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Authors

Sucevic, Jelena
Althaus, Nadja
Plunkett, Kim

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Shaping the Dynamics of Category Learning in Infants and Adults by Varying Learning Context

Jelena Sucevic (jelena.sucevic@psy.ox.ac.uk)
Department of Experimental Psychology, University of Oxford, 9 South Parks Road
Oxford, United Kingdom

Nadja Althaus (nadja.althaus@psy.ox.ac.uk)
School of Psychology, University of East Anglia, Norwich Research Park
Norwich, United Kingdom
Department of Experimental Psychology, University of Oxford, 9 South Parks Road
Oxford, United Kingdom

Kim Plunkett (kim.plunkett@psy.ox.ac.uk)
Department of Experimental Psychology, University of Oxford, 9 South Parks Road
Oxford, United Kingdom

Abstract

During the first year of life, infants develop a remarkable ability to group objects based on their similarities and differences. This ability of category formation represents one of the main mechanisms underlying the organisation of the semantic system. Early categories are formed spontaneously, in a non-supervised fashion and this type of category acquisition remains present even when more sophisticated forms of supervised category learning emerge. Even though there are various models of categorisation mechanisms across the lifespan, there is a gap in the research investigating implicit categorisation at different stages of cognitive development. Therefore, the aim of the current study was to compare processes of spontaneous concept formation in infants and adults using an experimental paradigm based on novelty preference. We discovered that both infants and adults show evidence of category learning (Experiment 1), though with different amount of training being needed to achieve the task. Adults successfully categorised objects already after a single block of training. Infants reached a level comparable to that of adults after twice the amount of training. As these tasks inevitably pose different cognitive and sensory demands to the two groups, in Experiments 2 and 3 we explored how varying parameters of the learning context affect dynamics of category formation. Decreasing memory demands of the task resulted in an acceleration of infants' category formation (Experiment 2), whereas posing memory load in an implicit category learning task decelerated adults' dynamics of category formation (Experiment 3).

Keywords: categorisation, learning context, non-supervised category acquisition, novelty preference, cognitive load, memory demands, infants, adults, eye tracking

Introduction

The ability to group objects based on their similarities and differences represents one of the main mechanisms underlying the organisation of the semantic system. Concepts "embody much of our knowledge of the world telling us what things there are and what properties they have" (Murphy, 2002, p. 1). Therefore, categorisation ability is considered to be critical for the organisation and stability of cognition (Mareshal & Quinn, 2001). The ability to detect regularities in the environment and form categories emerges early in development. At the age of 3-4 months, infants already demonstrate the ability to differentiate categories of dogs and cats (Eimas & Quinn, 1994), but also to form abstract perceptual categories (Bomba & Siqueland, 1983). This ability becomes even more refined around ten months of age when infants become able to shape categories based on statistical regularities of category members (Younger & Cohen, 1986).

In the domain of infant research, novelty preference is a standard method employed to explore categorisation processes. Typically, a familiarisation phase consisting of a set of training items (for instance members of two categories), is followed with a test phase where infants are presented with two novel items, one belonging to the familiarised category and one coming from a different category. Under the assumption of novelty preference, i.e. that infants look longer at the object that is perceived as less familiar, differences in looking times are interpreted as an index of category formation (e.g. Eimas & Quinn, 1994). For instance, in a study exploring how infants form categories based on correlational feature structure, two test items are presented, one of them depicting an average of all presented items and the second object representing a sub-category average of one of two categories that could be formed (e.g. Plunkett et al., 2008). Infants who formed two categories demonstrated preference for the novel out-of-category overall average.

Despite the fact that processes of implicit, non-supervised category formation have been extensively studied in adults as well as in different patient populations (Reed, Squire, Patalano, Smith, & Jonides, 1999), there have been few attempts to directly compare category learning processes in infants and adults. One recent computational model of categorisation offered an integrative account for infant and adult category learning (the SUSTAIN model, Gureckis &

Love, 2004). Initially developed as a model of adult categorisation, the model proposes that mechanisms underlying infant and adult categorisation are not substantially different and assumes a continuous trajectory of conceptual development. Two explanations are offered to account for developmental differences – memory limitations and stimulus encoding limitations (Gureckis & Love, 2004). In order to empirically test these assumptions, in the present study we developed an experimental paradigm for adults providing similar learning conditions as employed in the infant study. We aimed to address the question whether there are shared mechanisms of spontaneous conceptual organisation across the lifespan.

To parallel the visual familiarisation procedure used with infants, we designed a task to explore implicit category learning in adults where preferential looking was used as an index of category learning, and which provided similar learning conditions as those encountered in the infant study. As infants were merely presented with a set of objects, adults did not receive any explicit training or feedback on category formation. The adult task was also designed to tap into implicit, unsupervised category learning. As in the infant experiment, we presented adults with a series of objects as part of the familiarisation phase, followed by a test phase in which two test objects were presented and looking preferences were measured. Several studies using visual paired-comparison procedure with adults have shown that novelty preference can be used as an index of visual recognition in adults (Richmond, Colombo & Hayne, 2007). As the magnitude of novelty preference increases with familiarisation time in object recognition (Richmond et al., 2007), we propose that the same effect can be interpreted as an index of category formation.

Even though the same type of experimental task was used with both infants and adults, there are inevitable differences in the demands to the two groups of participants this task poses. Task difficulty and memory demands might lead to differences in performance. One recent study has demonstrated the importance of learning conditions in altering categorisation in adult participants. Carvalho and Goldstone (2014) showed that category structure influences how efficiently category representations will be formed, and that this effect is tied to the way in which category members are presented. The authors conclude that there is category-specific attention allocation – simultaneous presentation promotes attention to commonalities among objects, while sequential presentation emphasizes differences among objects. These studies suggest that categorisation cannot be seen only as an extraction of abstract rules or computation of feature statistics, but emphasize that the dynamics of learning have an important role in category formation.

After discovering that adults and infants both showed categorisation, but at different rates (Experiment 1), we conducted Experiments 2 and 3 to investigate further which factors are relevant for categorsation in these cases. In order to explore how the context of learning affects category learning, we varied the task difficulty and investigated its effects on categorisation in infants and adults. Our hypothesis was that decreasing the task demands will accelerate category formation in infants (Experiment 2), whereas adding an additional cognitive load to the task will delay category formation even in adults (Experiment 3).

Experiment 1

The aim of the first experiment was to compare implicit category learning processes in infants and adults. In addition, we were interested in exploring the effects of the amount of training on forming categories based on statistical regularities, i.e. features correlations. Thus, three training blocks were interleaved with three blocks in which category formation was tested.

Participants

Thirty-two 10-month-old infants took part in this study (two participants were excluded due to fussiness and refusal to look at the screen). Participants were recruited at the local maternity ward and all were full-term babies with no known health conditions. All participants came from homes where English was the only language spoken.

In addition, 24 adults took part in the experiment (mean age = 23.67 years (SD=3.08)). Two participants were excluded from the analyses (one due to calibration failure and one due to eye-tracker track loss).

Stimuli

A set of novel objects was designed for the purposes of this study. Coloured and textured 3D looking objects represented novel creatures (called Sukis). As illustrated in Figure 1, each Suki consisted of four features: body, antennae, hands and legs. Each feature varied systematically on a scale of seven dimensions (body shape, number of antennae, hand size, length of legs), (see table 1). A set of 24 Sukis was designed in a way to resemble the structure of objects used in several categorisation studies (Younger & Cohen, 1986; Plunkett et al., 2008; Mather & Plunkett, 2011). Values of one feature were predictive for values on other dimensions, thus inviting participants to form two categories (defined as *the narrow condition* in Plunkett et al., 2008). However, the range of potential dimensions each feature can take was extended, thus instead of a range of 5 dimensions used in above mentioned studies, we introduced 7 potential variations of each feature.
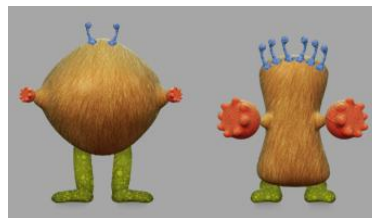

Figure 1. Examples of the Sukis: Subcategory average objects

The reason for increasing the variability of the stimuli set is to have the possibility to create test items made of completely novel dimensions that have not been presented in any instance during the familiarisation phase. Four additional Sukis were designed to be presented as test items: an overall average object (consisting of mean values on each dimension, i.e. 4444), two subcategory averages (2222 and 6666). In addition, completely novel, out-of-category objects which comprised of the same features as all objects, but organized in a completely different manner were presented in the final trials of the test phase. All objects were depicted against a 5% grey background.

Table 1: Stimulus structure (first familiarisation set)

Stimulus	Category	Antenna	Hand	Body	Legs
1	1	1	1	3	3
2	1	1	3	1	3
3	1	3	1	3	1
4	1	3	3	1	1
5	2	5	5	7	7
6	2	5	7	5	7
7	2	7	5	7	5
8	2	7	7	5	5

Procedure

Infants After written consent was obtained from a carer, an infant was seated on a carer's lap approximately 50 cm from a 1920x1080 inch screen in a sound-proof experimental booth. The parent was asked to keep their eyes closed for the duration of the experiment. Data was recorded using a Tobii TX300 Eye Tracker with a 120 Hz sampling frequency and four point calibration. The study was run with a custom Matlab stimuli presentation software PresentMate based on the Psychophysics Toolbox. Infants' behaviour was monitored via a centrally-located camera above the screen. Trials were initiated by the experimenter when the infant was attending the screen. Each familiarisation block consisted of eight trials. Each trial started with a presentation of an animated star in the central location of the screen accompanied by a chiming sound for the duration of 2000 ms. Following this, one stimulus (500 x 500 pixels) was presented in the central location for 6000 ms. As a previous study has shown that the order in which stimuli are presented may affect category formation (Mather & Plunkett, 2011), we calculated mean Euclidean distance (as an average of seven distances between consecutive objects) for all possible stimuli sequences (40320 sequences) and selected sequences that fall within the range between the 40th and 60th percentile (8112 sequences). Then, for each participant a particular sequence from this pool was randomly selected. Three test blocks were interleaved with learning blocks. In each test, after an attention getter was presented for 2000 ms, two test objects were presented simultaneously for 10 000 ms. The first two trials were category formation test trials in which the *overall category average* (object 4444) and *a subcategory average object* (2222 or 6666) were presented. The positions of the two objects were counterbalanced across the two trials. The third test trial was always a novelty preference test in which one of the learning items from the previous learning phase was presented along with the novel, previously unseen out-of-category object. The purpose of this trial was to check whether infants were engaging in the task and expressing the expected novelty preference. The choice of the subcategory average object (2222 or 6666) presented in a particular test block was balanced across test blocks. The third test block was identical to the first test block for half of the participants, whereas others saw identical items as in the second test block. Which subcategory average object was presented first was counterbalanced across participants.

Adults Participants were instructed they would take part in a free viewing task so their only task would be to look at the objects presented on the screen. After written consent was obtained, participants were seated in front of the eye-tracker and their eye-movements were recorded using 120Hz tracking frequency. Upon completion of the experiment, none of the participants reported they were aware what the purpose of the experiment was. The experimental design was kept as similar as possible to the infant version. Participants were presented with 3 blocks of training, each consisting of 8 trials. Each trial started with a centrally presented fixation cross for 500 ms followed by a presentation of a training items for the duration of 2000 ms. Training blocks were interleaved with test blocks. Analogous to the infant version, each test consisted of two categorisation test trials and a novelty preference trial. After the fixation cross was presented for 500 ms, test trials were presented on screen for 3000 ms.

Results: Infants

Category Formation Test For category formation test trials, preference scores were calculated for all trials by dividing looking at the overall average object by total looking time to the overall and modal object. A repeated-measures ANOVA with factors Block (1, 2 and 3) and Test (1 and 2) showed no significant effects (all ps>0.05)[1]. Planned comparisons against chance were performed for each test. Infants expressed a preference for the overall average object in the second trial of the second test block (t(25)=1.99, p<0.05), (Figure 2).

Novelty Preference Test To validate that infants' behaviour was driven by novelty preference, infants were presented with the novelty preference test after each category formation test block. Infants' looking to the novel object was divided by the total looking time and a one-way

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[1] Only participants who contributed to all trials were included in this analysis

ANOVA with Block as a within-subjects factor revealed no effect of Block. Planned comparisons showed that infants' preference for the novel object differed from chance only in the second block (t(26)=2.58, p<0.05).
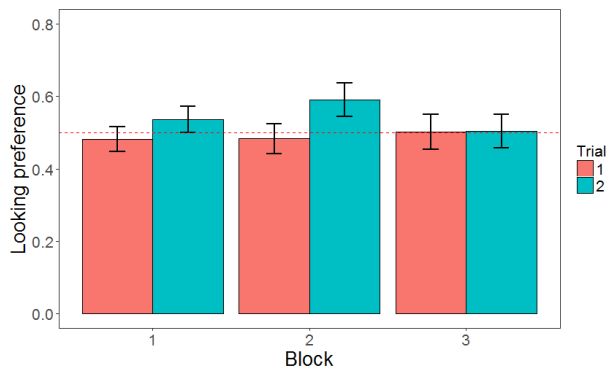

Figure 2: Looking preferences in test

Results: Adults

Category Formation Test Looking preference scores were calculated in the same way as for infants. The proportion of looking toward the overall average object was divided by the total looking time to both overall and modal objects. A repeated measures ANOVA with the within-subject factors Block and Trial revealed a significant main effect of Block (F(2,44)=3.07, p=0.05). Planned comparisons against chance revealed that preference towards overall average was significant only in the first block (t(22)=2.07, p=0.05), whereas in the remaining does not significantly differ from chance (p>0.05; Table 2).

Novelty Preference Test Participants exhibited preference for the out-of-category object in all three novelty preferences tests (no difference was found between 3 novelty preference trials).

Table 2: Mean looking preferences on test
(Experiment 1, Adults, SDs provided in brackets)

Block	Test	Novelty
1	0.55 (0.17)*	0.67 (0.22)*
2	0.51 (0.13)	0.67 (0.18)*
3	0.47 (0.17)	0.61 (0.20)*

Experiment 1: Discussion

Results of Experiment 1 have shown that both infants and adults show evidence of category formation based on feature correlations in a free viewing task. In addition, this experiment revealed that paradigms based on novelty preference might be a useful tool in studying non-supervised category learning in adults. The results also showed that infants were slower in forming categories requiring a greater amount of familiarization to demonstrate similar level of performance as adults. The observed differences in the performance might be due to various factors related to developmental differences. We hypothesize that one of the main factors driving these differences are memory demands. In order to compare an item presented during familiarisation with a previously presented one, information about the former items needs to be kept active in the working memory for comparison with the currently presented item. This might result in slower category formation in infants as it takes more resources to perform in this task due to limited memory abilities.

In order to test this hypothesis, we conducted the second experiment in which we decreased memory demands of the task by presenting familiarisation items in pairs. We hypothesized that, if memory load is reduced, infants will be faster in extracting category information.

Experiment 2

Participants

Twenty-eight 10-months old infants took part in this study (two infants were excluded from the later analyses due to failing to reach minimum amount of looking time during familiarisation).

Stimuli and procedure

The stimuli set used in this experiment was identical to the one in Experiment 1. As opposed to sequential presentation in the first experiment, familiarisation items were presented in pairs. A total of four trials were presented in each learning block. Following the presentation of an attention getter, two objects were presented simultaneously for 12 000 ms. Pairs of objects were selected based on sequences used in the sequential condition. Namely, each sequence used in Experiment 1 had a corresponding paired sequence in Experiment 2. It is important to note that despite the difference in the number of trials in each learning block, the total duration of learning blocks was identical across the two experiments.

Results

Category Formation Test For category formation test trials, preference scores were calculated for all trials by dividing looking at the overall average object by total looking time to the overall and sub-category average object. A repeated measures ANOVA with factors Block (1, 2 and 3) and Test (1 and 2) revealed a main effect of Block (F(2, 36)=3.15, p<0.05) (only participants who contributed to all trials were included in this analysis, N=19). As there was no main effect of Trial, we averaged performance in the two test of the same block and performed planned comparisons. Performance in each block was compared against chance and we found that preference for the overall average object was significantly above the chance in the first block

(t(25)=2.91, p<0.01), whereas in the remaining two blocks preference did not significantly differ from chance (mean preference values and dispersion are depicted in Table 3).

Novelty Preference Test To validate that infants' behaviour in test trials was driven by novelty preference, following each category formation test block, infants were presented with the novelty preference test. A one-way ANOVA with Block as a within-subjects factor revealed a near significant effect of Block (Greenhouse-Geiser F(2, 38)=0.76, p=0.06). Planned comparisons revealed that infants' preference for the novel object differed from chance only in the first block (Wilcox signed rank test: V=242, p<0.05).

Table 3: Mean looking preferences on test (Experiment 2, SDs provided in brackets).

Block	Test	Novelty
1	0.57 (0.12)*	0.63 (0.26)*
2	0.46 (0.18)	0.48 (0.29)
3	0.49 (0.14)	0.60 (0.27)

Experiment 2: Discussion

Experiment 2 revealed that the dynamics of infants' category formation can be shaped by varying the parameters of the learning context. Decreasing memory demands in the task leads to a boost in extracting category relevant information. Infants' faster learning was also resembled in the fact that they demonstrated novelty preference already in the first test. Diminished novelty preference in the following tests and well as a larger attrition rate suggests that infants learned faster and then disengaged from the task. We conducted Experiment 3 to investigate whether increasing memory demands would lead to a decrease in the speed of category formation in adult participants. For the purpose of investigating implicit category learning in adults we adapted the N-back task, which is typically used in studies of working memory. Infants in the sequential condition were presented with one object at a time and had to mentally compare objects that were presented. Thus, we used a 1-back version of the task and investigated whether participants spontaneously form categories under higher cognitive load conditions. If this incidental categorisation occurs, we expect that participants will judge between-categories pairs faster than they would judge within-category comparisons. Having perceptual similarity and semantic distance between to-be-compared items controlled, we predict that differences in the discrimination speed might reflect processes of categorisation.

Experiment 3

Participants

Twenty-four participants, students at Oxford University took part in this study (mean age = 23 years (SD= 2.54)).

All participants were right handed and had normal or corrected-to-normal vision. Prior to taking part in the experiment, all participants signed an informed consent and upon experiment completion received course credits for their participation.

Stimuli and Procedure

An identical stimuli set to the one in Experiments 1 and 2 was used in this study. The experiment consisted of seven blocks. Each block had two parts. A total of 36 learning trials were presented in the first part, and 10 test trials in the second part of each block. The order of presentation was pseudorandomised within each block. In order to balance the number of "identical" and "different" responses, participants were instructed to give a response only for probed trials, where a red dot would appear in the centre of the screen. In the learning part, there were 16 "different" comparisons (and an equal number of "identical"), half of which were within category, whereas the other half crossed the category boundary. In the test part, there were four "identical" and four "different" comparisons. While visual similarity and semantic distance (expressed through Euclidean distance) between the two compared objects was identical, some pairs crossed the category boundary (3333-5555), one pair was on the boundary (4444-6666) and some pairs were within the same category (1111-3333, 5555-7777).

Results

In order to explore whether there is a difference in reaction times for between and within category judgments during the course of the experiment, growth curve analysis (Mirman, 2014) was used. Mean reaction times in each test block are presented in the Figure 3. The reaction time in mismatch trials were modeled using a linear growth curve model with a fixed effect of mismatch type (within-category and between-categories comparison) on the intercept and slope terms and random effects of participants on the intercept and slope to model individual differences in initial speed and rate of change. The fixed effect was added to the base model and its' effect on model fit was evaluated using model comparisons. All analyses were carried out in R version 3.3.1 using the lme4 package (version 1.1-12). There was a significant effect of mismatch type on the intercept ($\chi^2(1)$=4.13, p<0.05) suggesting that participants responded faster when comparing items from different categories as opposed to performing within-category comparisons. This result suggests that participants organised items into two separate categories which resulted in making members of the same category look more similar than items belonging to different categories, even though perceptual similarity for both types of comparisons was identical.
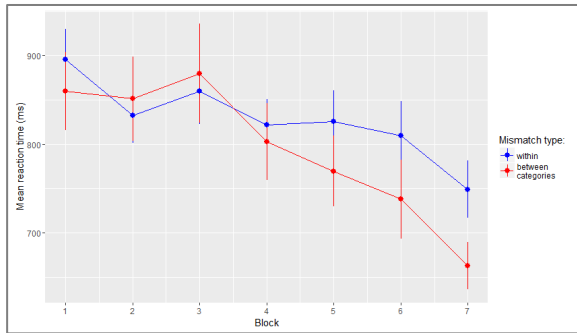
Figure 3. Mean reaction time across 7 test blocks

General Discussion

Taken together, the results of the experiments reported in this paper demonstrate how changing parameters of the learning context affect the dynamics of category learning in infants and adults. Experiment 1 provided evidence that both infants and adults can form categories in a free-viewing task, though it takes a different amount of exposure to succeed. Infants showed evidence of category formation after two blocks of familiarisation, whereas adults reached a similar level already after one training block. In addition, this experiment suggests that experimental paradigms based on novelty preference, the standard approach in infant research, can be used to explore non-supervised category learning in adult population as well.

Findings obtained in the second and the third experiment suggest that changing the task difficulty can accelerate (Experiment 2) or decelerate (Experiment 3) the process of extracting category relevant information for infants and adults, respectively. That the task structure can modulate infants' learning is further confirmed by the significant interaction between Experiment (1 and 2) and Block (1, 2 and 3) in a combined analysis (F(2, 66)=4.518, p<0.05). The finding that paired presentation leads to faster category formation in infants is consistent with existing literature suggesting positive effects of comparison on learning and memory (Oakes & Ribar, 2005). In addition, the results of Experiment 3 with adults also suggest that increasing the load impedes category formation. Initially developed to explain cross-modal effects of labels on categorisation, the perceptual load hypothesis can also offer a way of interpreting the obtained results (Plunkett, 2010). This hypothesis assumes that extraction of statistical information during category formation is also dependent on the perceptual load required to process individual stimuli and not exclusively on the feature correlations alone. Paired presentation may represent an optimal amount of available information for category formation in infants. Alternatively, it might be the case that the invitation to compare stimuli is contributing to the modulations of category learning. Future research needs to explore does manipulating load in other ways would result in a similar modulations of learning timecourse.

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