the results.

Experiment 3A: Noun Repetition. As reported in Table 15 (1), a significant main effect of prime conceptual order showed more PC responses following PC primes (59.6 %, *SE* = 1.6 %) than CP primes (6.5 %, *SE* = 0.8 %). The prime conceptual order × noun repetition indicated a larger effect of conceptual order priming when the noun was repeated (63.0 %) than when the noun was not repeated (42.8 %). The simple effects of prime conceptual order were significant both in the noun repeated condition and in the non-repeated condition. As in Study 1, a significant conceptual order × prime syntax interaction indicated a larger effect of prime conceptual order with AAN primes (57.2 %) than with ANRC primes (48.8 %), though the simple effects of prime conceptual order were significant with both primes.

Experiment 3B: Color Repetition. Table 15 (2) summarizes the results. A main effect of prime conceptual order showed more PC orders after PC primes (62.0 %, *SE* = 1.6 %) than after CP primes (14.1 %, *SE* = 1.1 %). Importantly, as in Study 2, the prime conceptual order × color repetition interaction was also significant, with enhanced conceptual order priming when color was repeated (54.6 %) compared to when color was not repeated (41.1 %). As in Study 1, the prime conceptual order × syntax interaction indicated a larger effect of conceptual order priming with AAN (53.4 %) than with ANRC primes (42.2 %), though the simple effects of conceptual order priming were significant with both primes.

Experiment 3C: Pattern Repetition. Table 15 (3) summarizes the results. The main effect of prime conceptual order found more PC orders after PC primes (62.9 %, *SE* = 1.6 %) than after CP primes (10.5 %, *SE* = 1.0 %). As in Study 2, the prime conceptual order × pattern repetition interaction revealed a larger effect of conceptual order priming when pattern was repeated (64.7 %) than when pattern was not repeated (40.0 %). A significant conceptual order × prime syntax × pattern repetition interaction found that pattern repetition enhanced conceptual order priming more when the prime had the AAN structure than when it had the ANRC structure, though the prime conceptual order × pattern repetition interactions were significant for both ANRC and AAN primes. Finally, as in Experiments 3A and 3B, conceptual order priming was greater with AAN primes (60.5 %) than with ANRC primes (44.1 %), but the effects of prime conceptual order were significant for both AAN primes and ANRC primes.

Cross-experiment comparison. We examined if conceptual order priming was affected by noun repetition differently from adjective repetition (see Appendix H for a full summary). The comparison between Experiment 3A and Experiments 3B/C included prime conceptual order, prime syntax, repetition, and experiment (noun vs adjective repetition) as fixed effects, which were all mean-centred and standardized. The analysis revealed a main effect of experiment, which indicated somewhat fewer PC responses in Experiment 3A than in Experiments 3B/C, *Estimate* = -0.50, *SE* = 0.24, *z* = -2.09, *p* = .037. However, there was no significant conceptual order × repetition × experiment interaction, providing no evidence that noun repetition and adjective pattern repetition boosted conceptual order priming differently, *Estimate* = 0.06, *SE* = 0.10, *z* = 0.58, *p* = .563. Comparison between Experiment 3B (color repetition) and Experiment 3C (pattern repetition) showed a significant conceptual order × repetition × experiment interaction, *Estimate* = -0.18, *SE* = 0.05, *z* = -3.44, *p* = .001, however, indicating conceptual order priming was boosted more by pattern repetition (24.8 %) than by color repetition (13.5 %). As in Study 2, pattern repetition boosted CP responses after CP primes, *Estimate* = -0.44, *SE* = 0.13, *z* = -3.37, *p* <.001, and PC responses after PC primes, *Estimate* = 0.49. *SE* = 0.10, *z* = 5.06, *p* <.001. By contrast, color repetition boosted PC responses after PC primes, *Estimate* = 0.52. *SE* = 0.09, *z* = 5.69, *p* <.001, but not CP responses after CP primes, *Estimate* = 0.19, *SE* = 0.11, *z* = 1.70, *p* = .089.

Discussion

Study 3 showed that whereas noun repetition boosts syntactic priming (Experiment 3A), neither color nor pattern repetition results in stronger syntactic priming (Experiments 3B & 3C). These findings are in accord with the residual activation model (Branigan & Pickering, 2017; Carminati et al., 2019; Cleland & Pickering, 2003; Pickering & Branigan, 1998), which assumes that syntactic processes are "head-driven" (cf., Pollard & Sag, 1994); that is, syntactic nodes specify how the head noun combines with other words. Hence, when speakers activate the AAN node or ANRC node in the prime, they do so by activating the head noun and its syntactic category, not by activating the lemmas of the adjectives; thus, the syntactic node is linked to the head noun, but not to the adjective nodes. This is why the repetition of the head noun can boost the activation of the primed syntactic structure, whereas the repetition of the adjectives cannot. There was no evidence that noun repetition *generally* increased relative clause responses because of the higher availability of the repeated noun; if so, noun repetition should have

[3] The results remain the same with Helmert coding.

Table 15
Analysis of conceptual order priming in Study 3.

Fixed effects	*Estimate*	*SE*	*z*	*p*
(1) Experiment 3A (Noun repetition)				
(Intercept)	−1.45	0.21	−6.95	<.001
Prime conceptual order	1.98	0.13	15.39	<.001
Prime syntax	−0.02	0.08	−0.24	.808
Noun repetition	0.17	0.09	1.95	.052
Prime conceptual order × syntax	−0.18	0.08	−2.15	.032
Prime conceptual order × noun repetition	0.38	0.09	4.06	<.001
Prime syntax × noun repetition	0.07	0.08	0.79	.432
Prime conceptual order × syntax × repetition	−0.06	0.08	−0.75	.455
AAN prime				
(Intercept)	−1.41	0.23	−6.10	<.001
Prime conceptual order	2.11	0.15	13.78	<.001
ANRC prime				
(Intercept)	−1.45	0.21	−6.98	<.001
Prime conceptual order	1.76	0.17	10.05	<.001
Noun repeated prime				
(Intercept)	−1.26	0.23	−5.50	<.001
Prime conceptual order	2.35	0.20	11.48	<.001
Non-repeated prime				
(Intercept)	−1.62	0.23	−6.99	<.001
Prime conceptual order	1.59	0.14	11.00	<.002
(2) Experiment 3B (Color repetition)				
(Intercept)	−0.97	0.22	−4.35	<.001
Prime conceptual order	1.70	0.14	11.81	<.001
Prime syntax	−0.07	0.09	−0.79	.428
Color repetition	0.36	0.08	4.81	<.001
Prime conceptual order × syntax	−0.20	0.07	−2.70	.007
Prime conceptual order × color repetition	0.18	0.08	2.41	.016
Prime syntax × color repetition	0.06	0.07	0.88	.381
Prime conceptual order × syntax × repetition	−0.12	0.07	−1.75	.080
AAN prime				
(Intercept)	−0.81	0.21	−3.84	<.001
Prime conceptual order	1.74	0.16	11.04	<.001
ANRC prime				
(Intercept)	−1.04	0.25	−4.13	<.001
Prime conceptual order	1.47	0.16	9.12	<.001
Color repeated prime				
(Intercept)	−0.53	0.24	−2.24	.025
Prime conceptual order	1.80	0.15	11.68	<.001
Non-repeated prime				
(Intercept)	−1.23	0.21	−5.74	<.001
Prime conceptual order	1.39	0.15	9.24	<.001
(3) Experiment 3C (Pattern repetition)				
(Intercept)	−1.12	0.18	−6.20	<.001
Prime conceptual order	1.85	0.15	12.63	<.001
Prime syntax	0.05	0.09	0.58	.564
Pattern repetition	−0.04	0.09	−0.50	.617
Prime conceptual order × syntax	−0.41	0.08	−4.92	<.001
Prime conceptual order × pattern repetition	0.55	0.09	5.94	<.001
Prime syntax × pattern repetition	0.19	0.08	2.27	.023
Prime conceptual order × syntax × repetition	−0.29	0.08	−3.57	<.001
Pattern-repeated				
(Intercept)	−0.97	0.18	−5.32	<.001
Prime conceptual order	2.17	0.19	11.36	<.001
Non-repeated				
(Intercept)	−1.03	0.18	−5.73	<.001
Prime conceptual order	1.23	0.13	9.27	<.001
AAN prime				
(Intercept)	−1.07	0.19	−5.81	<.001
Prime conceptual order	2.07	0.18	11.78	<.001
Pattern repetition	−0.20	0.13	−1.57	.117
Prime conceptual order × pattern repetition	0.79	0.13	5.99	<.001
ANRC prime				
(Intercept)	−1.07	0.20	−5.39	<.001
Prime conceptual order	1.42	0.15	9.50	<.001
Pattern repetition	0.16	0.10	1.63	.102
Prime conceptual order × pattern repetition	0.24	0.10	2.54	.011

boosted relative clause responses even after adjective-adjective-noun primes.

Study 3 also replicated the findings from Studies 1 and 2. As in Study 1, syntactic priming was larger with CP primes than with PC primes in Experiments 3B and 3C, though this interaction was not observed in Experiment 3A, where noun repetition enhanced syntactic priming. Likewise, conceptual order priming was larger with AAN primes than with ANRC primes in all experiments. As in Study 2, adjective repetition interacted with conceptual order priming. When the prime and the target had the same color or pattern in the utterance, it led to a stronger tendency to repeat the relative conceptual category order of the prime. Again, there was no evidence that adjective repetition generally resulted in the earlier placing of the repeated adjective; if so, the repetition of the second adjective in the prime should not have increased primed responses. Pattern repetition enhanced adjective order priming not only when pattern occurred first (in PC primes) but also when it occurred second (in CP primes). Likewise, color repetition led to more PC responses when color occurred second (in PC primes).

As in Study 2, color repetition did not boost CP orders following CP primes. Recall that the interactive priming account predicts that the repetition of a concept increases the persistence of the same concept-conceptual order mapping. In Fig. 7, the concept GREEN is linked to the PC node. When the concept GREEN is repeated after a PC prime, it should increase PC responses because the residual activation of the GREEN-PC link should boost the activation of the PC node. Likewise, the repetition of SPOTTED after CP primes should increase CP responses, because the CP node receives a boost from the residual activation of the SPOTTED-CP link. When GREEN is repeated after a CP prime, it does not boost CP responses, however. We suggest that this is because *regardless of repetition*, the higher accessibility of GREEN influences the GREEN-CP mapping, so that GREEN is produced earlier. It is not that CP responses cannot be boosted by any repetition nor color repetition does not boost any response. As we have just discussed, CP responses can be boosted by the repetition of SPOTTED after CP primes, and the repetition of GREEN can boost PC responses after PC primes. These effects are driven by the SPOTTED-CP and GREEN-PC mappings, not GREEN-CP mapping which underpins accessibility-based ordering. That is, accessibility affects adjective ordering because speakers select a particular conceptual order that enables the earlier placing of a particular concept, the same kind of abstract ordering information that underpins conceptual order priming.

To summarize, Studies 2 and 3 showed that whilst both noun repetition and adjective repetition enhance conceptual order priming, only noun repetition enhances syntactic priming. The findings thus provided further support for the interactive priming account: Adjective category orders and syntactic structures are represented separately and at different levels, such that conceptual order priming and syntactic priming can be activated independently and differently boosted.

General discussion

The current study began by asking the extent to which the priming of the use of relative clause structures (*syntactic priming*) is independent from the priming of the conceptual category order of the adjectives (*conceptual order priming*). In Study 1, participants tended to use a relative clause structure such as *spotted bow that's green* (ANRC structure) as opposed to *spotted green bow* (AAN structure) more often when they had heard the same structure in the preceding trial, demonstrating syntactic priming. Participants were also primed by the relative order of the concept categories, producing pattern-before-color (PC) orders more often after having heard PC orders than after having heard color-before-pattern (CP) orders, demonstrating conceptual order priming. Critically, syntactic priming was larger when participants chose the same conceptual order as in the prime rather than a different conceptual order from the prime, and conceptual order priming was larger when participants chose the same syntactic structure as in the prime than when they chose a different syntactic structure. As a result, the prime syntax was more likely to persist in the target when it was combined with conceptual orders (i.e., CP orders) that were more likely to be repeated in the target and hence enhance syntactic priming via *cross-level* interactive priming. Likewise, the prime conceptual order persisted more in the target when it was realized with the syntactic structure (i.e., AAN structures) that was more likely to be repeated in the target and hence trigger cross-level interactive priming. Studies 2 and 3 further examined *within-level* interactive priming, demonstrating that conceptual order priming and syntactic priming can be boosted independently: Whereas conceptual order priming is enhanced by noun, color or pattern repetition, syntactic priming can only be enhanced by noun repetition.

These findings supported the **interactive priming model**, which extends the residual activation model (Cleland & Pickering, 2003; Pickering & Branigan, 1998) in significant ways. Whilst the residual activation model primarily focuses on syntactic priming, the interactive priming model takes account of the existence of abstract conceptual orders. As illustrated in Fig. 6, the two conceptual order nodes, the CP node and the PC node, are represented at the conceptual level, separate from syntactic structures, the AAN node and ANRC node, at the lemma/syntactic level. The same conceptual orders are shared across different syntactic structures. Hence the processing of a prime activates not only its conceptual order node and syntactic structure node but also the links that binds them. Whilst the residual activation of a conceptual order node or a syntactic node increases the chance of each node being reselected, the binding link influences the persistence of the conceptual order-syntax mapping. This *cross-level interactive priming* increases the likelihood of both nodes being selected again. That is, the processing of *spotted bow that's green* activates the PC node, the ANRC node, and the PC-ANRC link that binds the two nodes. The residual activation of the PC-ANRC link will enhance the persistence of the PC-ANRC mapping, by boosting the activation of the ANRC node when the PC order is activated for selection, or by boosting the PC node if the ANRC node gets activated for selection. Cross-level interactive priming explains why in the current study, a syntactic structure perseverated more in the target when the prime had CP order rather than PC order, and why a conceptual order perseverated more in the target when the prime had the AAN structure than the ANRC structure. Participants generally persevered with CP order primes and with AAN structure primes more than their alternatives, and this increased the likelihood of cross-level interactive priming.

As the repetition of a syntactic head enhances syntactic priming (Pickering & Branigan, 1998), conceptual order priming can be enhanced by the repetition of associated concepts. We propose that both enhancements, albeit involving different representations, are underpinned by the same mechanisms that drive cross-level interactive priming. At the conceptual level, the processing of *spotted bow that's green* activates the PC node, the concepts of SPOTTED, GREEN, BOW, and the links between them. The repetition of GREEN enhances the priming of the PC node because the residual activation of the GREEN-PC link will increase the probability of the GREEN-PC mapping in the target. At the syntactic level, *spotted bow that's green* activates the ANRC node, the lemma, *bow,* and the link between them. The repetition of *bow* enhances syntactic priming because the residual activation of the *bow*-ANRC link will increase the probability of the *bow*-ANRC mapping in the target, by boosting the activation of the ANRC node when *bow* is repeated. Noun repetition also enhances conceptual order priming: At the conceptual level, the residual activation of the BOW-PC link influences the persistence of the BOW-PC mapping, increasing PC responses when BOW is repeated. By contrast, adjective repetition does not enhance syntactic priming, because the lemma, *green,* is not linked to the ANRC node at the syntactic level.

Our findings have implications for theories of grammatical encoding. As discussed earlier, a common assumption has been that conceptual representations are "unordered" (e.g., Bock & Levelt, 1994), so different word orders or structures must originate from single conceptual representations (e.g., Bock et al., 1992; Hartsuiker et al., 1999). Study 1 thus pitched the interactive priming account against two alternative accounts, both of which assume that adjective order priming occurs during grammatical encoding. The two-stage syntactic priming account was motivated by the two-stage model of language production (Bock & Levelt, 1994; Garrett, 1980; Hartsuiker et al., 1999), which assumes that speakers select a linearly unspecified syntactic structure before deciding the linear order of the lexical items. Hence, whilst syntactic priming can arise in the absence of conceptual order priming, the reverse cannot hold. The second hypothesis was motivated by a one stage model of constituent assembly (Pickering et al., 2002), which assumes that structural priming is driven by linearly specified syntactic representations. On this view, both adjective order priming and syntactic priming should be driven by the syntactic structure that specifies adjective ordering, such that neither syntactic priming nor conceptual order priming can occur in the absence of its counterpart. In the current study, syntactic priming occurred even when speakers adopted a different conceptual order from the prime and conceptual order priming occurred even when speakers adopted a different syntactic structure from the prime.

Our account thus offers an alternative explanation to the findings that motivated these accounts. Hartsuiker et al. (1999) showed in Dutch that fronted locatives (*Op de tafel ligt een bal*, On the table is a ball) prime fronted locatives, and standard locatives (*Een bal ligt op de tafel*, A ball is on the table) prime standard locatives. Fronted locatives share the same functional relations as standard locatives but differ in the linear order of the constituents. Hartsuiker et al. interpreted their finding as supporting the two-stage model, attributing the effect to the priming of linearization processes. Pickering et al. (2002) found in English that shifted prepositional object structures such as *The racing driver showed to the helpful mechanic the torn overall* do not elicit prepositional object responses such as *The patient showed the book to the nurse* as opposed to double-object alternatives such as *The patient showed the nurse the book*, relative to a baseline condition. Interestingly, Pickering et al. interpreted their findings as supporting the one-stage model of constituent assembly; shifted prepositional object structures did not prime non-shifted prepositional object structures, because these two structures differ in word order and hence are represented by separate combinatorial nodes. Given the current findings, both Hartsuiker et al.'s (1999) findings and Pickering et al.'s (2002) findings could be attributable to the priming of non-syntactic, conceptual-level representations. Fronted locatives prime fronted locatives in Dutch at least in part because speakers repeat the relative order of the location concept in the prime description. Shifted prepositional object structures do not prime prepositional object structures in English because these two structures differ in non-syntactic structure, i.e., the order of thematic roles; *recipients* precede *themes* in shifted prepositional object structures, whereas this is reversed in the prepositional object structures. Hence, the priming of thematic role order at a non-syntactic level and the priming of syntactic structure at the syntactic level may cancel each other out; that is, shifted-prepositional objects elicit double-object alternatives on some occasions, via the priming of thematic role order, whereas they elicit standard prepositional object forms on other occasions, via syntactic priming.

Furthermore, the interactive priming model sheds new light on accessibility-based production models. Accessibility has been assumed to affect word order choice (e.g., Bock, 1986a; Bock & Irwin, 1980; Bock & Warren, 1985; Fukumura, 2018; McDonald et al., 1993; Prat-Sala & Branigan, 2000; V.Ferreira & Yoshita, 2003) because grammatical encoding matches the order of conceptual encoding by assigning the more accessible information a syntactic role or position that occurs early (Levelt, 1989; De Smedt, 1990; Kempen & Hoenkamp, 1987), but crucially, not vice versa: Conceptual processes are assumed to proceed without any access to grammatical knowledge (cf. Garrett, 1975; 1980;

Kempen & Hoenkamp, 1987). However, there is evidence indicating that the order in which speakers generate a string of concepts could be affected by the syntax of the language in use. Brown-Schmidt and Konopka (2008) found that English-Spanish bilinguals tend to fixate an un-mentioned size contrast (e.g., a large butterfly for *small butterfly*) earlier when speaking in English, where the size modifier precedes the noun, than when speaking in Spanish, where the size modifier follows the noun. Assuming that fixation patterns to un-mentioned size contrasts reflect conceptual encoding, such a cross-linguistic difference would be hard to account for if conceptual encoding proceeds without access to the grammar in the language.

Hence, we suggest that accessibility influences word order choice not only because grammatical encoding matches the order of conceptual encoding but also because conceptual encoding matches the to-be-selected syntax generated by grammatical encoding at least under some circumstances. In line with other language production theories (e.g., Levelt, 1989; De Smedt, 1990; Kempen & Hoenkamp, 1987), we assume that although conceptual encoding normally starts earlier than grammatical encoding, these processes occur *in parallel*; language production occurs incrementally, and grammatical encoding can commence before conceptual encoding completes. Importantly, as we have seen in the current study, both processes can be primed, influenced by the lingering representations from earlier processing; that is, conceptual encoding can be led by the conceptual order of the prime, and grammatical encoding can be driven by the syntactic structure of the prime. Because both representations are pre-activated, the primed syntactic structure can become available early, possibly as early as the primed conceptual order. Moreover, the conceptual order and the syntactic structure of the prime are associated. As well as simultaneous availability afforded by priming, this primed association between them makes it highly likely that speakers choose the primed conceptual order in association with the primed syntactic structure, so that they can generate concepts in a manner compatible with the to-be-selected syntactic structure. Hence accessibility affects structural choice because speakers choose a conceptual order that enables the earlier placing of more accessible concepts in the to-be-selected syntactic structures. This should not be taken to imply an overly broad scope of planning at the conceptual level, however, because the primed representations can be activated very quickly.

Chang et al. (2006) proposed that structural priming results from *implicit learning*, the mechanism that underpins language acquisition. In their Dual Path model, structural priming arises from changes in the network responsible for the sequencing processes. On this account, structural priming should thus have a long-lasting impact on structural choice, consistent with evidence that structural priming persists across many intervening trials (e.g., Bock & Griffin, 2000; Hartsuiker et al., 2008). Although the sequencing processes operate separately from the conceptual processes that generate event semantics, the network can learn the non-syntactic information that guides the message-syntax mapping. Hence, unlike the residual activation model (Pickering & Branigan, 1998), the implicit learning account predicts thematic role order priming between sentences that have the same syntactic structures (Chang et al., 2003), by encoding semantic information from the distribution of words in the input into its syntactic representations (Twomey et al., 2014). Hence, the model might be extended to predict the conceptual order priming found in the current study. However, the sequencing processes are assumed to proceed without involvement of specific lexical representations. Thus, although the model can predict small independent priming, it does not predict interactive priming, which boosts priming substantially. The implicit learning account attributes the boost effects to an explicit memory mechanism in which the repeated verb (or for that matter, any repeated word, head or non-head) acts as a cue to the structure of the prime, which is separate from the one responsible for structural priming (Chang et al., 2012).

According to the interactive priming account, syntactic priming is enhanced when speakers adopt the same conceptual order of the prime (via cross-level interactive priming) or when they repeat the head noun (via within-level interactive priming), because when the prime conceptual order or the prime head noun is activated for selection, it will send a boost to the associated primed syntactic structure. Hence, indeed, the boost effects may arise because the repeated information serves as a retrieval cue for the primed structure. Crucially, for such boost effects to arise, there must be an established association between the repeated information and the primed structure. Assuming that abstract syntactic structures are associated with their heads, but not non-heads at the lemma/syntactic level (Branigan & Pickering, 2017; Carminati et al., 2019; Pickering & Branigan, 1998), we can explain why syntactic priming is boosted by noun repetition, but not by adjective repetition. Likewise, assuming that abstract conceptual category orders are associated with conceptual category tokens that underpin such representations, we can explain why conceptual order priming can be boosted by adjective repetition.

Some findings suggest that lexical boost effects are short-lived, whereas structural priming is long-lasting (Bock & Griffin, 2000; Hartsuiker et al., 2008; Branigan & McLean, 2016). These findings could be taken as supporting the implicit learning account, which assumes that boost effects due to the prime and target lexical overlap rely on short-term memory so they must be short-lived, whilst priming with no lexical overlap relies on implicit learning so the effect must be long-lasting. The current study did not manipulate the lags between primes and targets. Whilst this could be addressed in future research, such investigation may not inform whether the mechanisms that underlie the boost effects differ from those underlying priming without lexical overlap. Research has shown that priming with no lexical overlap also declines as the lag between the prime and target increases (Bernolet et al., 2016). Hence, even if abstract priming effects last over longer lags than the boost effects, it might just be that the links between the nodes are less activated or their activation decays faster than that of the nodes themselves (cf., Malhotra et al., 2008). There is also evidence against the explicit memory account of the lexical boost effect. Yan et al. (2018) found a lexical boost effect as well as abstract structural priming with people with explicit short-term memory deficits, with no reliable correlation between the degree of short-term memory deficits and the magnitude of the lexical boost effect. Most important, the main findings of the current study are that syntactic priming interacts with conceptual order priming, with stronger syntactic priming when the conceptual order of the prime also persists than otherwise, and syntactic priming can only be boosted by noun repetition, whilst conceptual order priming can be enhanced by adjective repetition as well as by noun repetition. We have proposed a novel account that can explain these findings.

Bernolet et al. (2009) proposed bindings of *emphasis* as a mechanism of structural priming: Speakers are primed with the binding of emphasis to certain thematic roles (see also Cai et al., 2012; Vernice et al., 2012). Their cross-linguistic priming experiments showed that Dutch agent-initial passives do not prime agent-final passives in English. By contrast, both agent-medial and agent-final Dutch passives, which match English passives in the relative order of the thematic roles, prime English passives. In Dutch, agent-medial passives and agent-final passives did not prime each other. Bernolet et al. assumed that both grammatical function assignment and linearization contribute to emphasizing. Indeed, their norming data indicated that the agent role was perceived as emphasized more in agent-initial active sentences, where the agent was the grammatical subject, than in agent-initial passives, where the agent was an oblique object. Perceived emphasis on the agent role decreased further in agent-medial or final passives, where the agent was mentioned after the patient role, and the perceived agent-emphasis did not differ between agent-medial and agent-final passives. Hence, according to Bernolet et al., structural priming is driven by the persistence of emphasis on thematic roles. Critically, the emphasis account does not fully specify the representations and processes that underpin the computation of emphasis. Suppose that conceptual order priming and syntactic priming are both driven by emphasis in the current study. Because the emphasis account does not distinguish between the levels of processing, it does not explain why conceptual priming should interact with syntactic priming and why conceptual order priming and syntactic priming can be differentially boosted.

Finally, relative clause (ANRC) responses occurred primarily when the prime had the ANRC structure; the rates were very low following adjective-adjective noun (AAN) primes. This was in line with Cleland and Pickering's study (2003) and in part because AAN primes elicited AAN responses. Although ANRC structures were less preferred, they can occur spontaneously with no priming task, as was observed in Experiment 1 in Fukumura (2018) (e.g., *chequered pipe... that's red*; *blue bowl that is striped*). Some may wonder under what conditions these constructions may occur more frequently. For instance, it is possible that these constructions are more sensitive to the information status of the attributes (than simpler constructions); speakers may use these constructions to discriminate the referents by a *given* attribute first, before restricting them further with a *new* attribute in the relative clause. This is a separate question that can be examined in future research. Importantly, studies have used constructions that are rare (e.g., shifted prepositional object structures in English, Pickering et al., 2002), ungrammatical (e.g., double object structures with verbs such as *donate*, Ivanova et al., 2012) or even non-existent in the target language (e.g., Bernolet et al., 2009) to examine structural priming. In the current study, the relative clause structures were found to be highly sensitive to priming and to share representations with simpler, more frequent structures and to help discriminate competing hypotheses.

The fact that the rates of less frequent ANRC structures and PC orders in the current study were strongly dependent on priming may appear to be in line with evidence that suggests that the magnitude of priming is inversely related to the frequencies of different constructions (i.e., less frequent structures prime more strongly) (see Ferreira & Bock, 2006); for instance, active–passive priming can be driven primarily by the priming of passive structures, which are less frequent than actives (e.g., Bock, 1986a; Hartsuiker & Kolk, 1998). However, without a baseline, it is not possible to determine whether the ANRC structure and PC order were affected by priming more than other structures and orders. Certainly, it was not the case that the priming effects were driven by the less frequent prime constructions only in the current study; the AAN structure and the CP order were repeated from the prime to the target more often (in part due to the differences in the baseline preference), and when less frequent structures (ANRC structures) or orders (PC orders) were combined with more frequent counterparts (CP orders, AAN structures, respectively) in the prime, we found stronger syntactic priming or conceptual order priming, respectively, and we have proposed an account that explains this.

Summary and conclusions

We showed that syntactic priming interacts with conceptual order priming in noun phrase production. Syntactic structures tend to perseverate more often when the associated conceptual order persists from the prime to the target than otherwise, and conceptual orders tend to perseverate more when the associated syntactic structure persists in the target than otherwise. Importantly, conceptual orders and syntactic structures are represented separately and at different levels, and they can be activated independently: Whereas syntactic priming can only be enhanced by noun repetition, conceptual order priming can be enhanced by not only noun repetition but also by adjective repetition. Thus, although adjective orders and syntactic structures are activated separately and at different levels, conceptual order priming and syntactic priming interact because the interface between them is primed, leading to cross-level interactive priming.

CRediT authorship contribution statement

Kumiko Fukumura: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization, Supervision, Project administration, Funding acquisition. **Shi Zhang:** Methodology, Investigation, Data curation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

We have shared the link to the data/code in the manuscript.

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Appendix A: Distribution of target responses by prime in Study 1

Prime	Target response											
	CP AAN			CP ANRC			PC AAN			PC ANRC		
	n	%	*SE*	*n*	%	*SE*	*n*	%	*SE*	*n*	%	*SE*
Experiment 1A: Noun repeated												
CP AAN	397	92.3 %	1.3 %	3	0.7 %	0.4 %	29	6.7 %	1.2 %	1	0.2 %	0.2 %
CP ANRC	130	31.0 %	2.3 %	263	62.8 %	2.4 %	22	5.3 %	1.1 %	4	1.0 %	0.5 %
PC AAN	129	30.1 %	2.2 %	8	1.9 %	0.7 %	289	67.5 %	2.3 %	2	0.5 %	0.3 %
PC ANRC	119	28.0 %	2.2 %	42	9.9 %	1.4 %	74	17.4 %	1.8 %	190	44.7 %	2.4 %
Experiment 1B: Noun not-repeated												
CP AAN	362	85.2 %	1.7 %	10	2.4 %	0.7 %	52	12.2 %	1.6 %	1	0.2 %	0.2 %
CP ANRC	142	35.1 %	2.4 %	197	48.6 %	2.5 %	60	14.8 %	1.8 %	6	1.5 %	0.6 %
PC AAN	163	38.7 %	2.4 %	12	2.9 %	0.8 %	241	57.2 %	2.4 %	5	1.2 %	0.5 %
PC ANRC	145	36.0 %	2.4 %	68	16.9 %	1.9 %	109	27.0 %	2.2 %	81	20.1 %	0.2 %

Note. *SE* = Standard error.

Appendix B: Analysis of each target response by prime in Study 1

Contrast	Experiment 1A: Noun repeated				Experiment 1B: Noun not-repeated			
	Estimate	*SE*	*z*	*p*	*Estimate*	*SE*	*z*	*p*
CP ANRC responses								
CP ANRC vs CP AAN	−11.70	2.39	−4.89	<.0001	−5.00	0.43	−11.52	<.0001
CP ANRC vs PC AAN	−10.70	2.18	−4.88	<.0001	−4.41	0.43	−10.27	<.0001
CP ANRC vs PC ANRC	−4.80	0.63	−7.66	<.0001	−2.05	0.27	−7.67	<.0001
PC ANRC responses								
PC ANRC vs CP AAN	−11.07	2.75	−4.02	.0002	−5.72	1.72	−3.33	.0025
PC ANRC vs CP ANRC	−9.44	2.55	−3.70	.0006	−3.81	1.37	−2.79	.0148
PC ANRC vs PC AAN	−6.29	0.78	−8.11	<.0001	−3.57	0.51	−6.96	<.0001
CP AAN responses								
CP AAN vs PC AAN	−3.93	0.33	−11.89	<.0001	−2.78	0.25	−11.24	<.0001
CP AAN vs CP ANRC	−4.20	0.42	−9.91	<.0001	−2.95	0.27	−10.82	<.0001
CP AAN vs PC ANRC	−4.89	0.55	−8.91	<.0001	−3.00	0.29	−10.18	<.0001
PC AAN responses								
PC AAN vs CP AAN	−3.82	0.24	−15.80	<.0001	−2.98	0.27	−11.01	<.0001
PC AAN vs CP ANRC	−4.06	0.26	−15.46	<.0001	−2.71	0.26	−10.31	<.0001
PC AAN vs PC ANRC	−2.65	0.19	−14.21	<.0001	−1.56	0.17	−9.11	<.0001

Note. *P* value adjustment: Dunnett's method for 3 tests.

Appendix C: Cross-experiment comparisons in Study 1

Fixed Effects	*Estimate*	*SE*	*z*	*p*
Comparison on syntactic choice				
(Intercept)	−3.04	0.29	−10.66	<.001
Prime syntax	3.14	0.25	12.46	<.001
Prime conceptual order	−0.02	0.11	−0.14	.885
Experiment (noun repeated vs non-repeated)	0.00	0.23	0.00	.998
Prime syntax × conceptual order	−0.43	0.11	−3.74	<.001
Prime syntax × experiment	0.66	0.22	2.98	.003
Prime conceptual order × experiment	0.08	0.12	0.67	.506
Prime syntax × conceptual order × experiment	−0.06	0.12	−0.48	.629
Comparison on conceptual order choice				
(Intercept)	−1.20	0.14	−8.60	<.001
Prime conceptual order	1.74	0.11	15.21	<.001
Prime syntax	−0.10	0.06	−1.56	.119
Experiment (noun repeated vs non-repeated)	−0.07	0.13	−0.52	.605
Prime conceptual order × syntax	−0.15	0.06	−2.55	.011
Prime conceptual order × experiment	0.41	0.11	3.68	<.001
Prime syntax × experiment	−0.03	0.06	−0.56	.573
Prime conceptual order × syntax × experiment	0.09	0.06	1.63	.104

Appendix D: Analyses of syntactic and conceptual order congruence in Study 1

Fixed Effects	Experiment 1A: Noun repeated				Experiment 1B: Noun not-repeated			
	Estimate	*SE*	*z*	*p*	*Estimate*	*SE*	*z*	*p*
Conceptual order congruence as outcome variable								
(Intercept)	2.22	0.21	10.54	<.001	1.30	0.13	9.75	<.001
Prime conceptual order	−1.31	0.19	−7.03	<.001	−1.11	0.19	−5.76	<.001
Prime syntax	−0.06	0.09	−0.67	.505	−0.25	0.07	−3.64	<.001
Prime conceptual order × syntax	−0.15	0.11	−1.36	.175	−0.05	0.07	−0.77	.440
Syntactic congruence as outcome variable								
(Intercept)	4.32	0.51	8.46	<.001	2.28	0.25	9.28	<.001
Prime syntax	−3.33	0.47	−7.11	<.001	−2.70	0.31	−8.81	<.001
Prime conceptual order	−0.55	0.24	−2.26	.024	−0.36	0.12	−2.98	.003
Prime syntax × conceptual order	0.05	0.22	0.25	.804	−0.10	0.12	−0.79	.432

Appendix E: Cross-experiment comparisons on conceptual ordering in Study 2

Fixed Effects	*Estimate*	*SE*	*z*	*p*
Experiment 2A (noun repetition) vs Experiment 2B/2C (adjective repetition)				
(Intercept)	−1.21	0.13	−9.16	<.001
Prime conceptual order	1.56	0.09	18.08	<.001
Repetition	0.02	0.04	0.43	.666
Experiment (noun vs adjective repetition)	−0.26	0.12	−2.11	.035
Prime conceptual order × repetition	0.33	0.04	7.63	<.001
Prime conceptual order × experiment	−0.02	0.08	−0.28	.776
Repetition × experiment	−0.11	0.05	−2.33	.020
Prime conceptual order × repetition × experiment	−0.02	0.05	−0.47	.636
Experiment 2B (color repetition) vs Experiment 2C (pattern repetition)				
(Intercept)	−1.03	0.15	−6.96	<.001
Prime conceptual order	1.59	0.10	15.63	<.001
Repetition	0.07	0.05	1.29	.198
Experiment (color vs pattern repetition)	−0.03	0.14	−0.25	.802
Prime conceptual order × repetition	0.37	0.05	6.95	<.001
Prime conceptual order × experiment	0.29	0.09	3.29	.001
Repetition × experiment	−0.22	0.05	−4.14	<.001
Prime conceptual order × repetition × experiment	0.12	0.05	2.28	.023

Appendix F: Distribution of target responses by prime and repetition in Study 3

Repetition	Prime	Target response											
		CP AAN			CP ANRC			PC AAN			PC ANRC		
		n	%	*SE*	*n*	%	*SE*	*n*	%	SE	*n*	%	*SE*
Experiment 3A: Noun repetition													
Noun repeated	CP AAN	227	95.4 %	1.4 %	1	0.4 %	0.4 %	10	4.2 %	1.3 %	0	0.0 %	0.0 %
	CP ANRC	73	31.5 %	3.1 %	143	61.6 %	3.2 %	11	4.7 %	1.4 %	5	2.2 %	1.0 %
	PC AAN	64	27.0 %	2.9 %	3	1.3 %	0.7 %	170	71.7 %	2.9 %	0	0.0 %	0.0 %
	PC ANRC	53	22.6 %	2.7 %	28	12.0 %	2.1 %	42	17.9 %	2.5 %	111	47.4 %	3.3 %
Non-repeated	CP AAN	215	91.5 %	1.8 %	3	1.3 %	0.7 %	16	6.8 %	1.6 %	1	0.4 %	0.4 %
	CP ANRC	94	41.4 %	3.3 %	115	50.7 %	3.3 %	17	7.5 %	1.8 %	1	0.4 %	0.4 %
	PC AAN	104	44.8 %	3.3 %	3	1.3 %	0.7 %	125	53.9 %	3.3 %	0	0.0 %	0.0 %
	PC ANRC	89	39.2 %	3.2 %	32	14.1 %	2.3 %	47	20.7 %	2.7 %	59	26.0 %	2.9 %
Experiment 3B: Color repetition													
Color repeated	CP AAN	202	86.7 %	2.2 %	1	0.4 %	0.4 %	24	10.3 %	2.0 %	6	2.6 %	1.0 %
	CP ANRC	84	36.5 %	3.2 %	102	44.3 %	3.3 %	35	15.2 %	2.4 %	9	3.9 %	1.3 %
	PC AAN	56	23.8 %	2.8 %	2	0.9 %	0.6 %	173	73.6 %	2.9 %	4	1.7 %	0.8 %
	PC ANRC	65	28.6 %	3.0 %	13	5.7 %	1.5 %	75	33.0 %	3.1 %	74	32.6 %	3.1 %
Non-repeated	CP AAN	202	87.1 %	2.2 %	1	0.4 %	0.4 %	27	11.6 %	2.1 %	2	0.9 %	0.6 %
	CP ANRC	96	41.2 %	3.2 %	109	46.8 %	3.3 %	25	10.7 %	2.0 %	3	1.3 %	0.7 %
	PC AAN	97	42.0 %	3.3 %	3	1.3 %	0.7 %	127	55.0 %	3.3 %	4	1.7 %	0.9 %
	PC ANRC	86	37.7 %	3.2 %	28	12.3 %	2.2 %	59	25.9 %	2.9 %	55	24.1 %	2.8 %
Experiment 3C: Pattern repetition													
Pattern repeated	CP AAN	226	95.4 %	1.4 %	5	2.1 %	0.9 %	5	2.1 %	0.9 %	1	0.4 %	0.4 %
	CP ANRC	73	32.2 %	3.1 %	127	55.9 %	3.3 %	26	11.5 %	2.1 %	1	0.4 %	0.4 %
	PC AAN	46	19.7 %	2.6 %	3	1.3 %	0.7 %	182	78.1 %	2.7 %	2	0.9 %	0.6 %
	PC ANRC	62	27.2 %	3.0 %	19	8.3 %	1.8 %	61	26.8 %	2.9 %	86	37.7 %	3.2 %
Non-repeated	CP AAN	194	83.3 %	2.5 %	6	2.6 %	1.0 %	33	14.2 %	2.3 %	0	0.0 %	0.0 %
	CP ANRC	83	36.7 %	3.2 %	112	49.6 %	3.3 %	28	12.4 %	2.2 %	3	1.3 %	0.8 %
	PC AAN	90	39.0 %	3.2 %	6	2.6 %	1.0 %	130	56.3 %	3.3 %	5	2.2 %	1.0 %
	PC ANRC	78	35.1 %	3.2 %	35	15.8 %	2.5 %	54	24.3 %	2.9 %	55	24.8 %	2.9 %

Appendix G: Cross-experiment comparisons on syntactic choice in Study 3

Fixed Effects	*Estimate*	*SE*	*z*	*p*
Experiment 3A (noun repetition) vs Experiment 3B/3C (adjective repetition)				
(Intercept)	−2.99	0.23	−12.78	<.001
Prime structure	2.87	0.17	17.16	<.001
Prime conceptual order	−0.07	0.09	−0.81	.419
Repetition	0.05	0.09	0.56	.579
Experiment (noun vs adjective repetition)	−0.11	0.20	−0.57	.570
Prime structure × conceptual order	−0.29	0.10	−3.02	.002
Prime structure × repetition	0.22	0.08	2.55	.011
Prime conceptual order × repetition	0.00	0.09	0.02	.987
Prime structure × experiment	0.39	0.14	2.72	.007
Conceptual order × experiment	0.02	0.10	0.19	.849

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Fixed Effects	*Estimate*	*SE*	*z*	*p*
Repetition × experiment	0.02	0.10	0.21	.835
Prime structure × conceptual order × repetition	0.04	0.09	0.52	.605
Prime structure × conceptual order × experiment	0.03	0.11	0.26	.793
Prime structure × repetition × experiment	0.20	0.10	2.06	.039
Prime conceptual order × repetition × experiment	0.17	0.10	1.75	.080
Prime structure × conceptual order × repetition × experiment	−0.12	0.10	−1.26	.206
Experiment 3B (color repetition) vs Experiment 3C (pattern repetition)				
(Intercept)	−2.95	0.27	−11.01	<.001
Prime structure	2.63	0.19	13.75	<.001
Prime conceptual order	−0.08	0.10	−0.80	.426
Repetition	0.06	0.09	0.67	.505
Experiment (color vs pattern repetition)	−0.23	0.22	−1.04	.300
Prime structure × conceptual order	−0.32	0.11	−2.93	.003
Prime structure × repetition	0.04	0.09	0.46	.646
Prime conceptual order × repetition	−0.13	0.09	−1.43	.153
Prime structure × experiment	0.00	0.15	−0.02	.988
Conceptual order × experiment	0.00	0.10	0.02	.980
Repetition × experiment	0.09	0.09	1.03	.302
Prime structure × conceptual order × repetition	0.14	0.09	1.60	.110
Prime structure × conceptual order × experiment	−0.03	0.10	−0.24	.807
Prime structure × repetition × experiment	−0.15	0.09	−1.60	.110
Conceptual order × repetition × experiment	0.01	0.09	0.08	.937
Prime structure × conceptual order × repetition × experiment	0.04	0.09	0.42	.672

Appendix H: Cross-experiment comparisons on conceptual ordering in Study 3

Fixed Effects	*Estimate*	*SE*	*z*	*p*
Experiment 3A (noun repetition) vs Experiment 3B/3C (adjective repetition)				
(Intercept)	−0.98	0.14	−6.93	<.001
Prime conceptual order	1.70	0.09	18.18	<.001
Prime syntax	−0.04	0.06	−0.68	.494
Repetition	0.19	0.05	3.58	<.001
Experiment (noun vs adjective repetition)	−0.50	0.24	−2.09	.037
Prime conceptual order × syntax	−0.27	0.05	−5.32	<.001
Prime conceptual order × repetition	0.32	0.05	6.36	<.001
Prime syntax × repetition	0.09	0.05	1.74	.083
Prime conceptual order × experiment	0.30	0.16	1.94	.053
Prime syntax × experiment	0.02	0.10	0.19	.846
Repetition × experiment	−0.03	0.10	−0.29	.772
Prime conceptual order × syntax × repetition	−0.17	0.05	−3.43	.001
Prime conceptual order × syntax × experiment	0.08	0.10	0.82	.411
Prime conceptual order × repetition × experiment	0.06	0.10	0.58	.563
Prime syntax × repetition × experiment	−0.02	0.10	−0.21	.832
Prime conceptual order × syntax × repetition × experiment	0.11	0.10	1.12	.261
Experiment 3B (color repetition) vs Experiment 3C (pattern repetition)				
(Intercept)	−1.01	0.13	−7.53	<.001
Prime conceptual order	1.71	0.09	18.11	<.001
Prime syntax	−0.01	0.06	−0.11	.915
Repetition	0.15	0.05	2.87	.004
Experiment (color vs pattern repetition)	0.10	0.13	0.78	.437
Prime conceptual order × syntax	−0.29	0.05	−5.50	<.001
Prime conceptual order × repetition	0.35	0.05	6.60	<.001
Prime syntax × repetition	0.12	0.05	2.23	.026
Prime conceptual order × experiment	−0.13	0.09	−1.41	.158
Prime syntax × experiment	−0.05	0.06	−0.91	.361
Repetition × experiment	0.18	0.05	3.46	.001
Prime conceptual order × syntax × repetition	−0.20	0.05	−3.81	<.001
Prime conceptual order × syntax × experiment	0.10	0.05	1.93	.053
Prime conceptual order × repetition × experiment	−0.18	0.05	−3.44	.001
Prime syntax × repetition × experiment	−0.06	0.05	−1.23	.221
Prime conceptual order × syntax × repetition × experiment	0.09	0.05	1.64	.101

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