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ARTICLE

The challenge of relational referents in early word extensions: Evidence from noun-noun compounds

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Abstract
Young children struggle more with mapping novel words onto relational referents (e.g., verbs) compared to non-relational referents (e.g., nouns). We present further evidence for this notion by investigating children's extensions of noun-noun compounds, which map onto combinations of non-relational referents, i.e., objects (e.g., *baby* and *bottle* for *baby bottle*), and relations (e.g., a *bottle* FOR *babies*). We tested two- to five-year-olds' and adults' generalisations of novel compounds composed of novel (e.g., *kig donka*) or familiar (e.g., *star hat*) nouns that were combined by one of two relations (e.g., *donka* that has a *kig* attached (=attachment relation) versus *donka* that stores a *kig* (=function relation)). Participants chose between a relational (shared relation) and a non-relational (same colour) match. Results showed a developmental shift from encoding non-relational aspects (colour) towards relations of compound referents, supporting the challenge of relational word referents. Also, attachment relations were more frequently encoded than function relations.

Keywords: Noun-noun compounds; compound-nouns; relational word referents; relational shift

Introduction

Early language development rests on the acquisition of words, i.e., on the understanding that words refer to objects and relations between objects. But not all words are equally easily acquired. In particular, words that have relational referents may be more difficult to acquire (e.g., Gentner, 1982; Gentner & Rattermann, 1991; Gentner & Boroditsky, 2001). There is a wealth of evidence from a range of different word types such as verbs and nouns. The present study focuses on noun-noun compounds which are special in that they combine relational with non-relational aspects.

The most famous debate that has highlighted the challenge of relational words is the one about differences between nouns and verbs. Nouns have been found to dominate children's early vocabularies in many languages, while verbs are much rarer (e.g., Gentner, 1982; for a review see Waxman et al., 2013). There is also experimental evidence that linking verbs to actions is more difficult for young children than linking nouns to objects. When asked to generalise a novel verb, younger children tend to focus too much on the objects involved in an action – struggling, for instance, when the instrument of the action changes (Behrend, 1990; Forbes & Farrar, 1993). Furthermore, it has been found in the same experimental paradigm that three- and five-year-olds were able to generalise a novel noun to a different event, but only five-year-olds were able to generalise a novel verb to a different event if the object being acted on changed (Imai, Haryu & Okada, 2005; Imai et al., 2008). Correct verb extension in younger children appears to require additional support. It can be facilitated through repeated exposure to the action paired with the verb (Waxman et al., 2009) or through the presentation of semantically rich descriptions of action-scenes and the use of an informative syntactic frame that provides information on the verbs' argument structure (Arunachalam & Waxman, 2011; 2015). The requirement for this additional support again demonstrates the challenge of acquiring verbs.

Challenges have also been reported for other word categories. For instance, it takes quite some time to fully master comparative adjectives such as *more* versus *less* or *high* versus *low*, with even four- and five-year-olds sometimes incorrectly using the opposite member of a relational pair (e.g., Clark, 1970; Wales & Campbell, 1970). And, while nouns dominate children's early vocabulary in many languages, not all nouns are equally easily acquired. Children take a while to acquire the full meaning of nouns with a relational meaning such as *passenger* (Hall & Waxman, 1993) or *taxi* (Keil & Batterman, 1984). They appear to purely interpret such nouns as referring to objects that are perceptually similar instead of interpreting them in a relational way (e.g., they fail to interpret a *passenger* as somebody riding a vehicle or *taxi* as a car that takes people wherever they want to go for the exchange of money). This is illustrated in the finding of Hall and Waxman's (1993) experiment, which found that children chose a doll similar to the original referent of "blicket" (defined as somebody riding a car = *passenger*) instead of another doll riding a car. And, interestingly, relational nouns appear in the MacArthur Communicative Developmental Inventory (Fenson et al., 2007) not before the 17 to 30-month range (Gentner, Anggoro & Klibanoff, 2011).

Gentner pointed out that what makes all these words challenging is that they have relational referents (e.g., Gentner, 1982; Gentner & Rattermann, 1991; Gentner & Boroditsky, 2001). For instance, many verbs, especially those in the child's vocabulary, refer to actions that relate people with objects or with other people. Take the verb 'to kick'; it relates an agent who kicks with an object that is kicked. In contrast to verbs, many of children's nouns refer to objects (e.g., *dog* or *bed*). While some of these are (partly) relational (for instance, a *bed* is an object that one sleeps on; see also *taxi* or *passenger* above), many nouns are non-relational and can be purely defined by their perceptual features (e.g., *dog*, *tree*, *banana*). For instance, a prototypical *tree* has a stem, roots, branches, is tall, and has leaves. And even nouns that have a relational component can often be defined by their perceptual features. For instance, a *computer* typically has a base unit, monitor, a mouse, etc. Children can therefore learn what the word *computer* refers to by learning what a computer typically looks like, without incorporating into its meaning the fact that computers are used for writing, gaming, and surfing the internet, etc. This difference between nouns and verbs is likely one of the reasons that makes the acquisition of verbs more challenging than that of nouns (e.g., Gentner, 1982; Gentner & Boroditsky, 2001; Gentner & Rattermann, 1991; Golinkoff & Hirsh-Pasek, 2008).

In sum, previous experimental evidence supports the hypothesis that mapping words onto relations is challenging for young children. The present study aimed to add to this support by focusing on a different word type: namely, English noun-noun compounds. In contrast to verbs and many nouns, noun-noun compounds have both non-relational and relational aspects.

Acquisition of English noun-noun compounds

The meaning of noun-noun compounds is closely linked to their structure. The vast majority of English compounds are modifier-head constructions, also called endocentric compounds; they commonly retain the meaning of the head, and often of the modifier (e.g., Murphy, 1988; Wisniewski, 1996). Thus, a *bedroom* can be paraphrased as a room with a bed. In addition, the meaning of noun-noun compounds also includes an invariable relation between the two nouns. This can take various forms including that of HAS relations (e.g., a *clocktower* is a tower that has a clock attached to it) or function relations (e.g., a *hairbrush* is a brush used to detangle hair; for a discussion of relation types see, e.g., Hatcher, 1960; Downing, 1977; Warren, 1978; Levi, 1978). Since the relations are not overtly expressed, they need to be inferred from experience with compound referents. Relation types occur with varying frequency within children's vocabularies, but relative frequency has been found not to influence children's understanding of a given relation type (Krott, Gagné & Nicoladis, 2009). To illustrate, children need to understand that the compound *clocktower* is not used to refer to, for instance, a tower that is shaped like a clock (i.e., a clock LIKE a tower); and a *hairbrush* is not used to refer to, for instance, a brush that has a picture of hair on it. Similar to the fact that children have to learn that referents of simple nouns such as *ball* can vary in perceptual features (colour, size, etc.), they also have to understand that a compound refers to two constituents and a relation between them, but the exact identity of the constituents (e.g., the colour of the clock or the type of clock) is not part of the compound's meaning. Therefore, a *clocktower* can be ANY tower that has ANY type of clock, and a *hairbrush* can be ANY brush that is used for detangling ANY hair. Note that, similarly, verbs refer to relations between objects and agents and the identity of the objects and agents is not part of their meaning.

English-speaking children possess a good understanding of the status of the two nouns in noun-noun compounds and of their use to refer to interacting objects from around 2 years. At this age, children produce both existing and novel noun-noun compounds (e.g., Clark, 1981; 1983; Snyder, 2001; 2007). They also generally understand the roles of the two nouns as that of the modifier and the head. Clark, Gelman, and Lane (1985) tested whether children successfully map novel compounds onto a combination of a head and a modifier using a forced choice paradigm. For instance, for the novel compound *mouse-hat,* children were asked to pick from a picture of a mouse, a picture of a hat, a picture of a hat on a mouse (the target) and a picture of a hat on a fish. They found that by 2 ½ years children picked the correct picture in on average 50% of all cases (chance level was 25%), and that by three years they rarely made any errors (85% correct responses).

Two-year-olds also start to distinguish between inherent, semi-inherent and accidentally related combinations. This was evident in a compound elicitation task by Clark et al. (1985), for which children were asked to label pictures with objects that were either inherently related (e.g., a house made of a pumpkin), semi-inherently related (e.g., a box with a banana picture on it), or accidentally related (e.g., a mouse

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sitting in a pan). Already 2 ½ year olds named inherently and semi-inherently related objects much more frequently with the means of a compound than accidentally related objects. These results are in line with Snyder's (2001; 2007) work on children's compound acquisition. He suggested that English speaking children acquire a "Generalised Modification" rule around the end of the second or first half of the third year of life. This rule is a "rule of semantic composition" (Snyder, 2012) that accounts for the merging of two nouns into an endocentric compound, both on a syntactic and semantic level. The rule is very general in that it does not specify any specific semantic relation between the nouns of a compound, and it also holds for other syntactic constructions such as English separable particle construction (e.g., "to pull the lid off"). Note also that the rule is relevant only for particular languages (e.g., English, German, and Japanese) – as not all languages have productive compounding.

While a basic understanding of noun-noun compounding is present already in two-year-olds, a full understanding of the relational component of compounds develops much more slowly: namely, into the early school years. For instance, Nicoladis (2003) found that three-year-olds were more likely than four-year-olds to interpret a novel compound (e.g., *sun bag*) as two objects accidentally related (a bag and a sun next to each other) than two objects semi-inherently related (a bag with suns on it). Parault, Schwanenflugel, and Haverback (2005) found that even six- to nine-year-olds occasionally interpret novel compounds as two objects accidentally related to each other, explaining the meaning of a *book magazine* as 'a big magazine next to a little book'.

Children have also been shown to overuse particular relations in their compound interpretations. Comparing children's interpretations of novel compounds (e.g., *egg bag*) with those of adults revealed that they overused relations such as HAS (e.g., "a bag what [sic] got pictures of eggs on it") and LOCATED (e.g., "an egg in a bag") when adults used function relations (= FOR relations; e.g., "a bag FOR eggs") (Krott et al., 2009). Similarly, a forced-choice experiment asked children to pick referents for novel compounds (e.g., *bindle fep*): in it, two- and three-year-olds, but not five-year-olds, preferred object-pairs with relations for which the two objects were permanently physically contiguous (attached to each other or where one object was permanently fixed in another object) over those with function relations (Krott, Gagné & Nicoladis, 2010). For instance, they tended to interpret the novel compound *bindle fep* as a bindle that had a fep attached to it (a type of a HAS relation) rather than a fep that was used to open a bindle (function relation). The question arises whether children's tendency of interpreting compound relations as attachment or location relations might also mean that they would encode attachment (or location) relations more easily as part of a novel compound's meaning than function relations.

The present study

As we have outlined above, previous research on children's word acquisition shows that mapping words onto relations, including compound relations, is challenging for young word learners. Previous findings suggest that young word learners focus their attention too much on non-relational aspects when understanding the meaning of novel words and not enough on relational information. Over the development, they seem to shift their focus towards relational information and their performance becomes adult-like. The primary aim of the present study was to investigate such a developmental focus shift from non-relational towards relational aspects in children's compound word acquisition. Thus, young children (e.g., two-year-olds) might encode the meaning of

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the compound constituents (e.g., *star* and *hat* for the novel compound *star hat*) into their compound representations, but not the specific relation (e.g., 'hat used to store a star'). But the relation might be encoded more often, the older the children are. For that we tested two- to five-year-olds in a word extension paradigm. We also added an adult group to confirm that adults do indeed extend compound words on the basis of relations. Experiments testing verb extensions suggest that young children focus too much on the identity of objects when learning to map a word onto a relation. We therefore pitted a shared relational component against perceptual identity of the constituent objects as a potential basis for extension. A developmental focus shift from non-relational towards relational information would mean that younger children extend compounds on the basis of perceptual identity of constituent objects, while older children and adults extend on the basis of shared relational identity.

Based on previous evidence that children's interpretation and extension of novel noun-noun compounds in other experimental paradigms was affected by whether the constituent objects were related by an attachment or function relation (Krott et al., 2009; 2010), the secondary aim of our study was to investigate whether this might affect children's compound extensions. We therefore constructed two different types of compounds: attachment relation compounds, where constituent objects were related by being permanently attached to each other, and function relation compounds, where constituent objects were related by one of the objects serving a function for the other (e.g., to contain the other object or to manipulate the other object). We used very similar items and relations to those used in Krott et al. (2010). Given previous findings (Krott et al., 2009; 2010), we expected that children would encode attachment relations more easily as part of a compound's meaning than function relations and that they would therefore extend compounds more often on the basis of the relation in case of attachment relations.

Krott et al. (2009) had found that children's and adults' interpretation of a novel compound composed of familiar words (e.g., *egg bag*) is affected by their experience with relations in compounds with the same constituents as the novel compound. More specifically, four- to five-year-olds were affected by their knowledge of compounds with the same head as the novel compound (e.g., *sandwich bag, sandbag, lunch bag, handbag etc.*) and adults more by their knowledge of compounds with the same modifier (e.g., *egg yolk, egg salad, eggcup, egg sandwich*). Utilising novel objects with novel labels provides a true test of whether children understand that relations are important parts of compounds' meaning. In Experiment 1, we therefore tested compounds composed of novel words (words that have not yet occurred in any compounds: e.g., *kig donka*). We expected that the relational component of the compounds (e.g., a *donka* being used as a container for a *kig*) would be encoded more often by the older children and adults than the younger children. Since young children had been found to focus too much on perceptual features and identity of objects, the younger children in our sample might extend the compounds on the basis of perceptual features (e.g., colour) instead of on the relation between the constituent referents.

Experiment 1: Method

Participants

Participants were 14 (old) two-year-olds (mean age 33 months, $SD = 2.8$, range = 27–35 months, 7 males), 26 three-year-olds (mean age 43 months, $SD = 3.8$, range = 36–47

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months, 16 males), 20 four-year-olds (mean age 52 months, $SD = 3.7$, range = 49–58 months, 11 males), 21 five-year-olds (mean age 64 months, $SD = 2.8$, range = 60–70 months, 9 males), and 20 adults (mean age 35 years, $SD = 12.6$, range = 20–59 years, 12 males). A further participant was removed from the study due to not being present for the second day of testing. All participants were recruited from the West Midlands region of the United Kingdom. Nurseries and schools who participated in the study serve middle-class families of this region. Participants were predominantly (95%) White-British. Consent for participation of children was obtained from head-teachers, nursery owners, or parents (parents' consent was requested in these cases by head teacher or nursery owner). All participants were native speakers of English. Two four- and three five-year-olds spoke an additional language and were therefore excluded from the analyses.

Materials

The materials were very similar to those of Krott et al. (2010). Twelve novel objects were given twelve novel names (e.g., *kig, sav, mov*) and paired to serve as referents for six compounds (for complete list, see Supplementary Materials). Each object had two colour versions, which were combined to form two colour versions of the object-pairs (e.g., *kig donka: Version 1* = purple *kig* and orange *donka*; Version 2 = orange *kig* and blue *donka*). See Figure 1 for an example. Objects were combined via relations very similar to those in Krott et al., (2010): via an attachment relation, in which one object was permanently attached to the other (as in *clocktower, pearl ring,* or *ruby necklace*), or via a function relation, where one object had a function for the other (as in *ball pit, hairbrush,* or *egg cup*).

Procedure

Participants were tested individually in a quiet environment over two consecutive days (Figure 1). On day 1, participants learned the names of the novel objects (Part 1) and the compound names of the object-pairs (Part 2) (10–15 minutes). On day 2, participants were asked to extend the compounds to one of two new exemplars (Part 3; 5–10 minutes). We chose to test participants on their compound extension on the next day – instead of immediately after the training – as we wanted to make sure that their responses were based on their representations of the compounds in their mental lexicons and not simply by information stored in their short-term memory.

Part 1: Training of constituent object labels

First, participants learned the names of all novel individual objects (Panels A and B of Figure 1). Participants were introduced to the first object of a particular object-pair (e.g., *kig)* in both colour versions: "This is an X, and this is an X. They are both X. Can you say X? Do you like the X" (e.g., X = *kig).* This was repeated for the second object (e.g., *donka*). Then followed a memory test. Participants were presented with randomly placed examples of each of the two objects (e.g., *kig* and *donka*) and a randomly chosen distracter object (pen, pencil, spoon, or teddy bear), and asked to select one of the two novel objects (e.g., *kig*, decided at random). This procedure was repeated for all object-pairs. None of the participants failed the memory test

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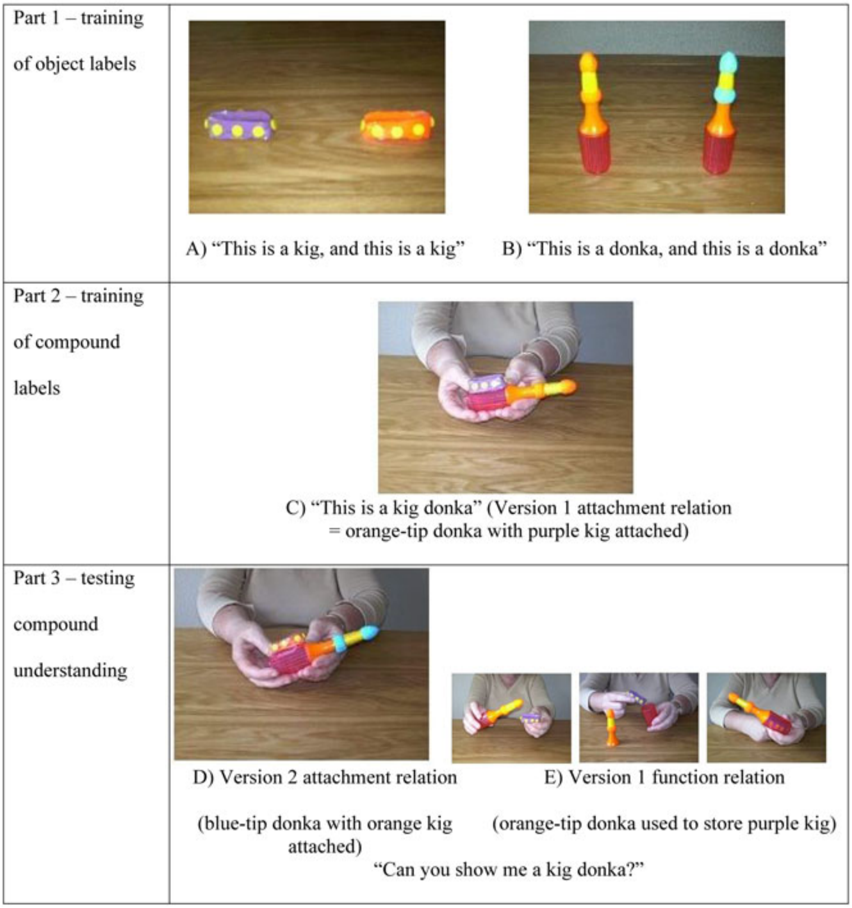

Figure 1. Experimental procedure with example for Experiment 1. Panel A shows Version 1 and 2 kig. Panel B shows version 1 and 2 donka. Panel C shows Version 1 attachment relation kig donka. Panel D shows Version 2 attachment relation kig donka. Panel E shows the function of Version 1 function relation kig donka being demonstrated, i.e., kig and donka are separate in first picture, then kig is placed inside donka in second picture, then kig is inside donka in third picture. The three pictures in Panel E represent one fluid motion.

Part 2: Training of compound labels for object-pairs

Participants were then introduced to the object-pairs and their compound labels. Object-pairs were presented in colour version 1 with either an attachment relation (i.e., one object attached to the other) or a function relation (i.e., one object had a function for the other, e.g., used as a storage container). For example, participants might have seen a version 1 *kig donka* with an attachment relation (Panel C of Figure 1). For attachment relations, constituent objects were presented permanently attached to each other, while, for function relations, constituent objects were separate and it was demonstrated how they functionally relate to each other (for a complete list of object-pairs and relations see Supplementary Materials). Attachment and function relation object-pairs were handled by the experimenter very similarly and for the same amount of time. Attachment relation object-pairs were presented in an

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engaging way by holding and rotating them in different ways. During presentation the experimenter said "this is an XY, isn't the XY interesting, do you like the XY, can you say XY?" (e.g., XY = *kig donka*). This procedure was repeated for all compounds. A participant only saw one relation (attachment relation or function relation) for each object-pair, but saw three attachment relation and three function relations. Presentation of attachment relations or function relations for a particular object-pair was counterbalanced across participants.

Part 3: Testing compound understanding

In the testing phase, participant were told "I'm going to show you some toys and we'll see if you know the names of those toys, is that okay?" They were then shown the same object-pairs that they had seen in Part 2 in two versions: with the same relation as before but in a different colour version (Panel D of Figure 1); and in the same colour version as before but with a different relation (Panel E of Figure 1). During presentation of each option the experimenter said "Look at this, have a good look at it". Object-pairs and relations types were presented as in Part 2. The presentation order of the two options was counterbalanced across participants and object-pairs were randomly placed on the table. Participants were asked: "can you show me an XY" (e.g., XY = *kig donka*). Participants always chose one of the two object-pairs. Part 3 was repeated for all compounds.

Analysis

We analysed the data of all experiments, taking the following two steps. First, we conducted logistic regression analyses using generalised linear mixed effect models in RStudio (2012) version 1.1.383 and the lme4 package version 1.1–14. For all experiments, we tested the effect of age (in months) and the compounds' relation type (attachment vs. function) on relational match responses (1 = relational match, 0 = perceptual match) by starting off with a full model with intercept, Age in months and Relation Type (attachment vs. function) as fixed factors plus their interactions. Following Barr et al. (2013), we included the random factors Participants and Items (= object-pairs) as well as random slopes for Relation Type for both Participants and Items. Since this full model did not converge for any of the experiments, we reduced the complexity of the model step-wise until the model converged. We first reduced the random effect structure, taking out the random slopes for Relation Type for Participants and Items in a step-wise fashion. If a converging model included any random slopes, we tested whether we could reduce the random effect structure by means of model comparisons, using the Akaike information criterion (AIC). Having settled on a random effect structure, fixed effects were tested by step-wise reducing the fixed-effect structure, starting with the interaction Age x Relation Type. Factors and interactions were kept in the model when their removal led to a less powerful model, using maximum likelihood comparisons and an alpha level of .05.

While the logistic regression analyses enabled us to determine whether children's extensions were more often based on compound relations with increasing age, we conducted additional analyses to test whether children's performance in the different age groups was different from chance and whether this was different for the two relation types (attachment and function). These analyses can show whether children of different ages relied predominantly on relational or perceptual similarity for compound extensions. A performance above chance indicates predominant relational compound

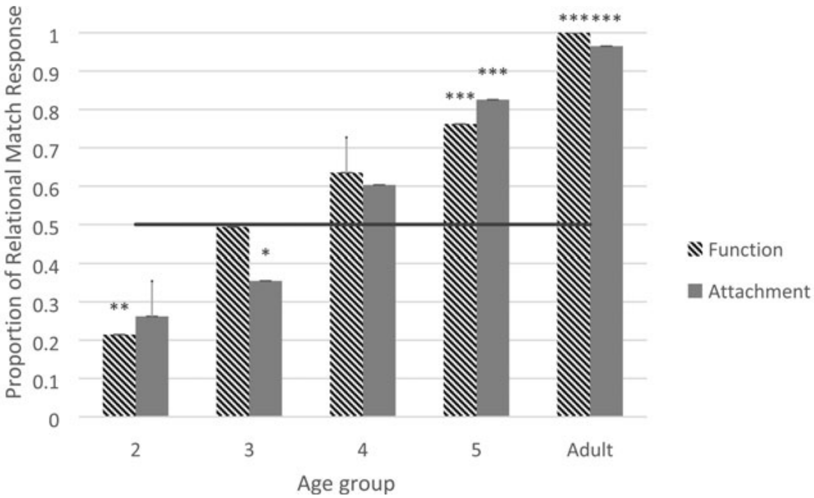

Figure 2. Proportion of extensions of novel noun-noun compounds on the basis of relational identity in Experiment 1, split into Age groups and Relation types; difference from chance level: '.' <.06, '*' p < .05; '**' p < .01; '***' p < .001). Horizontal bar shows chance level and error bars represent standard errors. Below chance performance indicates extensions on the basis of perceptual identity of constituent objects. Above chance performance indicates extensions on the basis of relational identity. Two-year-olds, and partly three-year-olds, extended compounds predominantly by perceptual identity, while older children and adults did so by relational identity.

extensions, while a performance below chance indicates predominantly perceptual compound extensions. We split the participants into age-groups (years) and tested their performance against chance for each age group separately. For instance, for Experiment 1, we split participants into ages 2, 3, 4, 5 and adults. We fitted generalised linear mixed effect models for each age group, except for the adults in Experiment 1, since they clearly responded above chance level (112 relational match responses out of 114 total responses). The models included Relation Type as fixed factors, Participants and Items as random effects, and random slopes for Relation Type for both Participants and Items. In order to test performance against chance level, we tested models without intercepts (glmer(Responses ~ -1 + Relation_Type + (1 + Relation_Type|Participant) + (1 + Relation_Type|Item), data = dat, family = binomial, nAGQ = 1). We followed the same procedure of model reduction and testing as described above.

Results

Figure 2 shows the proportion of extensions made to the object-pair that shared the same relation as the original referent of the compound noun (relational matches) for the five age groups (versus the perceptual matches). Note that we avoid the term 'correct responses' here – because one could argue that, despite an adult preference to extend compounds on the basis of relations, there is no 'correct' response. For Experiment 1, the Relation Type x Age interaction did not converge with the adult data included, likely due to the fact that all adults responded with the relational match for the compounds with function relations. We therefore conducted two

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Table 1. Summary of the fixed effects of the final mixed logistic models for Experiment 1.

	Predictor	Coefficient	SE	*Z*	*p*
All participants	Intercept	−.60	.27	*−2.27*	*.023* *
	Age	.02	.00	*4.43*	*<.001* ***
All participants without adults	Intercept	−4.49	.61	*−7.34*	*<.001* ***
	Age	.10	.01	*7.79*	*<.001* ***
Comparisons against chance					
Age 2	Function relation	−1.54	.56	−2.73	.006 **
	Attachment relation	−1.16	.53	−2.21	.027 *
Age 3	Function relation	−.03	.28	−0.12	.901
	Attachment relation	.10	.29	−2.31	.021 *
Age 4	Function relation	.94	.49	1.93	.054
	Attachment relation	.67	.48	1.40	.162
Age 5	Function relation	1.29	0.37	3.47	<.001 ***
	Attachment relation	1.71	0.41	4.13	<.001 ***

.<.06; *<.05; **<.01; ***<.001

different analyses. First, we continued with a model without the Age x Relation Type interaction. Model comparison showed that the main effect of Relation Type (χ^2 = 0.98, *df* = 1, *p* = .322) was not significant, but the factor Age was (χ^2 = 58.4, *df* = 1, *p* < .001): with participants choosing the relation matched object-pair more often, the older they were. The final model is shown in Table 1. Second, we tested a model with the Age x Relation Type interaction included, but without the data from adults. We found that the interaction of Age and Relation Type was not significant (χ^2 = .00, *df* = 1, *p* = .973). Similar to the analysis with adults included, we found no significant main effect of Relation Type (χ^2 = 0.64, *df* = 1, *p* = .423), but of Age (χ^2 = 59.01, *df* = 1, *p* < .001) (see Table 1 for final model).

To determine predominant compound extensions by relational or perceptual identity for the two Relation Types and for each age group, we tested performance against chance. We ended up with final models that contained the random effects Participants and Items, but no random slopes, for all age groups. The factor Relation Type was significant for two- and five-year-olds, but only marginally for three-year-olds and not significant for four-year-olds (age 2: χ^2 = 6.27, *df* = 2, *p* = .044; age 3: χ^2 = 5.78, *df* = 2, *p* = .056; age 4: χ^2 = 3.64, *df* = 2, *p* = .162; age 5: χ^2=15.07, *df* = 2, *p* < .001). Thus, children's performance differed from chance for the two relation types and the age groups in different ways (see Figure 2 and Table 1). Two-year-olds chose the relation match less often than chance (thus the perceptual match more often than chance) for both relation types, but more clearly for function relations. Three-year-olds chose the relation match less often than chance (thus the perceptual match more often than chance) only for attachment relations, while their performance for function relations was at chance level. Four-year-olds chose relational matches marginally above chance level for compounds with attachment

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relations, while their performance with function relations was at chance level. Finally, five-year-olds chose relational matches above chance level for both relation types, but more so for attachment relations.[1] Importantly, the youngest group of children (two-year-olds) predominantly chose perceptual matches, while the oldest children (five-year-olds) and adults predominantly chose the relational matches, and this was the case for both types of relation.

Discussion

Experiment 1 tested whether children understand that relations are important parts of compounds' meaning. The results show that the ability to generalise novel noun-noun compounds on the basis of relational identity improved with age, with five-year-olds being the youngest group that showed strong evidence for this ability. At age five, children therefore seem to have fully understood that relational information is a crucial part of a compound's meaning and they take this information consistently into account when extending novel compounds to novel instances. Importantly, younger children – that is two-year-olds and, to some degree, three-year-olds – generalised compounds on the basis of perceptual identity of constituent objects, i.e., non-relational perceptual information, rather than on the basis of relational information. As below chance performance indicates a bias towards extensions on the basis of non-relational perceptual aspects and above chance performance indicates a bias towards extensions on the basis of relational aspects, our findings provide clear evidence for a developmental focus shift from generalising on the basis of non-relational aspects of the referents, towards generalising on the basis of relational aspects. Importantly, children were not simply becoming better at understanding and generalising noun-noun compounds with increasing age. There was a qualitative difference in performance, particularly when comparing two-year-olds with five-year-olds. Furthermore, there was almost no indication that the relation type made a difference in children's responses.

As we suggest, the finding that two-year-olds and partly three-year-olds extended compounds on the basis of perceptual identity (instead of relational identity) might mean that they might not have considered relational information to be part of the compounds' meanings. However, the question arises whether the information processing demand in our experiment might have been too high for these young children, so that they were not able to remember the relations. In other words, did they show a perceptual bias simply because they could not remember the relation? To rule out such an explanation, we conducted a control experiment with two-year-olds (Experiment 2) in which they experienced an identical procedure to that of the Experiment 1, with the exception of Part 3 of the procedure: They were tested on their memory for the relations of the object-pairs instead of being asked to generalise the compound-noun. If two-year-olds would be able in this memory experiment to identify the relations seen previously – i.e., if as a group they would choose the relational match above chance – then two-year-olds' performance in Experiment 1 cannot simply be due to bad memory for the relations. That would

[1]Comparing performance against chance with the means of t-tests led to the same results: two-year-olds (Attachment: $t(13) = -3.3$, $p = .005$; Function: $t(13) = -4.3$, $p = .001$); three-year-olds (Attachment: ($t(25) = -2.9$, $p = .008$, Function: $t(25) = -.1$, $p = .925$); four-year-olds (Attachment: ($t(20) = 1.4$, $p = .184$, Function: $t(20) = -1.8$, $p = .09$); five-year-olds (Attachment: $t(20) = 6.0$, $p < .001$; Function: $t(20) = 4.0$, $p = .001$).

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mean that they did remember the relation in Experiment 1, but did not encode the relational information as a crucial part of the compounds' meaning – instead, they focused on perceptual identity of constituent objects. If, on the other hand, the children would choose the relational match at or below chance in this memory experiment (Experiment 2), then it is possible that two-year-olds' performance in the compound extension experiment (Experiment 1) was due to poor memory of the relations. That would mean they focused on perceptual identity of constituent objects in Experiment 1 because they did not remember the relations at all. Thus, this experiment allowed us to determine whether the performance of the younger children in Experiment 1 was due to a true linguistic problem, rather than a memory problem.

Experiment 2: Method

Participants

Participants were twelve (old) two-year-olds (mean age 32.4 months, $SD = 2.1$, range = 29–35 months, 7 males). Children were recruited from the same region as those in the previous experiments and the process of obtaining consent was the same. Children were again from middle-class homes and predominantly White-British. All were monolingual speakers of English.

Materials

Materials used were identical to those in Experiment 1.

Procedure

The procedure was identical to that of Experiment 1, with the exception that in Part 3 (test) – when participants were required to pick between the two object-pairs – they were asked "Now, how did these toys go together yesterday, was it like this or like that?" instead of being asked to find a referent for the compound-noun they had learned before. Participants always chose one of the two object-pairs.

Results

Correct selections involved selecting the object-pair that shared the same relation as the object-pair they had been shown the previous day (relational matches). Two-year-olds chose the correct (relational) option in on average 83.3% (SD = 45.4) of all responses for function relation compounds and in 72.2% (SD = 37.8) for attachment relation compounds. We followed the same analysis procedure as in Experiment 1 and conducted a linear mixed effect model analysis of children responses with the fixed factors Age (in months) and Relation type. The final model contained the random factors Participants and Items and no random slopes. We were unable to test the Age x Relation Type interaction due to the model not converging. However, testing main effects of Relation Type and Age showed a significant effect of Age ($\chi^2 = 8.1$, $df = 1$, $p = .004$) and no effect of Relation type ($\chi^2 = 1.47$, $df = 1$, $p = .226$). Thus age, but not the relation type, affected participants' responses – with more relation match responses, the older the children were. See Table 2 for details of the final model. For a test of performance against chance, the final model contained the random factors Participants

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Table 2. Summary of the fixed effects of the final mixed logistic models for Experiment 2.

Predictor	Coefficient	SE	z	p
Intercept	−12.37	5.05	−2.45	.014 *
Age	.43	.16	2.67	.008 **
Comparison against chance				
Function relation	1.61	.45	3.60	<.001 ***
Attachment relation	.96	.37	2.57	.010 *

.<.06; *<.05; **<.01; ***<.001

and Items and no random slopes. We found a significant effect of the factor Relation Type (χ^2=12.66, $df = 2$, $p = .002$). Two-year-olds chose the relational match above chance level for both relation types, but their performance was more strongly above chance for function than attachment relation (see average percentages above and Table 2).[2]

Discussion

The results of Experiment 2 show that two-year-olds as a group can remember the relations of our object-pairs as they were presented in Experiment 1 very well. This indicates that the ability to remember relations plays only a minor role, if any, in explaining the age difference in the results of Experiment 1. We kept Experiments 1 and 2 as similar as possible so that the information encoding demand (during the training phase) and the memory demand (during the test phase) were the same in the two experiments. Therefore, we can use the result of Experiment 2 to estimate how two-year-olds in Experiment 1 would have responded if, hypothetically, they had interpreted compounds to refer to relations, just like adults. In Experiment 2, two-year-olds remembered the relation 77.8% of the time (here we average the results from function and location relations for brevity); thus, in Experiment 1, two-year-olds should have been able to choose the relation match 77.8% of the time. This percentage would be much closer to that of adults (who selected the relation match 98.2% of the time), than two-year-old's actual performance in Experiment 1, where they selected the relation match only 23.8% of the time. Thus, we can rule out the alternative explanation for the age difference in Experiment 1: that children interpreted compounds as referring to relations, just like adults, but children have poor memory for the relations. Our results also rule out the idea that the two-year-olds' group performance, and by extension the three-year-olds' group performance, in Experiment 1 was a result of them being simply overloaded with information; or of simply not being able to remember how the constituent objects in the training object-pairs were related. These findings therefore support the suggestion that the younger children in Experiment 1, especially the two-year-olds, generally did not consider the exact relations an important part of the compounds' meanings. They instead focused on perceptual identity of constituent objects.

[2]Comparing performance against chance with the means of t-tests led to the same results: Attachment: $t(11) = 3.2$, $p < .05$; Function: $t(11) = 5.2$, $p < .001$.

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An alternative possibility is that, as opposed to not considering relations at all, two-year-olds (and partly three-year-olds) in Experiment 1 might have considered them, but have come to the conclusion that they are a less important part of a compound's meaning than perceptual similarity of constituent objects – and therefore less valid as a basis for extension. Research on children's novel noun interpretations has found that two- and three-year-olds can generalise names of novel objects on the basis of factors other than perceptual features under the right circumstances (e.g., on the basis of object function, as in, for instance, Kemler Nelson, 1999; Kemler Nelson, Russel, Duke & Jones, 2000). Therefore, to determine whether two to three-year olds considered relations as a part of compound-noun meaning in Experiment 1, but thought they were less important than the perceptual identity of constituent objects, a further control experiment was carried out in which children's ability to extend compounds on the basis of relation was investigated in the absence of competing perceptual features of the objects.

Experiment 3

In Experiment 3, children were asked to extend compounds to one of two exemplars that differed in terms of relational information, but both had identical component objects to the training object-pair. For instance, both were pairs of a purple *kig* and an orange *donka*, but they differed in terms of the relation (attachment vs. function). We tested two- and three-year-olds because these two age groups both showed signs that they generalised compounds on the basis of perceptual identity instead of relational identity in Experiment 1. Five-year-olds were included as a comparison group because they had revealed a focus on relational information in Experiment 1. If two- or three-year-olds extended compounds by relational identity at a level above chance in this experiment, then this would suggest that their performance in Experiment 1 was the result of them considering the non-relational perceptual identity to be a more important part of a compound's meaning than relational identity. If their performance was at chance level, then this would support our conclusion that they did not consider the exact relations as important for a compound's meaning at all.

Method

Participants

Participants were 15 two-year-olds (mean age 31 months, $SD = 2.5$, range = 27–35 months, 8 males), 16 three-year-olds (mean age 40 months, $SD = 3.5$, range = 36–47 months, 7 males) and 25 five-year-olds (mean age 66 months, $SD = 2.9$, range = 61–71 months, 10 males). A further 5 participants were removed from the study due to not being present for both days of testing. Children were recruited from the same region as those in Experiment 1 and the process of obtaining consent was the same. Children were again from middle-class homes and predominantly White-British. All participants were monolingual speakers of English.

Design

The design of this experiment was identical to that of Experiment 1.

Materials

Objects and object-pairs were identical to those in Experiment 1, but only one colour version of each object was used to create the object-pairs.

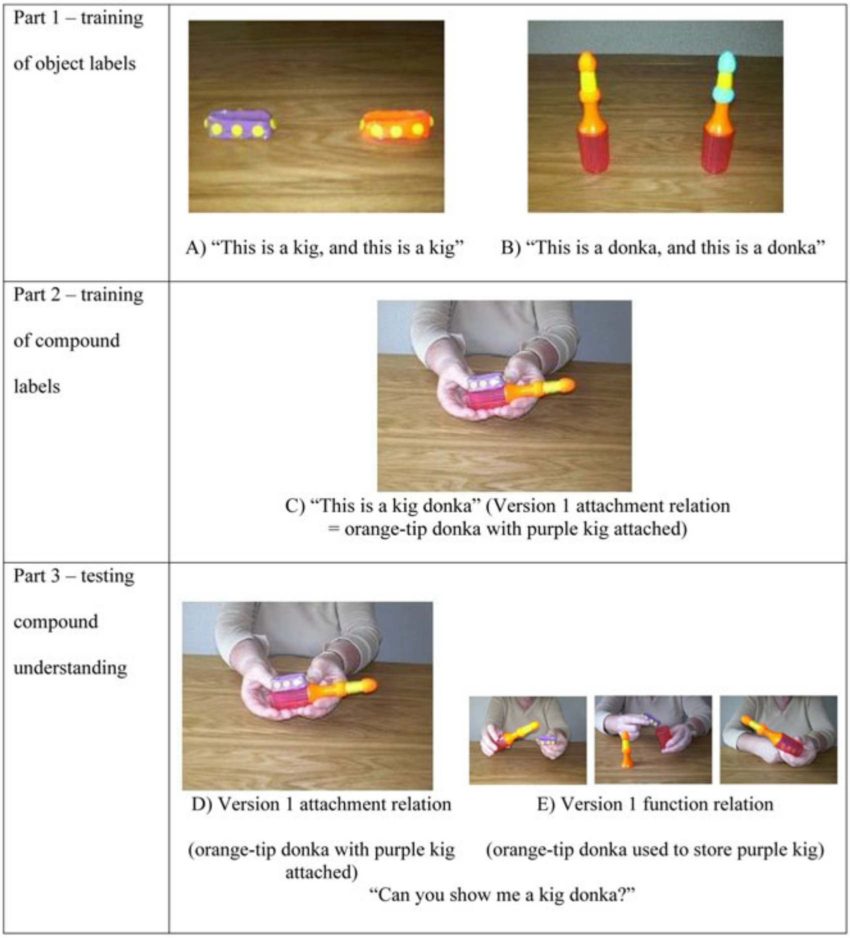

Figure 3. Experimental procedure with example for Experiment 3. Panel A shows Version 1 and 2 kig. Panel B shows version 1 and 2 donka. Panel C & D shows Version 1 attachment relation kig donka. Panel E shows the function of Version 1 function relation kig donka being demonstrated, i.e., a kig is placed inside a donka to store it. The three pictures in Panel E represent one fluid motion.

Procedure

The procedure was identical to that of Experiment 1, except for the options that were presented in the test phase (Part 3). Participants were asked to pick between two object-pairs, of which one was identical to the one used to introduce the compound in the training phase (Part 2) and the other consisted of the same constituent objects with the same perceptual features (e.g., same colour); but the objects were combined using a different relation (attachment instead of function or vice versa). See Figure 3 for an example. Participants always chose one of the two object-pairs.

Results

Figure 4 shows the proportion of extensions made to the object-pair that shared the same relation as the original referent of the compound noun (relational matches) for

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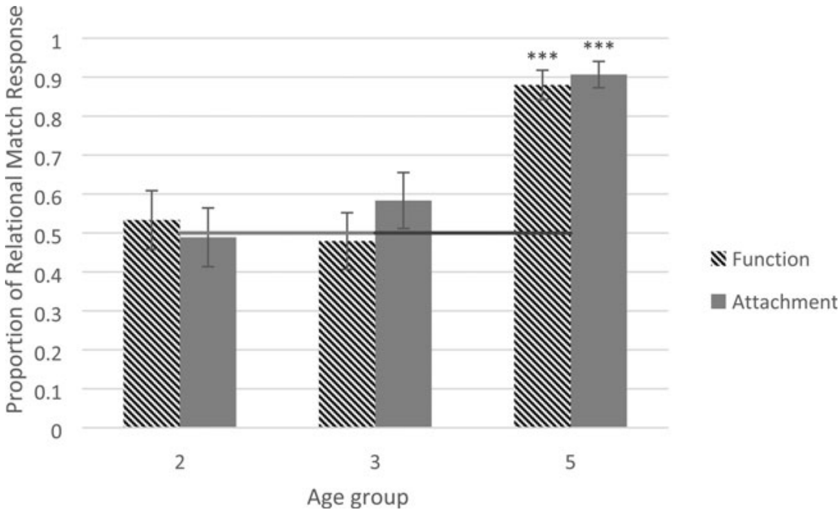

Figure 4. Proportion of extensions of novel noun-noun compounds on the basis of relational identity in Experiment 3, split into Age groups and Relation types; difference from chance level: '.' <.06, '*' p < .05; '**' p < .01; '***' p < .001). Horizontal bar shows chance level and error bars represent standard errors. Above chance performance indicates extensions on the basis of relational identity. Only five-year-olds extended compounds by relational identity.

Table 3. Summary of the fixed effects of the final mixed logistic models for Experiment 3.

	Predictor	Coefficient	SE	*z*	*p*
All participants	Intercept	−2.48	.55	−4.52	<.001 ***
	Age	.07	.01	5.93	<.001 ***
Comparisons against chance					
Age 2	Function relation	.13	.30	.45	.655
	Attachment relation	−.04	.30	−.15	.882
Age 3	Function relation	−.09	.32	−.28	.782
	Attachment relation	.36	.33	1.09	.274
Age 5	Function relation	2.91	.74	3.91	<.001 ***
	Attachment relation	3.26	.79	4.11	<.001 ***

.<.06; *<.05; **<.01; ***<.001

the three age groups. Following the same procedure for a linear mixed effect model analysis as before, the final model contained the random factors Participants and Items and no random slopes. We did not find a significant interaction of Age (in months) and Relation Type ($\chi^2 = 0.13$, $df = 1$, $p = .716$) or a main effect of Relation type ($\chi^2 = 0.45$, $df = 1$, $p = .503$). Only the factor Age (in months) was significant ($\chi^2 = 38.8$, $df = 1$, $p < .001$). For details of the final model see Table 3. Thus again, age but not relation type affected participants' responses.

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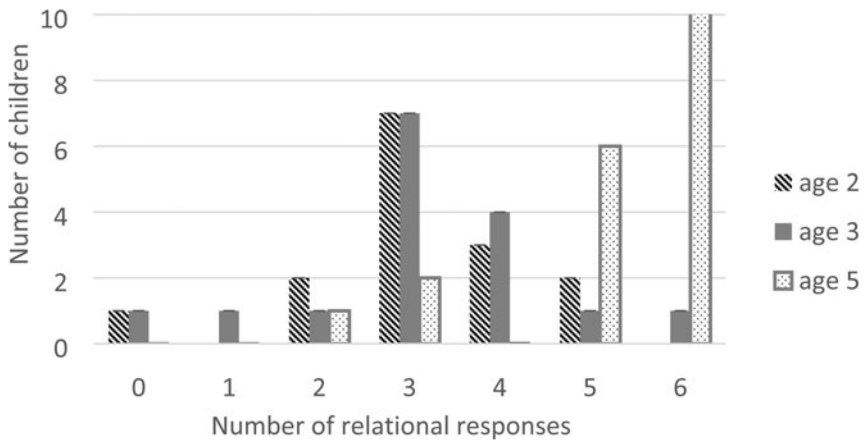

Figure 5. Distribution of the number of children who extended the novel noun-noun compounds on the basis of relational identity in Experiment 3, split into age groups.

For a test of performance against chance, we again followed the same procedure as in Experiment 1, fitting models for each age group (ages 2, 3 and 5) separately. The final models all contained the random factors Participants and Items, but no random slopes. Relation Type did not affect children's performance at ages 2 and 3 (age 2: $\chi^2 = 0.22$, $df = 2$, $p = .895$; age 3: $\chi^2 = 3.48$, $df = 2$, $p = .176$), but it did at age 5 ($\chi^2 = 20.87$, $df = 2$, $p < .001$). As shown in Figure 4 and Table 3, two- and three-year-olds chose the relational match at chance level for both function and attachment relations, while five-year-olds chose the relational match above chance level for both relation types. However, given the significant effect of Relation Type for five-year-olds, they chose the relational match more clearly above chance with attachment than function relations.[3]

We further investigated whether two- and three-year-olds' results meant that, as a group, they responded randomly or whether half of the children chose the relational match and the other half the non-relational choice. Figure 5 shows the distribution of the number of children that chose the relational match for the three age groups. In line with the results above, 84% of the five-year-olds chose the relational match for 5 or 6 of the 6 compounds. In contrast, two- and three-year-olds showed normal distributions. Half of the two- and three-year-olds chose the relational match in about 50% of the cases (age 2: 7 out of 15 children; age 3: 7 out of 16 children), and only very few children had a very strong preference for the relational match or non-relational choice. This distribution suggests that the two- and three-year-olds as a group chose randomly.

Discussion

In Experiment 3, we investigated the ability of children to generalise compounds on the basis of the relational components of a compound's meaning in the absence of competing perceptual features. As in Experiment 1, children's responses improved

[3]Comparing performance against chance with the means of t-tests led to the same results: age 2 (Function: $t(14) = .5$, $p = .647$; Attachment: $t(14) = -.1$, $p = .89$); age 3 (Function: $t(15) = -.3$, $p = .763$; Attachment: $t(15) = 1.2$, $p = .261$), age 5 (Function: $t(24) = 6.6$, $p < .001$; Attachment: $t(24) = 11.3$, $p < .001$).

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with age, in line with a developmental improvement of encoding relations as part of compounds' meanings. As groups, two- and three-year-olds chose randomly. There was also no indication that the relation type affected their responses. This fits the conclusion of Experiment 1 that two- and three-year-olds did not consider the exact relation of the object-pair an important part of the compound's meaning. Thus, their performance in Experiment 1 was not due to them considering relations, but as less important than perceptual identity of the objects.

Experiment 4

Even though Experiment 2 had shown that two-year-olds can remember the relations of compound referents composed of novel objects, compounds with unfamiliar constituents might be particularly difficult to process and map onto referents because children are not very familiar with the novel constituent words and their referents. In addition, such compounds are quite unusual in that compounds are usually composed of familiar, not novel words. Children might therefore have focused their attention too much on the novel objects and their perceptual features than on the relation of the object-pairs. In Experiment 4, we therefore aimed to replicate the findings of Experiment 1 with compounds composed of familiar words (e.g., *star hat*). Particularly, we investigated whether two- (and three-) year-olds did not encode the exact relations as part of the compounds' meaning even if the objects were familiar and whether they would again instead extend the compounds rather on perceptual features of the constituent objects.

Method

Participants

Participants were 20 two-year-olds (mean age 30.1 months, $SD = 3.3$, range = 24–35 months, 5 males), 22 three-year-olds (mean age 41.5 months, $SD = 3.3$, range = 37–47 months, 8 males), 25 four-year-olds (mean age 52.6 months, SD = 3.7, range = 48–58 months, 10 males), 18 five-year-olds (mean age 63.7 months, $SD = 4.2$, range = 60–71 months, 10 males), and 19 adults (mean age 20.6 years, $SD = 0.8$, 4 males)[4]. Children were recruited from English primary schools and nurseries located in Birmingham, Manchester, South London, Surrey and Staffordshire (all United Kingdom) with parental consent. Children were again from middle-class homes and predominantly White-British. Adult participants were undergraduate students at the University of Birmingham and participated for course credits. All participants were monolingual speakers of English.

Design

The design of this experiment was identical to that of Experiment 1.

Materials

Objects and object-pairs were similar to those of Experiment 1. However, instead of novel objects with novel names as in Experiment 1, familiar objects were combined

[4]Note that some of the age groups in this experiment as well as the participant group in Experiment 5 included more females than males. We therefore conducted the analyses for all experiments reported in this study with gender as an additional fixed factor. Gender did not affect participants' performance in any of the experiments, meaning the results did not change.

to serve as referents for novel compounds. Thus, exemplars of twelve familiar objects were combined to create six novel compound object-pairs: star-hat, apple-pen, ball-sock, bottle-duck, car-spoon and teddy-book. As in Experiment 1, each object-pair (e.g., star and hat) was given a function relation (a hat was used to store a star) and an attachment relation (a hat had a star attached to it). Unusual relations for the object-pairs were chosen so that previous knowledge of compounds with the same head or modifier words did not make one or the other relation more likely (see findings of Krott et al., 2009). See Supplementary Materials (Supplementary Materials) for details of each object-pairs' attachment relation and function relations.

Procedure

The procedure was mostly identical to that of Experiment 1. However, Part 1, i.e., the training of the constituent labels, was replaced with a check that all participants knew the names of all objects. For that, the experimenter laid out all constituent objects on the desk in front of the participant, with the two colour versions of each object next to each other. The experimenter then tested the knowledge of the object names in a fixed order by sequentially asking questions such as: "Where are the stars?" or "Do you see the bottles?" The participant responded by pointing to an item pair. The experimenter continued in this manner until knowledge of all item names had been confirmed. If a child did not know or seemed uncertain about the name of an object, the experimenter would teach the participant the object's name, saying, for instance: "Here are the hats. Can you say hats for me?" At the end of this phase (Part 1), the experimenter would check that the participant remembered the name taught to them – by asking, for instance: "Where are the hats?" The majority of participants did not need to be taught the names of any objects. The only exceptions were two two-year-olds who needed to be taught the name of the hats, but they both pointed correctly to the hats at the end of this phase. In the test phase, participants always chose one of the two object-pairs. See Figure 6 for an example of the procedure.

Results

Figure 7 shows the proportion of extensions made to the object-pair that shared the same relation as the original referent of the compound noun (relational matches) for the three age groups. As for the previous experiments, we analysed participants' compound extensions that were relational matches with the training items. Results, split by age groups, are displayed in Figure 7. Following the same model fitting procedure as for the previous experiments resulted in a final model with the random factors Participants and Items and no random slopes. We found no interaction between Relation Type and Age ($\chi^2 = 0.21$, $df = 1$, $p = .647$), but significant main effects of the factors Age (in months) ($\chi^2 = 17.04$, $df = 1$, $p < .001$) and Relation Type ($\chi^2 = 45.0$, $df = 1$, $p < .001$). For details of the final model see Table 4. Thus, the number of responses based on the object's relations increased with age. Also, participants responded on the basis of the relations more often for attachment relations than function relations, independent of age.

For a test of performance against chance, we followed the same procedure as in Experiments 1 and 3. The final models for all age groups contained the random factors Participants and Items, but no random slopes. Relation Type did affect participants' performance at all ages (age 2: χ^2=9.88, $df = 2$, $p = .007$; age 3: χ^2=20.84,

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Figure 6. Experimental procedure with example "star hat" for Experiment 4. Panels C and D show demonstration of Version 1 and 2 function relation, i.e., a hat is used to store a star. Panel E shows Version 1 attachment relation, i.e., a hat with a star attached.

$df = 2$, $p < .001$; age 4: χ^2=27.75, $df = 2$, $p < .001$; age 5: χ^2=28.37, $df = 2$, $p < .001$; adults; $\chi^2 = 24.96$, $df = 2$, $p < .001$), meaning that they responded with the relational match more often for attachment relations than function relations. As shown in Figure 7 and Table 4, two-year-olds chose the relational match significantly below chance level (thus they chose the perceptual match above chance) for function, but not for attachment relations. Three- and four-year-olds chose the relational match significantly above chance for attachment relations, but not function relations. Five-year-olds and adults chose the relational match above chance for both relations, but more so for attachment relations.[5]

[5]Comparing performance against chance with the means of t-tests led to the same results: age 2 (Attachment: $t(19) = -1.4$, $p = .065$, Function: $t(19) = -4.0$, $p = .001$); age 3 (Attachment: $t(21) = 5.6$, $p < .001$; Function: $t(21) = -.2$, $p = .844$); age 4: (Attachment: $t(24) = 8.2$, $p < .001$, Function: $t(24) = 1.3$, $p = .212$), age 5 (Attachment: $t(17)$=11.0, $p < .001$, Function: $t(17) = 3.1$, $p = .007$); adults (Attachment: $t(18) = 27.8$, $p < .001$, Function: $t(18) = 5.9$, $p < .001$).

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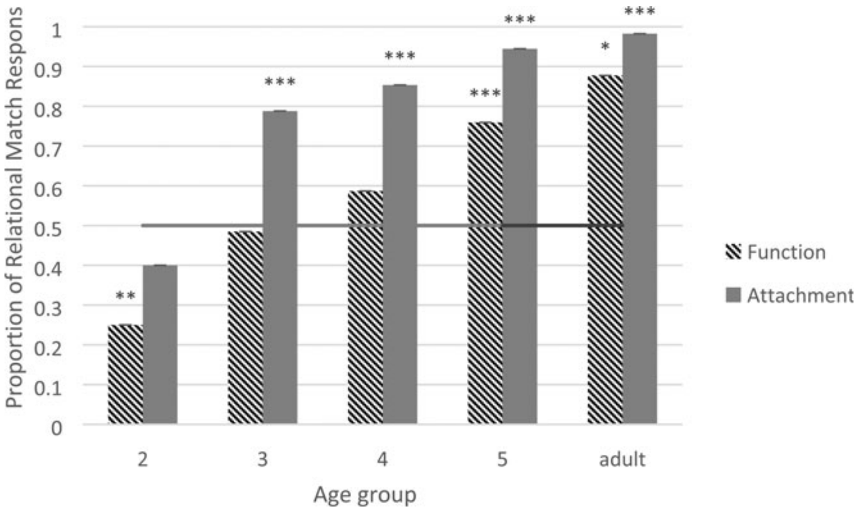

Figure 7. Proportion of extensions of novel noun-noun compounds on the basis of relational identity in Experiment 4, split into Age groups and Relation types; difference from chance level: '.' <.06, '*' p < .05; '**' p < .01; '***' p < .001). Horizontal bar shows chance level and error bars represent standard errors. Below chance performance indicates extensions on the basis of perceptual identity of constituent objects. Above chance performance indicates extensions on the basis of relational identity. Two-year-olds extended compounds with function relations predominantly by perceptual identity, while older children and adults did so by relational identity. Compounds with function relations were extended more often by relational identity than those with attachment relations.

Table 4. Summary of the fixed effects of the final mixed logistic models for Experiment 4.

	Predictor	Coefficient	SE	*z*	*p*
All participants	Intercept	−.35	.29	−1.21	.227
	Age	.01	.00	3.93	<.001 ***
	Relation Type	1.45	.23	6.28	<.001 ***
Comparisons against chance					
Age 2	Function relation	−1.22	.38	−3.24	.001 **
	Attachment relation	−.46	.34	−1.36	.174
Age 3	Function relation	−.07	.33	−0.21	.836
	Attachment relation	1.53	.40	3.82	<.001 ***
Age 4	Function relation	.36	.25	1.44	.15
	Attachment relation	1.81	.36	5.09	<.001 ***
Age 5	Function relation	2.41	0.00	1291	<.001 ***
	Attachment relation	4.95	0.00	2657	<.001 ***
Adults	Function relation	3.46	1.67	2.08	<.038 *
	Attachment relation	6.07	2.33	2.61	<.009 **

.<.06; *<.05; **<.01; ***<.001

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Discussion

Experiment 4 replicated the main findings of Experiment 1. Just as in Experiment 1, extending compounds on the basis of relations improved with age. Also, as in Experiments 1 and 3, two-year-olds did not extend compounds on the basis of relations. This fits our conclusions above that they did not seem to encode the relation as part of the compounds' meaning. Importantly, similar to Experiment 1, two-year-olds extended compounds on the basis of perceptual features, even if significantly only for compounds with function, not attachment relations. This finding confirms the importance of perceptual features for their compound extensions. But there was also one striking difference between the results of Experiment 4 and the previous experiments: all age groups extended compounds on the basis of relations more often for attachment relations than function relations. Also, when comparing results across Experiments 1 and 4, performance with attachment relations seem to be better in Experiment 4 across all ages (apart from adults who performed at ceiling in both experiments), while performance with function relations did not differ much across Experiments 1 and 4. This means that for attachment relations in Experiment 4, even three- and four-year-olds extended compounds by relational identity above chance level and two-year-olds performed close to chance level. We will return to the difference between Experiment 1 and 4 in the general discussion. We will first report a further experiment that aimed to confirm that two-year-olds can remember the relations in Experiment 4. For that we adopted the memory test of Experiment 2 with the compounds used in Experiment 4.

Experiment 5: Method

Participants

Participants were 17 two-year-olds (mean age 30 months, $SD = 3.1$, range = 29–35 months, 5 males). Children were recruited from the same region as those in Experiment 4 and the process of obtaining consent was the same. Children were again from middle-class homes and predominantly White-British. All participants were monolingual speakers of English.

Materials

Materials used were identical to those in Experiment 4.

Procedure

The procedure was identical to that of Experiment 4 with the exception that in Part 3, when participants were required to pick between the two object-pairs, they were asked "Now how did these toys go together yesterday, was it like this or like that?" Apart from the initial introduction to the constituent objects, which was identical to that of Experiment 4, this means that the procedure was equivalent to that of Experiment 2. At test participants always chose one of the two object-pairs.

Results

Correct selections involved selecting the object-pair that shared the same relation as the object-pair they had been shown the previous day (relational matches). Two-year-olds

Table 5. Summary of the fixed effects of the final mixed logistic models for Experiment 5.

Predictor	Coefficient	SE	*z*	*P*
Intercept	.80	.23	3.44	<.001 ***
Comparison against chance				
Function relation	.70	.31	2.27	.023 *
Attachment relation	.89	.32	2.76	.006 **

.<.06; *<.05; **<.01; ***<.001

chose the correct (relational) option in on average 66.7% (SD = 47.6%) of all responses for function relation compounds and in 70.6% (SD = 46.0%) for attachment relation compounds. Following the same procedure for the linear mixed effect model analysis as in Experiment 2 led to a final model with the random factors Participants and Items and no random slopes. There was no significant interaction of Age and Relation Type ($\chi^2 = 0.80$, $df = 1$, $p = .371$) nor any effect of Relation Type ($\chi^2 = 0.19$, $df = 1$, $p = .667$) or Age ($\chi^2 = 1.55$, $df = 1$, $p = .212$). Therefore, participants' responses were neither affected by Age nor Relation type. The final model therefore only included the intercept (see Table 5).

Only 4 out of 17 children (24%) performed at chance level in Experiment 5, other children chose the relational match above chance. Following the same procedure to test performance against chance – as in the experiments before – led to a final model with the random factors Participants and Items and no random slopes. There was a main effect of Relation Type (χ^2=8.75, $df = 2$, $p = .013$). Two-year-olds chose the relational match above chance level for both relation types (see Table 5). But, given the effect of Relation Type, they did so more clearly with attachment relations than function relations.[6]

Discussion

Experiment 5 confirmed that two-year-olds as a group are able to remember the relations of the object-pairs used in Experiment 4, with memory for both attachment and function relations above chance level. This stands in contrast to the results of Experiment 4, where we found that two-year-olds did not base their compound extensions on compound relations. This again suggests that the youngest children in Experiment 4 remembered the relations, but did not encode the relational information as a crucial part of the compounds' meaning. We can again use the result of Experiment 5 to estimate how two-year-olds in Experiment 4 would have responded if they had interpreted compounds to refer to a relation, just like adults. In Experiment 5, two-year-olds remembered the relation 68.7% of the time (averaging the results from function and location relations); thus, in Experiment 4, two-year olds should have been able to choose the relation match 68.7% of time. This percentage would be much closer to that of adults (who selected the relation match 93.0% of the time) than two-year-olds actual performance in Experiment 4, where they selected the relation match only 32.5% of the time. This is consistent

[6]Comparing performance against chance with the means of t-tests led to the same results: Attachment: $t(16) = 3.0$, $p = .009$; Function: $t(16) = 2.6$, $p = .019$.

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with what we had found for compounds composed of novel words in Experiment 2, and supports our conclusion that memory could have only played a relative minor role in our experiments. More concretely, children's relatively good memory for function relations means that their perceptual match bias for function relations and their at-chance performance for attachment relations in Experiment 4 cannot simply be explained by poor memory of the relations. This result again fits with our conclusion that two-year-olds' performance was linguistically driven and not the result of a memory problem.

General discussion

The main aim of the present study was to investigate a developmental focus shift from non-relational towards relational aspects in children's compound word acquisition. This would be reflected in younger children extending compounds on the basis of non-relational perceptual aspects while older children and adults were extending on the basis of relational aspects. For that we tested two- to five-year-olds and adults in a compound word extension paradigm, where below chance performance indicated a bias towards extensions on the basis of perceptual identity of constituent objects and above chance performance indicated a bias towards extensions on the basis of shared relational identity. We found that the result pattern was generally similar for compounds composed of novel or familiar words: Extensions of novel compounds on the basis of relations gradually improved with age. It was above chance level from age five onwards for compounds composed of novel nouns and from age three onwards for compounds composed of familiar nouns, even though the latter was only for compounds with attachment relations. Crucially, independently of whether the compounds were composed of novel or familiar nouns, it was very challenging for two-year-olds to link novel compounds to the relational features of the referents. Strikingly, they predominantly showed below chance performance, indicating that they were instead making extensions on the basis of non-relational perceptual aspects (i.e., colour of the constituent objects). This overall pattern of results suggests a developmental focus shift from non-relational towards relational aspects in children's compound word acquisition.

Our results for two-year-olds could potentially mean that they did not understand the compounds as compounds and might not have understood that we asked them to find a referent for a compound. Instead they might have considered our compounds to be disjunctions (e.g., kig or donka) or conjunctions of two nouns (e.g., *kig* and *donka*). But there are three arguments against this alternative explanation. First, previous research shows that two-year-olds understand novel noun-noun combinations as compounds. As mentioned in the introduction, Clark et al. (1985) showed that when two-year-olds are asked to select a referent of a compound (e.g., 'mouse-hat') from a picture of a combination object (a hat on a mouse), a picture of the modifier noun referent (a mouse), and a picture of a head noun referent (a hat), they successfully select the combination object. If the children understand compounds to be disjunctions of the two constituent nouns ("hat or mouse"), the three choices are equally appropriate. This indicates that two year olds do not interpret compounds like mouse-hat as "mouse or hat". Second, another counter-evidence comes from Krott et al.'s (2010) findings. Very similar to the present study, Krott et al. taught two-year old children the meaning of novel constituent nouns ("kig", "donka"). They then asked them what a compound

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consisting of the two novel nouns ("kig donka") referred to, in a two-alternative forced choice task: one choice was the two objects (the referents of the constituent nouns) combined with an attachment relation and the other was the same objects combined with a function relation. If the two-year-olds had understood the novel compounds as conjunctions ("kig and donka"), the two choices should have been equally appropriate, and thus they should have selected randomly. However, they selected the attachment combinations significantly more often than the function relation. Third, if two-year-olds understood the compounds in the present study simply as conjunctions of two nouns, one would have expected them to have pointed twice, once to each constituent object. But they did not do so, and neither did the older children. Thus, two-year-olds in our study likely understood our compounds as compounds.

Importantly, two-year-olds did not extend the compounds on the basis of the object relations. They therefore do not seem to have encoded a specific, but rather a vague relation between the objects. This vagueness of the relation fits with Snyder's "Generalized Modification" rule that young children acquire for compounding, which does not specify the concrete relation.

Experiments 2 and 5 ruled out that two-year-olds did not extend compounds on the basis of relations because they simply did not remember the relations. Keeping the procedure exactly the same as the compound extension experiments (Experiments 1 and 4) apart from the test question also ruled out that two-year-olds were overloaded with information during the training phase of the compound extension experiments. Furthermore, the results of Experiment 3 showed that two- and three-year-olds did not fail to extend compounds on the basis of relations because they considered it a less important part of the compounds' meaning than the perceptual identity of the constituent objects. This further supports the conclusion that younger children are not encoding the exact relation as part of the compounds' meaning.

The secondary aim of our study was to investigate whether the type of relation might affect children's compound extensions. We were particularly interested in following up the finding by Krott et al. (2009) and Krott et al. (2010) that, compared to adults, children interpret compounds more often as having HAS relations (=attachment/location relations) instead of FOR relations (=function relations). Note that both our attachment and function relations (as well as our stimuli) were very similar to those in Krott et al. (2010). And indeed, for compounds composed of familiar nouns, participants extended compounds more often on the basis of object relations when the compounds had an attachment relation compared to a function relation. This was the case for all age groups. In contrast, for compounds composed of novel nouns, there was no indication of an advantage for attachment relations. Note also that two-year-olds did not choose the relational match above chance level with attachment relations, independently of whether the compound was composed of novel or familiar nouns. Thus, while previous studies had shown that (young) children tend to interpret novel compounds as having attachment or location relations, we provide evidence (at least for compounds with familiar constituents) that children also more readily encode attachment relations than function relations as part of compounds' meaning. It needs to be noted that attachment relations, as used here, are not very typical HAS relations. Future studies should therefore investigate whether children show similarly good performance in extending other types of HAS relations (e.g., more similar to the ones in *cheese sandwich, chainsaw* or *telephone booth*) and LOCATED relations (similar to those in *doormat, mountain lion* or *nose hair*).

The potential reasons for attachment relations being more easily encoded as part of a compound's meaning are manifold. First, only the attachment relations were perceptually stable, while our function relations were visible only for a short period of time. Second, the attachment relations – namely, one object being glued to another – were conceptually more simple than our function relations: which expressed more complex relations such as the storage, coverage, movement, or flipping over of another object. Last, but not least, attachment relations were static, meaning that the physical relationship between the two constituent objects did not change (objects were glued together before the participants saw the combinations). In contrast, our function relations were dynamic in that the functions were shown by means of actions that changed the physical relationship between the two constituent objects. Our data do not allow to decide which features of the attachment relations made them easier to encode.

The characteristics of attachment relations also mean that, in principle, compounds with attachment relations (but not those with function relations) could have been extended on the basis of the overall shape of the object-pairs instead of their relations. This is particularly important for the younger children in our sample because the shape-bias literature suggests that particularly younger children are biased towards extending novel nouns on the basis of shape instead of conceptual features such as function (e.g., Gentner, 1978; Merriman, Scott & Marazita, 1993; Graham, Williams & Huber, 1999; Smith, Jones & Landau, 1996). However, if this was the case then two-year-olds should have been the age-group most affected. In contrast, this age-group extended the compound-nouns to the object-pairs that did not share the same relation as the original referent, and therefore did not share the same overall shape.

Comparing results for compounds composed of novel words with those composed of familiar words showed that the latter were not generally easier to extend. Particularly, encoding and extending function relation compounds was equally challenging for both types of compounds. Presenting a familiar object (such as a hat) with an unusual function could have been more confusing than presenting a function of novel objects. But it turns out that all age groups found encoding the function relation as part of the compounds' meaning similarly challenging for the two types of compounds, with five-year-olds and adults encoding the function relation very regularly. In contrast to function relations, attachment relations were generally encoded more often when compounds were composed of familiar than of novel nouns. The better performance with attachment relations discussed above was therefore a particular advantage for compounds with familiar constituents. It might be easier to understand an attachment relation if rich concepts of the referent objects exist. It might also be that novel objects draw more attention away from the relations between the objects than familiar objects when creating a meaning representation of a compound. Alternatively, if participants encoded the shape and used it to extend the compounds, novel objects might have drawn attention away from the overall shape.

One might wonder whether briefly presenting a function with novel objects or using novel functions for familiar objects might have made the relations appear accidental. Adults expect compounds to be used for relations that are NOT accidental (Downing, 1977). That means that the mere fact that somebody uses a compound to refer to an object combination signals to the listener that the object combination is not accidental. Our results for adults are in line with that. Children have been shown to slowly develop this assumption (Clark et al., 1985; Nicoladis, 2003; Parault, Schwanenflugel & Haverback, 2005). But that does not mean that this slow

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development can explain the developmental change in our data. In contrast, it means that children should not have any problems with compound relations that are seemingly accidental and this should especially be true for the youngest children. But those are the children that did not encode the relations in our study.

Our differences between the two relation types are in line with previous findings. Krott et al. (2009; 2010) reported a preference for HAS relations over FOR relations for children's interpretations of novel compounds for both familiar and novel nouns. Their HAS relations were very similar to our attachment relations and their FOR relations were very similar to our function relations. But there are some differences between our study and these studies. Both previous studies investigated participants' interpretations of novel compounds, while the present study investigated how far relations are used to extend novel compounds to new exemplars. Also, only Krott et al. (2010) and the present study presented physical referents. But while in Krott et al. (2010) participants were asked to choose between two potential compound referents that differed with regards to the object relations (HAS versus FOR), our study required that participants encoded the relations and used them to extend the compounds. These differences notwithstanding, our study supports previous evidence that an adult-like understanding of the relational component of compounds appears to be acquired slowly (e.g., Nicoladis, 2003; Krott et al., 2009; 2010). Importantly, two-year-olds and potentially three-year-olds might not have a full understanding of the importance of the relation for the meaning of a compound.

Interpretation of stimuli

The aim of this study was to investigate whether children incorporate relations into their compound interpretations. Therefore, we did not test children's memory for the names of the novel objects during the test phase or whether they correctly identified heads and modifiers of the compounds. As mentioned, Clark et al. (1985) found that already by the age of 2 ½ years English-speaking children have a fairly good, while not perfect, understanding that the second noun of a compound is the head, thus denotes the category of the compound, while the first noun is the modifier of the compound. It is therefore likely that the participants in our experiment were generally able to identify the direction of the relation. Also, not remembering words as such (for which object is called what) cannot explain our result that young children tended not to incorporate the relation into their compound meaning, but incorporated the perceptual features of the objects instead.

It is possible that some of our relations were not strongly interpreted the way we intended them to be and this might have affected the compound learning. We therefore asked 20 Psychology undergraduate students at the University of Birmingham to describe both attachment and function relations of all our compounds (with novel and familiar nouns), i.e., of all object relations used in our experiments. Both authors then, independently and blindly to the actual relations, coded the answers as function, attachment, and other relations (there were only two responses coded as other). The coders gave the same code to 91.7% of all responses. Disagreements were resolved by discussion. For compounds composed of novel nouns (e.g., *kig donka*), on average 55.8% of participants (SD = 49.9%) described our function relations as attachment relations, while 95.8% (SD = 20.1%) did so for the attachment relations. For compounds composed of familiar nouns (e.g., *bottle duck*), on average 37.5% of participants (SD = 48.6%) described our function relations as

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attachment relations, while 99.2% (SD = 9.1%) did so for the attachment relations. While more participants than expected described our function relations as attachment relations, the differences between the relation types were significant for both types of compounds (novel objects: $t(5) = 2.7$, $p = .042$; familiar objects: $t(5) = 3.6$, $p = .015$). This means that our function relations were still described more often as function relations than our attachment relations and for both types of compounds. As expected, the large number of attachment descriptions were due to descriptions of storage relations (e.g., for the container relations of *ball sock* (80%) or *koba sav* (85%)). We can see two possible reasons for the relatively high number of attachment descriptions of our function relations. First, our demonstrations of function relations can easily be broken up into different parts and participants might have chosen to describe only a part of the relation – one that we categorised as an attachment relation. For instance, participants often described the end state of storage relations (e.g., *ball sock* as "a sock that has a ball inside"). Second, items were ambiguous as to what the relation was, i.e., if it were a function or attachment relation. This scenario could indeed potentially have had an impact on the word learning. To rule out the latter option, we replaced the fixed factor Relation Type with the number of Functional Descriptions for each item into our mixed effect model analyses. Whenever Relation Type had predicted performance, replacing Relation Type with Functional Description led to worse model fits (all ps > .05 or AIC of model with Relation Type smaller than for model with Functional Description). Furthermore, whenever Relation Type had not affected performance, we did not find any effect of the Functional Description factor either (all ps > .05). Taken together, these results mean that function relations that were potentially more ambiguous were not responded to differently in our experiments than function relations that were potentially less ambiguous, neither by older nor younger participants. The first scenario is therefore the more likely one: namely, that the participants in our description experiment often opted to describe only one part of the function relations, which we categorized as an attachment relation. Nevertheless, given the descriptions of the function relations, differences between function and attachment relations should be treated with some caution.

The challenge of relational aspects in word learning and beyond

The results of our study support the notion that mapping novel words onto relations is challenging for young word learners (e.g., Gentner, 1982; Gentner & Ratterman, 1991; Gentner & Boroditsky, 2009). Similar to how they are with relational nouns such as *taxi* (Keil & Batterman, 1984) or *passenger* (Hall & Waxman, 1993), young children tend to encode perceptual features into the meaning of compounds rather than relational aspects. In the present study, we have shown how such a bias for compounds slowly shifts over the development.

This raises the question of what drives the developmental shift. It is important to note here that the challenge of relational information for young children is not to perceive or to understand it. We found that two-year-olds generally did remember relations they had seen before. It has been shown that even infants are sensitive to the conceptual components present in dynamic action scenes, i.e., scenes that they would need to process in order to acquire verbs and other relational terms (Pruden et al., 2012; Goksun, Hirsh-Pasek & Golinkoff, 2010; Pruden, Hirsh-Pasek & Golinkoff, 2008; Golinkoff & Hirsh-Pasek, 2008; Waxman et al., 2009; Arunachalam

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& Waxman, 2011). Therefore, it is the appropriate mapping of words to the relational part of scenes that young children appear to struggle with; an observation that has also been made for verbs (Gentner, 1982; Gentner, 2006; Gentner & Boroditsky, 2001; Golinkoff & Hirsh-Pasek, 2008).

The present findings fit into a wider literature on the relational shift in cognitive focus and similarity processing. For instance, children solve object-matching tasks at an earlier age than relation-matching tasks (Gentner & Rattermann, 1991; Smith, 1984), and, when given relation-matching tasks, children often match objects instead (Gentner & Toupin, 1986; Rattermann & Gentner, 1998; Richland, Morrison & Holyoak, 2006). They also struggle to extend relational categories like *home for* to new exemplars (Gentner, Anggoro & Klibanoff, 2011). The children's challenge of mapping words onto relations might therefore be to consider relations as candidate concepts for word meaning.

It needs to be noted that young children such as two-year-olds correctly produce and understand quite a number of verbs. But in order to do so they need more help than is provided by a fast-mapping paradigm used by us and elsewhere in word learning experiments (e.g., for verbs by Imai et al., 2005; 2008). This help could be in the form of repeated exposures to the verb paired with the action it names (e.g., Waxman et al. 2009) or semantically rich descriptions of action-scenes and informative syntactic frames that provide information on the verbs argument structure (Arunachalam & Waxman, 2011; 2015). Young children are also helped in mapping words to relations by the opportunity to compare exemplars. For instance, Snape and Krott (2018a) have shown that three-year-olds can map novel verbs to novel actions when seeing two scenes with the same actions performed by the same actor on two different objects. But the fact that such additional help is necessary shows that mapping words onto relations is not straightforward, and, as Imai and colleagues (2005; 2008) have shown for verbs, is more difficult than mapping words onto non-relational referents, i.e., simple nouns.

As we have seen, there are examples of developmental shifts from a focus on objects and their perceptual features to a focus on relations for various domains. What might drive these shifts? One option is cognitive maturation. This option is supported by the finding that three- to five-year olds' inhibition ability correlated with noun extensions in a previous study: Snape and Krott (2018b) asked children to extend unfamiliar names (e.g., *kig*) for familiar objects (e.g., an apple) to either a shape match (a balloon) or a taxonomic match (a banana). Children who were better at this task were also better in a non-verbal inhibition task, independent of their age. These results suggest that, if objects and their perceptual features strongly draw attention, a more developed inhibition ability helps to shift attention to other potential aspects of word referents such as conceptual or relational features. Since inhibition ability is less developed in younger children, older children will be more successful in shifting their attention. Note that the role of inhibition in disengaging from perceptual features has also been found for appearance-reality decisions (Bialystok & Senman, 2004) and object categorisation (Fisher, 2011).

It is, however, unlikely that cognitive maturation is the sole factor for a relational shift. Children need to deepen knowledge of two words / concepts combined into a compound in order to focus on the relation between them. Also, as previously pointed out by Gentner (1988; 2006), if a relational shift was solely due to cognitive maturation, then the shift should be domain-general. Gentner presents evidence that this is not the case and that, instead, relational shifts are domain-specific. For instance, Gentner and Rattermann, (1991) showed that the focus on objects versus

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relations occurs at different stages for different domains (e.g., usage of relational similarity in various analogical reasoning tasks and for verbal interpretations of metaphors). Also, learners of a new domain focus first on object properties and then on relations (Gentner, 1988; Gentner & Rattermann, 1991; Rattermann & Gentner, 1998). While, on an individual level, a deeper knowledge of the compound constituents and their functions increases children's understanding of a compounds' relations and meanings, Gentner suggests more broadly that a relational shift is caused by increasing knowledge of a particular domain instead of cognitive maturation.

In terms of noun-noun compounds, Gentner's suggestion would mean that children are more likely to encode relational information into a compound's representation with increasing understanding that the exact relation is part of a compound's meaning, and with increasing knowledge of compounds with similar relations. Relations that are part of compound representations are very similar to those that underlie verbs. Given the evidence that even infants understand the latter (see discussion above), it is rather unlikely that changes of relation encoding are caused by better understanding of relations. Instead, it is more likely that increasing exposure to compounds and their usage leads to the encoding of exact relations in familiar compounds and ultimately to the recognition of the need to encode relations in all compounds. In other words, on encountering a novel compound, older children and adults immediately make an inference about the exact relation between the compounds' constituents and add this to the compound's representation. Young children may need more experience with compounds to do this.

The relational or non-relational nature of referents is, of course, not the only important factor during early word learning. For instance, Golinkoff and Hirsh-Pasek (2008) present a variety of reasons why verbs are more difficult to acquire than nouns. Apart from the relational nature of words, they point out that young children may not be sensitive to other cues which benefit verb mapping until later, such as linguistic cues or the social intent of the speaker. Furthermore, McDonough et al. (2011) suggest that imagability – i.e., perceivability, concreteness and ease of individuation – determines age of acquisition. There is also evidence for the importance of language-specific linguistic factors for verb and noun acquisition (e.g., Imai et al., 2008; Tardif, 1996; Tardif, Gelman & Xu, 1999; Tardif, Shatz & Naigles, 1997). And last but not least, there are word type differences. For instance, in contrast to verbs, the relation in compounds does not have a linguistic expression – which might make it harder for young children to realise that it is not sufficient to map compounds onto constituent referents alone.

Conclusion

While there is by now a wealth of factors that has been shown to affect the ease of word acquisition in early years, the challenge is to determine the relative importance of these factors. Through the use of noun-noun compounds, we showed that the relational nature of a word makes it more difficult to acquire. Additionally, we have shown that exactly how constituents are related impacts on the acceptance of relational information as part of word meaning.

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