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Beyond the Shape of Things: Infants Can Be Taught to Generalise Nouns by Function

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Abstract

Two-year-olds typically extend labels of novel objects by the objects' shape ("shape bias"), while adults do so by the objects' function. Is this because shape is conceptually easier than function? To test if the conceptual complexity of function prevents infants from developing a function bias, we trained 12 17-month-olds (function-training group) to focus on *function* when labelling objects over seven weeks. Our training was similar to that of Smith and colleagues (2002), who successfully taught 17-month-olds to focus on the shape of objects, resulting in a precocious shape bias. We exposed another 12 infants (control group) to the same objects over seven weeks, but without labelling them or demonstrating functions. Only the infants in the function-training group developed a function bias. Thus, the conceptual complexity of function was not a barrier for developing a function bias, which suggests that the shape bias emerges naturally because shape is perceptually more accessible.

Keywords: noun learning, function bias, shape bias, vocabulary development, second-order generalisation

Statement of Relevance

Early language development is critical for children's general development. It supports their ability to communicate, is essential for social interaction, and predicts their future academic performance. This study investigated how to promote word learning in 17-month-olds, an age when children's noun learning strategies emerge. Research has suggested that a precocious word learning bias based on easy-to-access perceptual features of objects (shape) can be accelerated with training. We found that infants can also be taught a general word learning strategy that requires a focus on conceptually more complex properties (functions). This finding is important for cognitive and developmental psychology, as it demonstrates infants' cognitive abilities for learning about the names of objects based on their functions. It is also relevant for parents and early years practitioners as it could inform interventions for children who do not adopt typical word learning strategies or are at risk of developing poor language skills.

Beyond the Shape of Things: Infants Can Be Taught to Generalise Nouns by Function

Infants learn words rapidly, especially object names (Frank et al., 2017). Early vocabulary development has profound lasting consequences. For instance, children's early vocabulary size and language skills predict later academic success (Bleses et al., 2016; Morgan et al., 2015). It is therefore important to study word learning strategies that promote rapid vocabulary growth in infancy.

The Role of Shape and Function in Word Learning and Generalisation

When learning and extending object labels, infants, children, and adults prioritise different object properties depending on the task and information available (e.g. Diesendruck et al., 2003; Graham et al., 1999; Namy & Clepper, 2010). Older children and adults generalise labels based on an object's shape and function, but prioritise function over shape when function information is available (Gathercole & Whitfield, 2001; Graham et al., 1999; Mueller Gathercole et al., 1995). Function is important as it provides information about an object's intended use (Diesendruck et al., 2003) and therefore about its category (Booth & Waxman, 2002). The knowledge of function helps to classify objects into the right category. Because the shape and function of objects are often correlated, shape can also indicate the object category. However, shape can sometimes be misleading (e.g. slippers that look like rabbits). Nevertheless, infants and younger children typically generalise object labels by shape, a strategy called the "shape bias" (Gentner, 1978; Horst & Twomey, 2013; Hupp, 2015; Kucker et al., 2019; Landau et al., 1998; Perry & Samuelson, 2011). For example, Graham and colleagues (1999) showed that 3-to-5-year-olds generalise object labels based on shape similarities when shape is pitted against function. Two- and 3-year-olds show a function bias only when the object's function is demonstrated and explained (Diesendruck et al., 2003) or when children are allowed to manipulate and interact with the objects themselves (Kemler Nelson et al., 2000). Thus, whereas older children and adults prioritise function for generalising object labels, infants and younger children prioritise shape.

Why do Infants Spontaneously Develop a Shape, but not a Function Bias?

If adults name objects by both shape and function while prioritising function (e.g. Graham et al., 1999), then why do infants initially develop a shape bias? There are two possible reasons. First, shape is a perceptually more easily accessible property than function. Shape can be identified immediately upon encountering an object (Graham & Poulin-Dubois, 1999), and is usually stable over time (Gentner, 1982), whereas function becomes apparent only after manipulating an object, and it is usually transient (Landau et al., 1998). Second, shape is conceptually easier than function (Gentner, 1978). Shape is a simple object property because it does not consist of qualitatively different subcomponents (a complex shape can be seen as a combination of simple shapes, but these components are again shapes), whereas function is a complex object property, involving (causal) relations among qualitatively different subcomponents (e.g., agent, object, action, instrument) (Gentner, 1978; Gentner & Boroditsky, 2010). In addition, an object's shape usually does not change over time, whereas an object's function requires integration of information over time (e.g., a spoon is initially empty, and then gets filled with food) (Deák et al., 2002). Finally, shape is easier to individuate than function due to clear and stable boundaries (Gentner, 1982). Note that these reasons for the conceptual simplicity of shape have also been brought forward in the debate on why nouns (object names) are learnt before verbs (action names) (e.g. Gentner, 1982; Imai et al., 2008). Thus, the problem of mapping nouns to object functions resembles the problem of mapping verbs to actions.

If the preference of using shape over function in noun generalisation is due to conceptual simplicity, then it should be difficult to train infants who are developing a shape bias, to develop a function bias instead. It is possible to accelerate the emergence of a shape bias. Smith and colleagues (2002) found that after a 7-week training that highlighted the importance of shape for object labelling, 19-month-olds showed a precocious shape bias, and the training accelerated infants' noun vocabulary growth outside the laboratory. If a similar training for function can enable 19-month-olds to use a function bias, then this would show that conceptual difficulty is not the obstacle that prevents a function bias from emerging spontaneously.

The Current Study

Do 2-year-olds spontaneously develop a shape bias, but not a function bias, because shape is conceptually easier than function? If this is the case, then infants should not be cognitively ready to learn a function bias before their second birthday. To probe this question, we tested whether teaching infants to attend to function during object labelling leads to a function bias. We also investigated whether, like shape-training, function-training influences real-world vocabulary growth. We followed the same procedure as Smith and colleagues (2002), except that we taught infants to focus on function instead of shape. Thus, for seven weeks, an experimenter taught 17-month-olds that the same nouns can be used to label objects with the same function. A control group was introduced to the same stimuli in a similar 7-week programme, but was not taught any labels or shown any functions. After training, participants completed a first-order generalisation task (with familiar objects used in training) and a second-order generalisation task (with novel objects not used in training) to test whether they would extend object labels based on function, shape, or colour. Furthermore, parents reported infants' expressive vocabulary at the start and end of the study.

If infants can be taught to focus on function in word learning, then the function-training group should base their generalisations of familiar and novel object labels on function more often than the control group. If function-training indeed leads to a function bias, then the function-training group, but not the control group, should extend labels by function more often than chance, in both the first- and second-order generalisation tasks.

If function-training has an impact on word learning beyond the lab-based training, then it should accelerate the real-world vocabulary growth of the function-training group but not the control group. Because function-training focuses on a strategy for noun learning, the function-training group should have a larger noun vocabulary than the control group at the end, but not the start of the study. Given the similar challenge of mapping nouns to object functions and verbs to actions, teaching infants that objects with the same function (i.e. actions) have the same label might promote a general understanding that words can refer to actions. If this is the case, then the function-training group should have a larger verb vocabulary than the control group at the end, but not the start of the study.

Method

The raw data and materials of this study are available via the Open Science Framework (https://osf.io/yra56/?view_only=9ae3702551ca4d51a10d69dea5e74dff).

Power Analysis

We conducted two power analyses to determine our sample size using G*Power version 3 (Faul et al., 2007). Our first power analysis was based on Ware and Booth (2010). We calculated the effect size of the proportion of correct responses of the first block of their second-order generalisation task. The means and standard deviations (Group 1: $M = 0.53$, $SD = 0.23$, Group 2: $M = 0.33$, $SD = 0.13$) showed an effect size of 1.07 (Cohen's *d*). With this effect size, we estimated a sample size of 24 infants with an error probability of 0.05 and a power of 0.80.

Our second power analysis was based on Smith and colleagues (2002). We calculated the estimated effect size of the difference between the groups in the number of nouns produced at the end of the study. This was an estimated calculation as the results provided by

Smith and colleagues (2002) did not specify all the information required. The estimated means and standard deviations of both groups produced an estimated effect size of 0.71 (Cohen's *d*). We converted this effect size to Cohen's *f* following the formula suggested by Cohen (1988). This was done as we were interested in the number of participants required for a repeated-measures design and not only in the difference between two means. With the effect size of 0.357, we then estimated a sample size of 18 participants with an error probability of 0.05 and a power of 0.80.

Participants

Infants were recruited from Birmingham and surrounding areas through community groups, play groups, as well as databases of the Infant and Child Lab at the University of Birmingham and the Warwick Research with Kids Group at the University of Warwick. Our final sample included 24 typically developing 17-month-old infants, who were randomly assigned to one of two groups: function-training group (4 girls, $M = 17$ months, 11 days; range: 17 months, 1 day – 17 months, 28 days) and control group (7 girls, $M = 17$ months, 10 days; range: 17 months, 2 days – 17 months, 27 days). The groups did not differ in age ($p = .811$), gender ($p = .219$) or socioeconomic status ($p = .064$) (for more detail, see Table S1 in Supplemental Material). During the first-order generalisation test participants in the function-training group were on average 19.33 months old ($SD = 0.26$) and participants in the control group 19.28 months old ($SD = 0.44$). During the second-order generalisation test participants in the function-training group were on average 19.57 months old ($SD = 0.28$) and participants in the control group 19.58 months old ($SD = 0.40$).

The two participant groups had similar expressive vocabulary sizes at the start and end of the study, as measured via parent report using the UK-CDI Words and Gestures questionnaire (Alcock et al., 2017). A comparison against the UK-CDI norms showed that the vocabulary sizes of each group were also typical for British English infants. Participant groups did not differ significantly in expressive vocabulary size at the start of the study: function-training group, *M* = 56.1 words, 61st percentile based on the UK-CDI norms, *SD* = 59.7, range = 3 – 206; control group, *M* = 44.5 words, 54th percentile based on the UK-CDI norms, *SD* = 49.7, range = 8 – 190, *t*(22) = 0.52, *p* = .611, 95% CI = [-34.9, 58.1]. Neither did the groups differ significantly in their expressive vocabulary size at the end of the study: function-training group, *M* = 136.4 words, *SD* = 103.6, range = 6 – 331; control group, *M* = 103.6 words, *SD* = 71.4, range = 33 – 280, *t*(22) = 0.90 , *p* = .376, 95% CI = [-42.5, 108.2]. The UK-CDI (Alcock et al., 2017) was normed up to 18 months and therefore has no norms for the age of our participants at the end of the study (19 months).

Two assessments at week 1 ensured that the two groups of infants did not differ in their general attention or in their ability to pick up function similarities of objects (see Initial Assessments in Supplemental Material). Six additional infants were excluded from the analysis because they either did not complete the study (five infants) or were exposed to an additional language at home (one infant). The remaining participants were from monolingual English-speaking homes and did not have any history of language delay or hearing problems.

The study was approved by the Ethical Committee of the University of Birmingham and informed written parental consent was obtained. Parents were reimbursed for their travel expenses and infants received a sticker during each lab visit, as well as a book and a "Junior Scientist" diploma at the end of the final visit.

Socioeconomic Status Calculation

The above-mentioned socioeconomic status variable was calculated as a mean score of parent education, parent occupation, and household income. In one case, household income was not reported, so socioeconomic status was based on the remaining two scores.

Parent Education. A 4-point scale was used to determine parent education, with 1 = No formal education, 2 = Less than an undergraduate/bachelor degree, 3 =

Undergraduate/bachelor degree, 4 = Postgraduate education. The average education score of both parents was calculated and then converted to a value between 0 to 1.

Parent Occupation. Occupation of all participants was classified using the nine levels of the Office for National Statistics - Standard Occupational Classification Hierarchy (Office for National Statistics, 2010) and a score from 1 to 9 was assigned, with 9 being the highest value and 1 the lowest. The average score of both parents was calculated, apart from families with a stay at home parent, for which the occupation score was only based on the person that worked outside the house. This score was then converted to a value between 0 and 1.

Household Income. Income was measured on a 4-point scale (1 = less than £14,000, 2 = £14,001 - £24,000, 3 = £24,001 - £42,000, 4 = more than £42,000). This score was then converted to a value between 0 and 1.

Procedure

All participants were individually trained and assessed at the Infant and Child Lab at the University of Birmingham. The study took place over nine weekly visits: initial assessments (week 1), training sessions (weeks 1 to 7), and final assessments (weeks 8 and 9). The same initial and final assessments were used for both participant groups, but the training differed.

Initial Assessments

At week 1, parents of all infants filled in the UK Communicative Development Inventory: Words and Gestures (Alcock et al., 2017) and a socioeconomic and general development questionnaire. The UK-CDI (Alcock et al., 2017) was used to measure expressive vocabulary size at the start of the study. A socioeconomic and general development questionnaire was used to gather information about the infant's general development, the infant's family and their socioeconomic status. It also informed the eligibility criteria for the study (e.g., no history of a language delay and English as the only language used at home). Additionally, two assessments at week 1 (a sorting task and an attention task) ensured that the two groups of infants did not differ in their ability to pick up function similarities of objects or in their general attention (see Initial Assessments in Supplemental Material for more information).

Training

Participants were randomly assigned to either the function-training group or the control group.

Function-Training Group. Infants in the function-training group were taught four novel words (*kiv, pisk, dax, zav*). Each word was introduced with a set of three novel objects: two referent exemplars that shared the same name, and one contrasting object that did not share the name. The two referent exemplars also shared the same function with each other, but differed in both colour and shape. The contrasting object did not share the same function as the referent exemplars, but shared the same colour with one of the exemplars and the same shape with the other exemplar (see Figure 1). All objects were made from materials such as clay, cloth, or plastic and each set of exemplars performed different functions. *Kivs* were used to cut Play-Doh, *daxes* were used to pick up flowers with magnets, *pisks* made noises when shaken, and *zavs* were used to make a pattern on Play-Doh when pressing on it. Note that objects functions were not strongly correlated with object shapes. Infants were presented with each set in a play-like manner for 3 minutes each (total time of 12 minutes) and the presentation order of all four object sets was randomised across participants. The experimenter first presented one exemplar while saying, for example, *"Look it's a kiv and can cut Play-Doh"*. Then, the second exemplar was presented with a similar sentence (e.g.*"Look this is also a kiv and can cut Play-Doh"*). The experimenter also demonstrated each function while explaining it. Halfway through the presentation of each set (after about

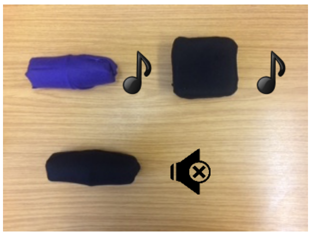
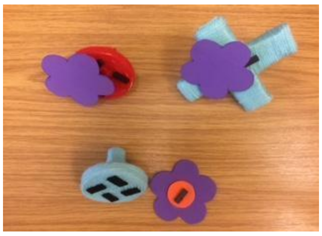
1.5 minutes), the contrasting object was presented. The experimenter tried to perform the same function as the two exemplars and said "*Oh no, this is not a kiv because it cannot cut Play-Doh"*. The contrasting object was then taken away and the experimenter and participant continued playing with the two exemplars. The same procedure was followed with the other three sets of objects. All object names and functions were mentioned and performed at least 10 times per play session.

The same introduction and play with the same novel objects was repeated for six further weekly training sessions (weeks 2 to 7), with the presentation order of object sets randomised across participants and sessions. Non-functional play occurred in some training sessions, especially in the last training sessions, to maintain infants' interest (e.g. hiding an object and finding it).

Control Group. Infants in the control group played freely with the same stimulus objects used in the function-training group during 7 weekly sessions (weeks 1 to 7), including any additional material (e.g. Play-Doh) required to demonstrate the object's function (see Figure 1). Object names and functions were not mentioned or demonstrated. As in the function-training group, each play session lasted 12 minutes. Non-functional play occurred to maintain infants' interest in the later weeks.

Figure 1

Sets of Stimulus Objects Used for the Function-Training Group and Control Group

Set	Description	Set	Description
	Kiv – cuts Play-Doh Contrasting object – cannot cut Play-Doh		Pisk – makes noises Contrasting object – cannot make noises
	Dax – picks up flowers Contrasting object – cannot pick up flowers		Zav – makes small circles on Play-Doh when pressed onto it Contrasting object – cannot make small circles on Play-Doh when pressed onto it

Note. Object names and functions were not mentioned or demonstrated to the control group. Measurements and general descriptions of the stimulus objects can be found at https://osf.io/yra56/?view_only=9ae3702551ca4d51a10d69dea5e74dff.

Final Assessments

During weeks 8 and 9, infants from both groups were administered the same final assessments (first-order and second-order generalisation tests), described below. At the final visit, parents filled in the UK-CDI Words and Gestures questionnaire (Alcock et al., 2017) again to measure expressive vocabulary at the end of the study.

First-Order Generalisation Test. In week 8 all participants were presented with a first-order generalisation task. This task consisted of two practice trials (practice phase) and eight test trials (test phase). Both groups were presented with exactly the same objects and materials and the procedure of this test was identical for both groups.

Practice Phase. Infants were presented with two practice trials to familiarise them with the procedure of the task. In each practice trial, a standard object (a long blue spoon) of a familiar category (spoons) was presented, accompanied with three objects sharing one property each with the standard object (function: a short orange spoon, colour: a blue box, shape: a long brown block with a similar shape as the standard object). The experimenter said *"Look, this is a spoon and can be used to scoop food. Can you give me the other spoon?".* In a second practice trial, another set of familiar objects with a different function was introduced (a blue ball as an exemplar, a round rattle, a blue dinosaur and a green textured ball with a oval bumps that made it look different than the exemplar) and the same procedure as in the first practice trials was followed. In order to move on to the test phase, infants had to correctly choose both target objects (the short orange spoon and green ball). If necessary, both practice trials were repeated until infants responded correctly to both. Most infants chose the target objects during their first attempt. Infants who did not, were shown the correct choice and responded correctly in their second attempt. One infant from the control group and two infants from the function-training group required two attempts to respond correctly.

Test Phase. The test phase consisted of eight trials, one trial per exemplar used during the training weeks. In each trial, participants were shown one of the training exemplars and were asked to get an object that was called the same from a set of three possible options (see Figure 2). Each of the three objects to choose from shared only one property with the training exemplar (shape, colour or function). For each test trial the experimenter named the familiar training exemplar, explaining and demonstrating the function as during the function training sessions. For instance, "*This is a kiv and can be used to cut Play-Doh"*, while demonstrating the function of the *kiv.* She then said *"now look at these ones"*. After demonstrating in silence whether the three objects to choose from could perform the function of the familiar exemplar, she asked *"Can you get the other kiv?"*. The eight trials were presented in one of two orders, counterbalanced across participants.

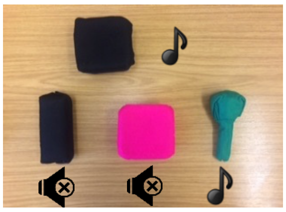
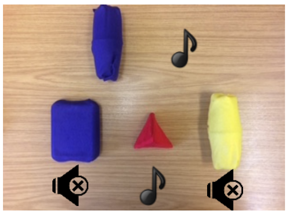
Second-Order Generalisation Test. In week 9, all participants were presented with a second-order generalisation task which consisted of a practice phase and a test phase. Both groups were presented with exactly the same objects and materials, and the procedure was identical for both groups.

Practice Phase. The practice phase was identical to that of the first-order generalisation test in week 8.

***Test Phase*.** Participants were tested with eight sets of completely new and unfamiliar objects, paired with four novel words and functions that participants had not encountered in the previous weeks (see Figure 3). The same procedure as for the first-order generalisation task was followed.

Figure 2

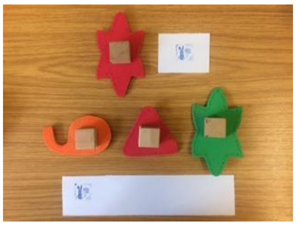
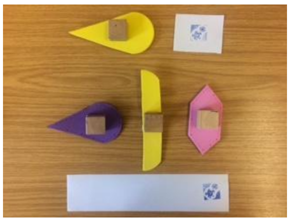
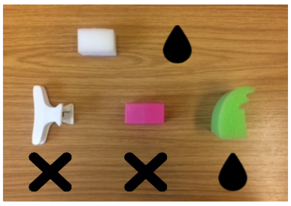
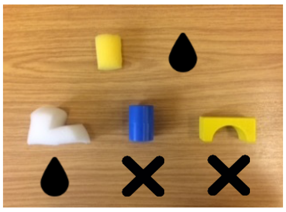
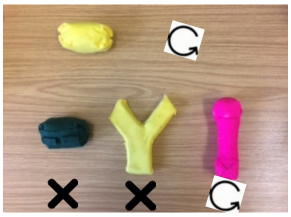
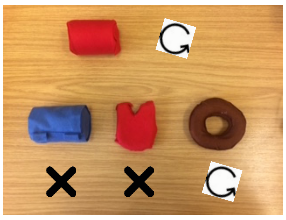
Sets of Stimulus Objects Used during the First-Order Generalisation Test (Week 8)

Trial Set	Description	Trial Set	Description
	Training exemplar – kiv, used to cut Play-Doh Target object: pink triangle		Training exemplar – kiv, used to cut Play-Doh Target object – yellow rectangle
	Training exemplar – dax, used to pick up flowers Target object – purple object		Training exemplar – dax, used to pick up flowers Target object – white object
	Training exemplar – pisk, makes sounds when shaken Target object – green object		Training exemplar – pisk, makes sounds when shaken Target object – red object
	Training exemplar – zav, makes small circles when pressed on Play-Doh Target object – purple object		Training exemplar – zav, makes small circles when pressed on Play-Doh Target object – red object

Note. Each set consisted of one referent object (used during training) and three further objects, with one object matching the standard object by function, one by shape and one by colour. Measurements and general descriptions of the stimulus objects can be found at https://osf.io/yra56/?view_only=9ae3702551ca4d51a10d69dea5e74dff

Figure 3

Sets of Stimulus Objects Used during the Second-Order Generalisation Test (Week 9)

Trial set	Description	Trial set	Description
	Exemplar – gip, used to trace circles on sand. Target object – orange object.		Exemplar – gip, used to trace circles on sand. Target object – yellow object
	Exemplar – toma, used to stamp. Target object – orange object		Exemplar – toma, used to stamp. Target object – pink object.
	Exemplar – soob, used to absorb water. Target object – green object		Exemplar – soob, used to absorb water. Target object – white object
	Exemplar – bosa, used to roll. Target object – pink object		Exemplar – bosa, used to roll. Target object – brown object

Note. Each set consisted of one referent object and three further objects, with one object matching the standard object by function, one by shape, and one by colour. None of the objects, labels, or functions had been used in the study before. Measurements and general descriptions of the stimulus objects can be found at https://osf.io/yra56/?view_only=9ae3702551ca4d51a10d69dea5e74dff

Design and Data Analysis

First- and Second-Order Generalisation Tests

For both the first- and second-order generalisation tasks, we calculated for each child the percentage of function choices out of their total number of choices. A choice was counted as a function choice if the chosen object shared the same function with the referent object. The total number of choices differed across participants because some choices were invalid. For both the first-order and second-order generalisation tasks, the maximum number of choices was eight. However, in the first-order generalisation task three of our 24 participants had a total number of seven because on one trial they chose more than one object. For the second-order generalisation task, five participants had a total number of choices of seven: two participants chose more than one object for one trial and three participants did not choose any object for one trial.

We analysed the percentage of function choices and compared it between the two groups (function-training group vs. control group) in both the first-order and second-order generalisation tasks using independent *t*-tests, and against chance (1 out of 3 objects = 33.33%) for each group using one-sample *t*-tests.

Vocabulary Growth

We analysed the expressive vocabulary of the infants as reported by their parents using the UK-CDI Words and Gestures questionnaire (Alcock et al., 2017). We investigated vocabulary growth with a 2 (group: function-training group vs. control group) x 2 (time: start vs. end of study) x 2 (word type: nouns vs. verbs) ANOVA. Group was a between-subject variable and time and word type within-subject variables. The dependent variable was the total number of words infants produced. Two word categories were analysed: nouns and verbs. For "nouns", words in the following categories of the UK-CDI (Alcock et al., 2017) were included: animal words, vehicle words, words for toys, food and drink words, words for body parts, words for clothes, words for small household items, words for people, 17 items from furniture words, and 19 items from outside words. For “verbs”, all words from the category action words were included.

Results

First-Order Generalisation

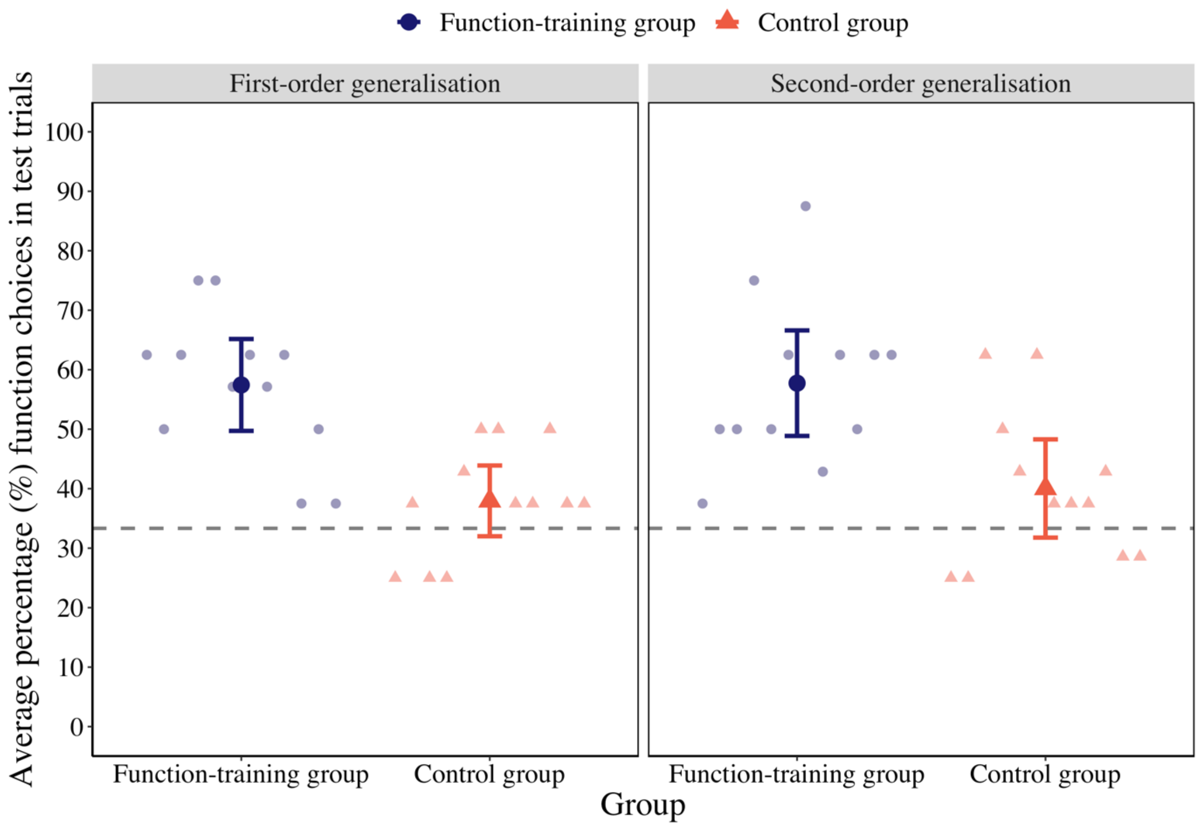
The left panel of Figure 4 shows the average percentage of function choices by group in the first-order generalisation test. Infants in the function-training group (M = 57.44%, SD = 12.15) generalised object labels based on function more often than infants in the control group (M = 37.94%, SD = 9.36), $t(22) = 4.40$, $p < .001$, $d = 1.79$, 95% CI = [10.39, 28.67]. The function-training group also extended object labels based on function significantly more often than chance (33.33%), $t(11) = 6.87$, $p < .001$, 95% CI = [16.38, 31.83], while the control group did not significantly differ from chance, $t(11) = 1.70$, $p = .116$, 95% CI = [-1.33, 10.56]. A stacked bar chart showing the percentages of all three choices in the first-order generalisation test can be found in the Supplemental Material (Figure S4).

Second-Order Generalisation

The right panel of Figure 4 shows the average percentage of function choices by group in the second-order generalisation test. Infants in the function-training group (M = 57.73%, SD = 13.96) generalised object labels based on function more often than infants in the control group (M = 40.03% , SD = 12.99), $t(22) = 3.21$, $p = .004$, $d = 1.31$, 95% CI = [6.28, 29.13]. The function-training group also extended novel labels by function significantly more often than chance (33.33%), $t(11) = 6.05$, $p < .001$, 95% CI = [15.53, 33.28], while the control group did not significantly differ from chance, $t(11) = 1.78$, $p = .102$, 95% CI = [-1.55, 14.95]. A stacked bar chart showing the percentages of all three choices in the second-order generalisation test can be found in the Supplemental Material (Figure S4).

Figure 4

Average Percentage of Function Choices by Group in First-Order and Second-Order Generalisation Tests



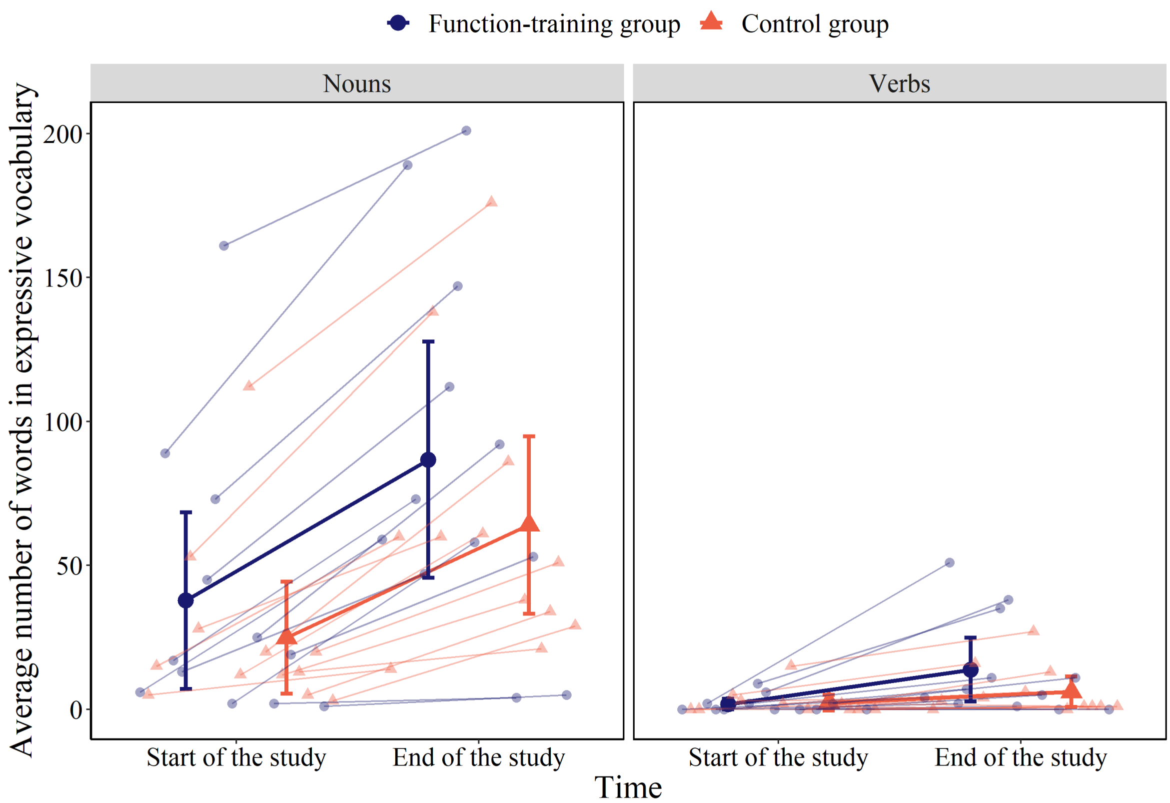
Note. Average percentages of function choices (*y*-axis) by group (*x*-axis), and first-order (left panel) and second-order (right panel) generalisation tests. Blue circles represent the means of the function-training group and red triangles the means of the control group. Error bars represent 95% CIs around the means. Percentages of function choices of individual participants are represented by faded blue circles (function-training group) and red triangles (control group). Dashed grey horizontal lines represent the chance level (33.33%).

Vocabulary Growth

Figure 5 shows the average expressive noun and verb vocabulary sizes of both groups at the start and end of the study, as measured via parent report using the UK-CDI Words and Gestures questionnaire (Alcock et al., 2017). There was a significant main effect of time, $F(1, 22) = 54.80$, $p < .001$, $\eta_p^2 = .71$, and word type $F(1, 22) = 33.22$, $p < .001$, $\eta_p^2 = .60$, on infants' expressive vocabulary, but no significant main effect of group, $F(1, 22) = 0.89$, $p = .356$, $\eta_p^2 = .03$, interaction between time and group, $F(1, 22) = 1.64$, $p = .213$, $\eta_p^2 = .07$, or interaction between word type and group, $F(1, 22) = 0.75$, $p = .395$, $\eta_p^2 = .03$. However, there was a significant interaction between word type and time, $F(1, 22) = 73.27$, $p < .001$, $\eta_p^2 = .76$. That is, children's noun vocabulary grew more than their verb vocabulary. Finally, there was no significant three-way interaction between group, time, and word type, $F(1, 22) = 0.03$, $p = .861$, $\eta_p^2 = .01$.

Figure 5

Average Number of Nouns and Verbs in the Expressive Vocabulary of the Function-Training Group and the Control Group at the Start of the Study and at the End of the Study



Note. Average number of words in the expressive vocabulary (*y*-axis) by group (blue circles represent the mean of the function-training group and red triangles the mean of the control group), and time (*x*-axis), for nouns (left panel) and verbs (right panel). Error bars represent 95% CIs around the means. Total numbers of words in the expressive vocabulary of individual participants at the start and end of the study are represented by the faded blue circles and connecting lines (function-training group) and red triangles and connecting lines (control group).

General Discussion

This study has two key findings. First, infants in the function-training group generalised familiar (first-order generalisation) and novel (second-order generalisation) object labels based on function more often than infants in the control group. The function-training group did so more often than chance, whereas the control group did not. Thus, 17-month-olds can acquire a function bias as a successful word learning strategy, which infants in the control group did not develop spontaneously. Second, the function-training group did not show accelerated real-world noun or verb vocabulary growth over the course of the study compared to the control group.

Function-Training Promotes First- and Second-Order Noun Generalisation

The current study extends the word learning literature in three important ways. First, our study is the first to show that infants can be taught a function bias for first-order noun generalisation. Successful first-order generalisation based on function had previously only been shown in 2- and 3-year-old children (Deák et al., 2002; Diesendruck et al., 2003; Kemler Nelson et al., 2000). Second, our study is the first to show an effect of function-training on second-order generalisation. Thus, it expands the existing literature on how to facilitate second-order generalisation (Aussems & Kita, 2020; Perry et al., 2010; Samuelson, 2002; Smith et al., 2002; Ware & Booth, 2010). Third, and most importantly, our results show that 19-month-olds are cognitively ready to use function for word learning. While Smith and colleagues (2002) accelerated a bias that infants would have developed naturally around the time of their training or soon thereafter, we introduced a bias that infants would not have developed until a few years later. This underlines that conceptual difficulty is not the obstacle that prevents infants from developing a spontaneous function bias.

Importantly, infants cannot be taught just any bias for word learning. Our training was likely successful because function is a relevant property for the naming and categorisation of objects that infants encounter. Samuelson (2002) was not able to teach 15-20-month-olds a material bias using a training very similar to ours and that of Smith and colleagues (2002). Only a small number of objects that infants typically encounter are non-solid objects that are organised and named by material (Samuelson, 2002). Therefore, infants appear to only pick up a bias that is strongly supported by their experience.

One limitation of this study is that we cannot know if seven weeks of training were necessary for infants to develop a function bias. Future studies should test infants' generalisation each week to assess how many training sessions are required.

Why Do Infants Initially Develop a Shape Bias, but not a Function Bias?

Our results suggest that the conceptual simplicity of shape is not the reason infants initially develop a shape bias instead of a function bias. Instead, infants seem to develop a shape bias because shape is a perceptually more easily accessible property than function. Shape can be identified as soon as infants encounter an object (Graham & Poulin-Dubois, 1999) and is stable over time (Gentner, 1982). In contrast, function requires manipulating an object and is mostly transient (Landau et al., 1998). Furthermore, many of the nouns infants acquire refer to objects with correlated shapes and functions (e.g., spoon). Thus, infants can use the highly accessible cue, object shape, to eliminate erroneous referents for novel labels.

Our conclusion is orthogonal to the debate of *how* a shape bias emerges. Two accounts have been proposed in the literature: 1) a shape bias emerges through associative learning during noun learning (e.g. Landau et al., 1988; Smith et al., 2002), or 2) the focus on shape is a part of broader cognitive development, also seen in categorisation behaviours (e.g. Bloom, 2000; Booth et al., 2005; Diesendruck et al., 2003) and in use of conceptual knowledge in noun extension (Booth & Waxman, 2002b). Neither of these accounts explains why shape is prioritised over function. Our answer to this question is compatible with both accounts.

Why Did Function-Training not Promote Vocabulary Growth?

Contrary to the shape-training by Smith and colleagues (2002), our function-training did not promote vocabulary growth outside the laboratory above and beyond that of the control group. Interestingly, though, our control group showed a spontaneous preference for generalising the familiar and novel labels by shape (see Figure S4 of the Supplemental Material), whereas the control group of Smith and colleagues (2002) showed no bias whatsoever. For objects that infants typically interact with (e.g., spoons), either shape or function is often sufficient to know what they are called. Thus, our taught function bias might have been as beneficial for vocabulary growth as the spontaneous shape bias in our control group.

The above explanation suggests that function-training may promote real-world vocabulary growth in populations that do not naturally develop a shape bias (e.g. children with ASD or late-talkers) (Field et al., 2016; Jones, 2003; Tek et al., 2008). This is an important topic for future research.

Conclusion

To conclude, infants can be taught a function bias as a successful strategy for noun learning, which they can use even for novel words never encountered before (second-order generalisation). Our study shows that by 19 months of age, infants can learn to systematically extend words based on perceptually hard-to-access and conceptually complex information. Thus, it is unlikely the conceptual simplicity of shape, but rather its easy-to-access perceptual feature, which explains why the shape bias spontaneously emerges.

Author Contributions

C. Zuniga-Montanez and A. Krott contributed to the study design. Recruitment was performed by C. Zuniga-Montanez and S. Aussems. Testing, and data collection was performed by C. Zuniga-Montanez, who also performed the data analysis under the supervision of A. Krott. All authors contributed to the interpretation of the results and to writing the manuscript, and approved the final version for submission.

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Declaration of Conflicting Interests

The authors declare no conflicts of interest with respect to their authorship or the publication of this article.

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Open Practices

The raw data and analysis scripts, as well as the code scripts for figures, and the videos demonstrating the stimulus objects and their functions are available via the Open Science Framework via https://osf.io/yra56/?view_only=9ae3702551ca4d51a10d69dea5e74dff.

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