How do Labels Impact Infant Categorisation?

How do Labels Impact Infant Categorisation?

Kim Plunkett
Department of Experimental Psychology, University of Oxford,
South Parks Road, Oxford, OX1 3UD, United Kingdom
E-mail: kim.plunkett@psy.ox.ac.uk

Abstract

A substantial body of experimental evidence has demonstrated that labels have an impact on infant categorisation processes. Yet little is known regarding the nature of the mechanisms by which this effect is achieved. This paper distinguishes two accounts, supervised name-based categorisation and unsupervised feature-based categorisation, and describes a neuro-computational model of infant visual categorisation, based on self-organising maps, that implements the unsupervised feature-based approach. The model successfully reproduces experiments demonstrating the impact of labelling on infant visual categorisation reported in Plunkett, Hu, and Cohen (2008). The model predicts that the impact of labels on categorisation is influenced by the perceived similarity of the objects and the sequence in which the objects are presented to infants. The results suggest that early in development, before 12-months-old, labels need not act as invitations to form categories nor highlight the commonalities between objects, but may play a more mundane but nevertheless powerful role as additional features that are processed in a similar fashion to other features that characterise objects and object categories.

An earlier version of this manuscript appeared as Plunkett, K. (2010) The Role of Auditory Stimuli in Infant Categorization, in L. M. Oakes, C. H. Cashon, M. Casasola, & D. H. Rakison, (Eds)*Infant Perception and Cognition: Recent advances, emerging theories, and future directions.* Oxford University Press (New York), A Festschrift in Honor of Leslie B. Cohen.

Introduction

In an extensive series of studies, Waxman and colleagues have provided evidence for the view that labels have an impact on category formation in young infants (Waxman & Markow, 1995; Balaban & Waxman, 1997; Waxman & Booth, 2003; Waxman, 2003; Fulkerson & Waxman, 2007). Using a novelty preference procedure, infants were familiarised with a series of objects taken from the same category and then given a choice between two novel objects, one of which is from the familiarised category. During familiarisation, the objects are accompanied by a novel label such as 'dax' or a neutral carrier phrase such as 'Look at this'. Infants show a preference for the out-of-category object when familiarised with the novel label, but not with the neutral carrier phrase. These findings are interpreted as demonstrating that 'labels facilitate categorisation', that labels 'act as invitations to form categories' and that labels 'highlight the commonalities between objects'. Their findings suggest that the effects are specific to the consistent use of labels that could be words in the infant's language. Tones and buzzers don't achieve the same effect and the same label needs to be used consistently throughout familiarisation. Using different labels doesn't work. These findings have been reported for infants well before their first birthday, indicating that labels have an impact on infant categorisation before they produce their first words and before they have acquired a substantial receptive vocabulary.

A contrasting set of studies by Sloutsky and Robinson point to a different conclusion: That novel labels overshadow the processing of visual stimuli by young infants and, therefore, that auditory stimuli (including novel labels) interfere with category formation (Robinson & Sloutsky, 2004, 2007; Sloutsky & Robinson, 2008). They base their conclusions on a series of habituation studies in which infants are familiarised with compound auditory-visual stimuli and are then exposed to a dishabituation stimulus that changes either the auditory component or the visual component. Infants notice the change in the auditory component but not the change in the visual component. Failure to dishabituate to a change in the visual stimulus is interpreted as a failure to process the visual stimulus as a result of the auditory stimulus overshadowing the visual information during familiarisation. It should be noted that familiar auditory stimuli, such as well-known names, do not produce such dramatic overshadowing effects. Furthermore, novel labels interfere with visual processing in 10 month olds but not at 16 months (Sloutsky & Robinson, 2008).

The finding that novel labels interfere with visual processing in 10 month-old infants does not sit well with the finding that novel labels can facilitate the categorisation of objects: Auditory dominance effects are more likely to impede categorisation than to facilitate infants' attention to the commonalities between objects. However, there are important differences in the procedures used to test infants in these studies that might readily explain the apparently discrepant findings: The categorisation studies are typically conducted in a one-on-one setting and don't require infant habituation. Auditory dominance studies are infant-controlled and testing does not occur until the infant reaches an habituation criterion. The stimuli and timing of events are also quite different. The categorisation studies make use of objects or pictures which are likely to be familiar to infants and which are readily interpretable as single whole objects, and perhaps more likely to be members of a category. The auditory dominance studies commonly exploit complex shapes unfamiliar to infants and which are readily segmented into separate objects with no obvious category alignment. In categorisation studies, labels are presented after infants have had an opportunity to examine the visual objects whereas in auditory dominance studies labels are syncronised with the onset (and often the offset) of the visual stimuli. Given the transient character of auditory stimuli compared to visual stimuli in the real world (as opposed to the laboratory), the human cognitive system may have evolved to prioritise auditory stimuli in order ensure that sufficient attentional resources are available for speeded processing. The observed auditory dominance effects may derive from the syncronisation of visual and auditory onsets, a condition which does not typically hold when objects are labelled for infants.

Although it may be possible to reconcile these apparently disparate findings by appealing to differences in stimuli, timing and experimental procedures, some difficulties of interpretation of the impact of labels on infant categorisation still remain. Waxman and colleagues report that infants show a novelty preference for the out-of-category object, and thereby evidence for categorisation, only when the familiarisation phase includes a novel label, not when the familiarisation phase involves a neutral carrier phrase, such as "Look at that". Hence, the locus of the categorisation effect would appear to be the novel label. However, it is well-established that infants will demonstrate novelty preference effects in experimental situations that indicate category formation, but in the absence of any auditory stimulus (Behl-Chadha, 1996; Eimas & Quinn, 1994). For example, after being familiarised with a sequence of cats, infants will prefer to look at a novel dog over a novel cat. Interpretation of the role of the novel label as a facilitator of category formation is compromised by the fact that infants exhibit robust category formation in the absence of any auditory stimulation. An alternative interpretation of the categorisation studies is that the neutral carrier phrase interferes with category formation, whereas novel labels don't block the process. However, this interpretation does not sit well with auditory overshadowing studies, since novel rather than familiar auditory stimuli are likely to interfere with visual processing. Neutral carrier phrases, such as "Look at this one", are likely to be familiar to infants and should not hinder visual processing.

In order to determine the locus of a labelling effect on infant categorisation, Plunkett et al. (2008) adapted an earlier experiment by Younger (1985). In the original experiment, Younger (1985) presented 10-month-old infants with line drawings of animal-like objects which varied in the length of their legs and necks, the size of their tails and the spread of their ears (see Figure 1). Infants were fa-

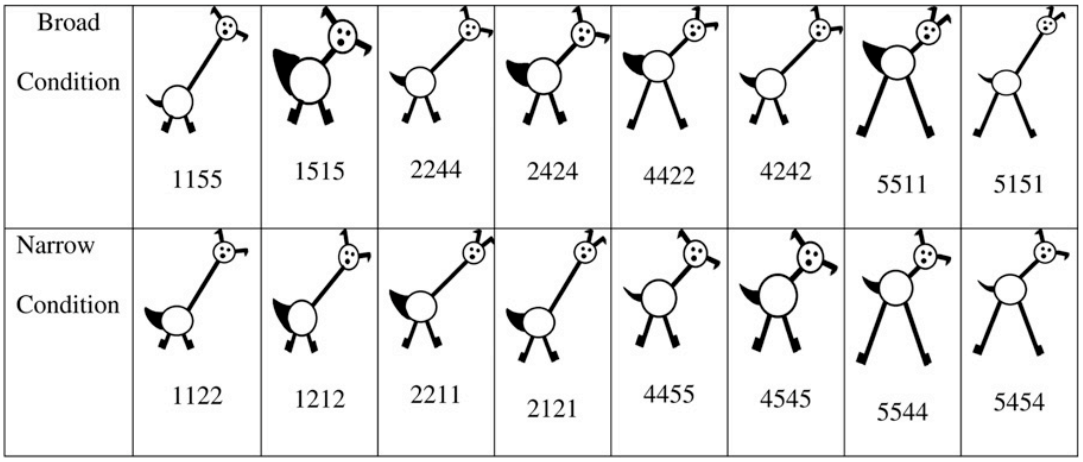

Figure 1. Cartoons shown to infants during familiarisation in Plunkett et al. (2008). The number under each figure represents the feature value for each of the four dimensions defining the cartoon, i.e., length of the legs and neck, size of the tail and separation of the ears, respectively.

miliarised with 8 drawings and then tested with novel drawings that differed from the familiarisation set in systematic ways. In one set of drawings called the Broad condition, the value of feature attributes across drawings were not predictive of each other. For example, long legs could just as well occur with long necks as short necks. However, in another set of drawings called the Narrow condition, feature values were predictive of each other. For example, spread ears predicted small tails and vice versa. When subsequently tested with pairs of novel objects, one of which depicted the average value for each of the features (3333) and one depicting the extreme values of each of the features (1111 or 5555), infants demonstrated a novelty preference for the extreme stimuli in the Broad condition whereas they preferred to look at the average stimulus in the Narrow condition. Younger (1985) interpreted these findings as indicating that infants had formed a single category centred on the average when familiarised with Broad condition stimuli. In contrast, they formed two categories when familiarised with Narrow condition stimuli where the average stimulus belonged to neither category and the extreme stimuli were close to the averages of the categories. These experiments demonstrated that 10-month-old infants are able to exploit the correlations between the feature values to determine category membership. Other experiments by Younger and Cohen (1986) demonstrated that younger infants do not exploit feature correlations in the service of category formation.

In Plunkett et al.'s (2008) adaptation, the original experiments were replicated and supplemented with three additional experiments in which the Narrow condition stimuli were accompanied by novel labels during familiarisation. In their Experiment 3, two labels ('dax' and 'rif') were paired with the eight familiarisation stimuli such that one of the labels was heard with members of one category (1122, 1212, 2211, 2121) and the other label with members of the other category (4455, 4545, 5544, 5454). In this case, the labels correlated with category membership, just as the visual feature values correlated with each other, so the labels were expected to support category formation and perhaps even enhance it. In Experiment 4, the two labels were pseudo-randomly paired with the Narrow condition familiarisation stimuli such that one label was heard with two members from each category and the other label was heard with the remaining stimuli. Label assignment was now in conflict with the visual feature correlations so category formation might be disrupted. Notice that Experiments 3 and 4 used identical novel auditory and visual stimuli. Hence, if auditory stimuli overshadow the processing of visual stimuli (Sloutsky & Robinson, 2008), then the same preferences should be observed in the test phase of each experiment where infants were given a choice between the average and extreme visual stimuli. Finally, in Experiment 5, the same label was used with each of the familiarisation stimuli. Infants might choose to ignore the label because it is redundant and form two categories as they did with the Narrow condition stimuli in (Younger, 1985). Alternatively, the label might overshadow the processing of the visual stimuli, thereby interfering with category formation. Or the label might highlight the similarities between the familiarisation stimuli, as in Waxman and colleagues studies, and encourage infants to form a single category, as they did with the Broad condition stimuli in Younger (1985).

The impact of the labels on the infants novelty preferences differed in each of the three experiments. When two labels correlated with visual category membership, infants formed two categories as indexed by their preference for the average stimulus during testing. When the two labels were decorrelated, infants showed no novelty preferences during testing, an indication that no categories had been formed during familiarisation. When a single label was used for all familiarisation stimuli, infants showed a novelty preference for the extreme stimuli, indicating that a single category had been formed. In other words, infants formed two categories, one category or no categories depending on the labelling contingencies to which they were exposed during familiarisation. Recall that the same visual stimuli were used during familiarisation in all three experiments. Furthermore, the infants viewed the same testing stimuli in all experiments in silence. The variation in their novelty preferences could only be driven by differences in the mental representations they had formed during familiarisation. These novelty preferences were reversed when infants were familiarised with two correlated labels versus a single consistent label, and obliterated when two labels were used in an uncorrelated fashion. We can conclude, therefore, that the relative perceptual familiarity of the test objects was affected by the impact of the labels on the categorisation of the visual stimuli during familiarisation: Novel objects that belong to a represented category are perceived as more familiar than novel objects outside a represented category.

Note that the impact of the labels cannot be explained by the overshadowing hypothesis (Sloutsky & Robinson, 2008). Overshadowing would predict that category formation be overridden in all three experiments because the novel labels should prevent infants from noticing the statistical correlation amongst the visual feature values. However, infants failed to demonstrate category formation in only one case—Experiment 4. Even this case indicates that infants are sensitive to the correlations between the labels and the visual stimuli, since they performed quite differently in Experiment 3 which used exactly the same familiarisation stimuli but with different patterns of correlation between labels and objects. The results of Plunkett et al. (2008) provide a clear demonstration that 10-month-old infants can compute detailed statistical correlations between the values of visual features across objects even when those visual objects are accompanied by novel labels. Moreover, these infants can compute the cross-modal statistics so that the outcome of these computations influence the process of visual object categorisation. Simply put, auditory labels impact visual categorisation in 10-month-olds.

Although the results of Plunkett et al. (2008) fail to support the overshadowing hypothesis, nor do they support an alternative view that 'labels facilitate categorisation' (Waxman & Markow, 1995). For labels to have a facilitative effect, the outcome of the categorisation process should be noticeably different to the outcome in the absence of labels. However, there were no apparent differences between infants novelty preferences in Experiments 1 and 3. If labels had facilitated categorisation one should expect a failure to demonstrate a novelty preference in Experiment 1 or an enhanced novelty preference in Experiment 3 compared to Experiment 1. The best we can conclude is that labels impact the process of categorisation by virtue of their correlation with the configuration of feature values defining the set of visual objects. What then is the role of the label in these types of experiments?

Names or Features? A Computational Investigation

Demonstrating that infants are sensitive to statistical correlations between labels and category instances does not reveal the nature of the mechanisms that are responsible for computing these statistics. One possibility, suggested by Waxman and colleagues, is that labels act as invitations to form categories by highlighting the commonalities between objects. On this view, labels play a supervisory role through their one-to-many associations with objects. Labels impact the process of categorisation because multiple objects are given the same name and objects that are given the same name belong to the same category. Categories formed in this manner often contain members that share other attributes, but they will always share the same name. A label can function as the name for the category and may even be understood or produced by the infant to refer to members of the category. Stimuli that do not count as names, such as tones and buzzers, cannot invite infants to form categories and will not have meaning. Let us call this approach the supervised name-based account of category formation. Theories of lexical development, such as Clark's (1973) semantic feature hypothesis, attribute a similar role to labels in the development of word meaning.

An alternative approach assumes that labels are additional feature values that enter into the statistical computations performed by infants during the process of category formation. On this view, labels are non-supervisory, i.e., they have the same status as other features and are handled in the same manner and as part of the same statistical computation as other features. Like other features, they may vary in their salience and thereby have a greater or lesser impact on the outcome of computations. Note that redundant features do not help discriminate between categories. Contrastive features are the most informative sources in category formation. On this view, labels that do not vary contrastively across sets of objects will be redundant and fail to contribute to category formation. Let us call this approach the unsupervised feature-based account of category formation. Theories of infant categorisation, such as Younger and Cohen's (1986) account of the perception of correlations among attributes, ascribe a similar role to features.

Evidence as to whether labels fulfil a supervisory or non-supervisory role for infant categorisation is scant. The categorisation studies reported by Waxman and colleagues involve just a single category of objects and, consequently, do not evaluate whether infants have learnt an association between the familiarisation label and the object category. It is, therefore, unclear whether the categorisation effect described in these studies is caused by the supervisory role of the label being associated with category members, or other factors, such as heightened attention due to the presence of a salient auditory stimulus. The results of Experiment 5 in Plunkett et al. (2008) offer some support for a name-based account. Recall that infants treat the Narrow condition stimuli as members of a single category when they are accompanied by the same label during familiarisation whereas they are grouped into two categories in the absence of any labels. On the feature-based account, the label is redundant and should be ignored. The result of Experiment 5 suggests that the label is playing a supervisory role and perhaps acting as the name of the category.

Hu (2008) reports evidence consistent with a feature-based account in a follow-up study of Experiment 3 described in Plunkett et al. (2008): After infants had been familiarised with Narrow condition stimuli and two correlated labels and tested using the standard novelty preference procedure, they were given an inter-modal preferential looking task (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987) in which novel but typical instances of the two categories (1111 and 5555) were displayed side-by-side and each of the labels were played to the infants. If infants had learnt the names for the two categories, then we would expect them to orient preferentially to the category instance associated with the appropriate labels (Pruden, Hirsh-Pasek, Golinkoff, & Hennon, 2006; Schafer, 2005). However, infants failed to demonstrate any preference upon hearing either label. Insofar as a null result can be interpreted as evidence, we may cautiously conclude that infants demonstrated no evidence of learning the names for the categories they had formed during the familiarisation phase of the experiment, even though labels clearly had an impact on the category formation process. One interpretation of this finding is that labels fulfilled a non-supervisory role in Experiment 3, acting simply as additional features that entered into the statistical computations leading to category formation. But why should labels play an unsupervisory role in Experiment 3 but take on a supervisory capacity in Experiment 5? One possible answer to this question may lie in the constancy of the labelling events. Infants can readily identify that labels are used in a contrastive fashion in Experiment 3 and may engage a different learning strategy than when the same label is used. However, this explanation suggests a somewhat capricious infant, ungrounded in the labelling contingencies of the real world. Labels are rarely repeated in the fashion of Experiment 5. How would the infant know which learning strategy to adopt in this situation?

Gliozzi, Mayor, Hu, and Plunkett (in press) investigated the possibility that an unsupervised feature-based approach could account for all the experimental findings reported in Plunkett et al. (2008). They used a neuro-computational model to simulate the infant patterns of looking behaviour. The model handled visual and acoustic information in an identical fashion and no direct associations were formed between objects and labels. In other words, the learning process was unsupervised. The model consisted of a layer of neurons laid out in a grid-like fashion. Each neuron in the grid received input from an array of visual and auditory sensors. In the simplified version of the model, the grid consisted of a 5x5 sheet of neurons and each sensory input consisted of 4 receptors cells, as shown in Figure 2. The visual stimuli were represented by input vectors with four dimensions, each value in the input vector corresponding to a feature in the cartoons presented to infants (the length of the legs and neck, tail width and ear separation). Each feature was first measured, and then divided by the maximal value the feature can take. A similar approach was adopted by Mareschal and French (2000) in their simulation of Younger's original experiments. The acoustic stimuli were also represented by four dimensions with two dimensions active for one label and the other two dimensions active for a second label. Each sensory receptor was connected to every neuron in the grid. Before training, the connections were set to small random values, reflecting an initial ignorant state of the system. During training, a single visual-acoustic stimulus was presented to the sensory receptors, e.g., the combination 1212 + 'dax'. Activity propagated through

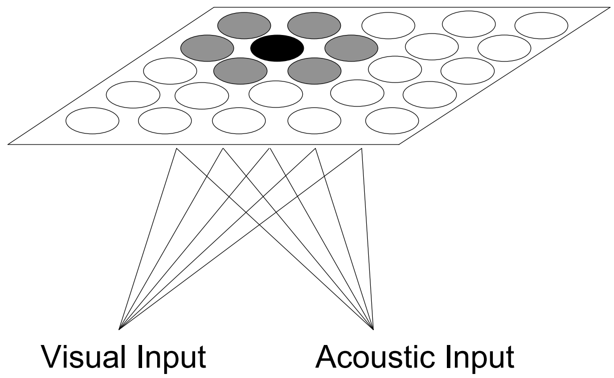

Figure 2. The architecture: both visual and acoustic input feed to the same map.

the connections to the neural map resulting in a pattern of activation across the map. The connections to the most active neuron in the map were adjusted so that they began to mirror the feature values of the current input vector. The connections feeding into immediately neighbouring neurons were adjusted in a similar fashion. Thus, if the same input pattern was presented to the sensory receptors again, the same set of neurons would be even more active. In fact, each input pattern was presented to the model just once, so the network was exposed to 8 different training items, one for each member of the familiarisation set. The size of the adjustments to the connections on each trial were positively correlated with the novelty of the input stimulus (how well the input vector matches the connections feeding into the most active unit) and negatively correlated with the length of the input stimulus. In the simulations of Experiments 1–2, only visual stimuli were presented to the receptors whereas in Experiments 3–5 both visual and acoustic stimuli were used during training. Hence, the rate of adjustment to connections tended to be higher when labels were not used. Gliozzi et al. (in press) argue that labels increase the cognitive load and lead to slower learning.

The training procedure adopted by Gliozzi et al. (in press) is essentially identical to that used in self-organising maps (Kohonen, 1988) where the neural grid forms a topological structure such that neighbouring neurons respond similarly to similar input stimuli. The ocular dominance columns in visual cortex are known to obey these self-organising principles. Clearly, the model used by Gliozzi et al. is not a copy of visual or auditory cortex. However, the model adopts learning procedures that are known to operate in the brain. The most important characteristics of the model, for present purposes, is that it functions in an unsupervised fashion—there is no explicit teaching signal—and it treats all the sensory feature receptors equivalently: Individual visual features are treated in the same way as individual acoustic features. In general, the more two stimuli overlap in their feature specification, the closer will be their representations—the pattern of neurons which are most active—on the self-organising map. Stimuli that tend to have non-overlapping features—such as those from different categories—will be represented at physically distant locations on the map. Note also that just as the model does not distinguish the contribution of acoustic and visual features to the organisation of the map, nor does it distinguish between the features within a modality. For example, the model embodies the assumption that the visual features such as leg length and ear separation are equally important for the learning process. This assumption may be incorrect[1] but was adopted in the absence of evidence to the contrary.

After the model had been trained with the relevant input stimuli for each experiment, it was tested with the same stimuli used by Plunkett et al. (2008), i.e., 3333 and 1111 or 5555. However, unlike the novelty preference procedure, the model does not have the facility for presenting two objects simultaneously. Instead, the novel visual stimuli are presented to the model individually with learning turned off. Looking time is measured by calculating how well the visual stimulus aligns with the connections feeding into the most active neuron evoked by the stimulus. A good fit indicates that the model interprets the current stimulus as familiar, resulting in short looking times, whereas a poor fit indexes relative novelty and longer looking times. A good fit would be expected when the input stimulus is similar to objects presented during the training phase of the simulation. Figure 3 shows the proportion of time that infants spend looking at the average stimulus in the five experiments of the Plunkett et al. (2008) study and the proportional preference for the average stimulus in the five corresponding conditions in the Gliozzi et al. model. Just as 24 infants were tested in each condition of the experimental study, 24 networks with different initial random connections were tested in the simulations. Looking preferences above 50% in the infants and the networks indicate that the average stimulus (3333) is perceived as more novel than the modal stimuli (1111 or 5555). Overall, the pattern of novelty preferences in the simulations mimics that of the infants quite closely. In the experiments where the infants showed a significant novelty preference for the average stimulus, so did the networks and where the infants preferred the modal stimuli over the average stimulus, the networks did too. The capacity of the model to mimic infant novelty preferences across all 5 experimental conditions shows that an unsupervised learning device which performs statistical computations on compound visual and acoustic stimuli offers a viable solution to the problem of how labels influence category formation in the infant experiments. In particular, the success of the Gliozzi et al. simulations adds credence to the unsupervised

[1]It is possible to override this assumption in the model so that certain features are attributed a greater salience than others.

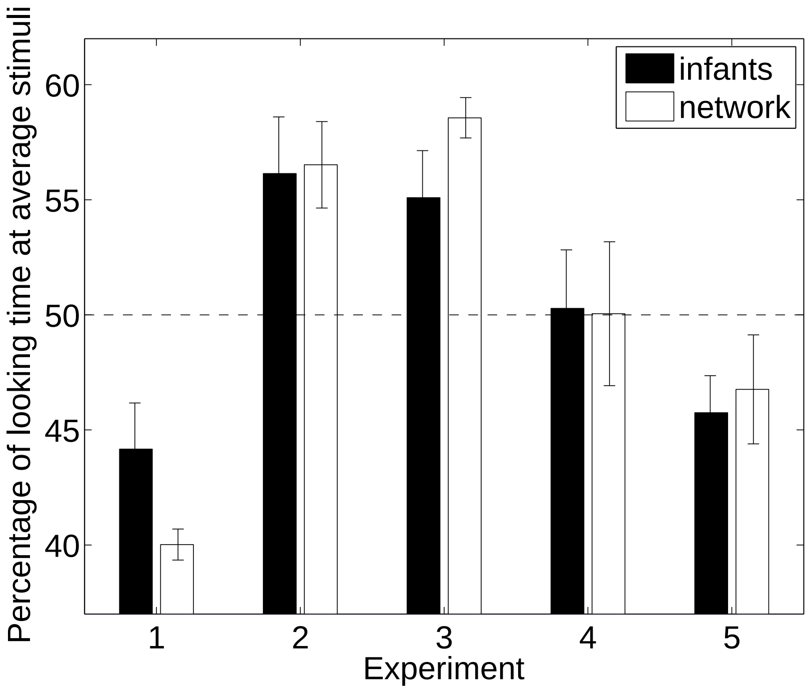

Figure 3. Infant and network performance during testing. The networks' behaviour mimics the behavioural pattern of infants in the testing phase.

feature-based account of infant categorisation: Labels need not act as names for the objects in order to have an impact on categorisation.

Models implement theoretical explanations of a dataset. The implementation may be successful but the theory may still be wrong. As with any other scientific explanation, the success of a model depends on the plausibility of its assumptions, its success in accounting for the data and its capacity to generalise to new circumstances, i.e., to generate novel empirical predictions. Of course, the Gliozzi et al. model was built specifically to investigate a particular dataset. However, it is possible to examine how the model fares when compared to infant performance on different parts of the original experiments. For example, Plunkett et al. report on the time course of infant looking during the familiarisation phase of the experiment. Specifically, they found that infants spent more time fixating the familiarisation stimuli in Experiment 1 (Broad condition) than Experiment 2 (Narrow condition) and that the presence of labels during familiarisation (Experiments 3–5) prolonged looking times compared to the absence of labels (Experiments 1–2). Furthermore, infants spent more time looking at the stimuli during the first 3 trials of familiarisation than the last 3 trials, in all experiments. It turns out that the Gliozzi et al. model accounts successfully for all of these effects on infant looking times during familiarisation. The reduction in looking time for the final trials of familiarisation is explained by the model in terms of the decreasing novelty of the input stimuli. Recall that before training, the connections are initialised to small random values. Consequently, any stimulus will appear novel to the network. However, after 5 training trials, the connections will have adapted to the kind of stimuli that are presented, so that even novel stimuli taken from the same domain will appear more familiar and hence attract lower levels of looking than the first few training trials. In essence, the model gets used to seeing these strange cartoon figures. The higher level of looking times in the presence of labels is a direct consequence of the cognitive load imposed by the greater complexity of the compound input stimuli. The learning algorithm for adapting the connections in the map imposes a damping effect on learning for complex (longer) stimuli. Stimuli that appear novel to the network will remain so for longer if they are complex than if they are simple. Compound visual-acoustic stimuli, therefore, produce longer looking times than uni-modal visual stimuli.

In order to understand how the model explains why infants look longer in the Broad condition than the Narrow condition, it is necessary to consider characteristics of the familiarisation stimuli themselves (see Figure 1). The model treats each visual object as a 4-bit vector, each bit corresponding to one of the visual features, so that any object corresponds to a single point in a 4-dimensional Euclidean space. The familiarisation phase of the experiment involves the successive presentation of 8 objects, so familiarisation can be likened to traversing a Euclidean pathway connecting 8 points with learning occurring at each point on the pathway. The distance between any 2 points in the space is a measure of the similarity of the 2 objects. The pathway traversed by the model will depend upon the particular random sequence of objects presented—some pathways will be longer than others—even though the same 8 objects are used in a given training condition. A simple calculation of the average Euclidean distance traversed by the 24 networks in the Broad condition reveals a significantly greater distance than that traversed in the Narrow condition. Since distance reflects perceived similarity and novelty, then the model exhibits longer looking times in the Broad condition than Narrow condition.

If the same calculations are performed for the object sequences to which infants are exposed in the Plunkett et al. (2008) study, then it is also found that Broad condition infants experience longer Euclidean pathways than Narrow condition infants. However, even within an experimental condition, Euclidean pathways differ. The model predicts that infant looking times should also differ within an experimental condition: Infants experiencing longer Euclidean pathways should look the longest during familiarisation. Gliozzi et al. reanalysed the infant data and found a significant positive correlation between looking times and Euclidean distances, as predicted. This finding indicates that infant looking times are directly influenced by the particular sequence of the same 8 objects to which they are exposed, suggesting that infants are performing on-line similarity comparisons of consecutive objects and these comparison are driving their looking behaviour. Furthermore, the metric of similarity that infants use in the experiments appears to be closely related to that used by the computational model.

A surprising success of the model was its ability to mimic the infant behaviour in Experiment 5 where one label was used with all Narrow condition stimuli and infants demonstrated a novelty preference for the modal testing stimuli indicating formation of just a single category. Recall that the model implements an unsupervised, feature-based account of categorisation and that redundant stimuli on such an account should be ignored by the statistical computations. The label in Experiment 5 is redundant because it is presented with all 8 objects and yet it has an impact on categorisation since in the absence of the label, the networks (and infants) form 2 categories rather than one. However, the model was only exposed to a single presentation of each compound acoustic-visual stimulus. When the networks in Experiment 5 were trained for multiple epochs, they learn to segregate the visual stimuli into two categories rather than one, thereby ignoring the label. In other words, the formation of the single category is a transient effect in the model.

This finding has several implications: First, it predicts that infants should show similar transient effects such that if they were continuously trained on the label-object contingencies of Experiment 5, they would eventually form two visual categories. Second, the transition from a single to a two category representation in the model implies that the label changes its status from being associated with a single visual category of objects to being associated with two discriminable visual categories of objects. This suggests that the model has the potential to represent a hierarchy of categorical organisation as a result of the introduction of a common label for members of the hierarchy. However, the organisational capacity of the label is obtained at a price: The model suggests that initially the label obliterates categorical distinctions and it is only through further experience and internal reorganisation that a hierarchical structure is achieved. Nevertheless, these transitions are emergent properties of a self-organising system which does not require explicit instruction or feedback. The model predicts that the demonstrated impact of labels on categorisation in 10-month-old infants does not represent an end-point of learning but rather is a step *en route* to the development of a more structured system—perhaps a system that underpins the organisation of the mental lexicon itself.

Perceptual Load Hypothesis

We have seen how labels can impact the formation of perceptual categories by infants such that the structure of labelling events influences the number of categories formed. Specifically, when labels correlate with the structure of perceptual categories, then the perceptual categories are maintained by the infants whereas if labels are uncorrelated they can either interfere with category formation or lead to the formation of completely new perceptual categories. This position is inconsistent with the view that auditory stimuli overshadow the processing of visual stimuli but is consistent with the view that labels impact infant categorisation (though as additional features rather than names). An additional experiment reported by Hu (2008) questions the validity of this conclusion. Recall that exposure to Broad condition stimuli in the absence of labels (Experiment 1 of Plunkett et al. (2008)) leads to the formation of a single category. Hu (2008) reports another experiment in which Broad condition stimuli are presented together with a single label during familiarisiation, thereby maintaining the correlation between category membership and label assignment. A straightforward prediction from the other experiments described by Plunkett et al. is that infants should continue to form a single category for the same reasons that they continued to form two categories in Experiment 3—a correlation between visual category information and labelling contingencies. However, Hu (2008) found that this was not the case. Infants exhibited no systematic novelty preference during testing, indicating that they had failed to form a category during familiarisation, even though they showed evidence of category formation with Broad condition stimuli in the absence of a label.

This finding is inconsistent with the view that infants exploit the correlation between visual category structure and labelling contingencies. Two explanations seem plausible: The presence of the label persuades infants to treat all familiarisation stimuli as equally good members of the category. The category no longer has a family resemblance structure but is of the classical, definitional kind. On this view, the average stimulus has no special status and the modal stimuli are no longer perceived as particularly novel. However, the attribution of this role to the label would predict that infants in Experiment 5 of Plunkett et al. (2008) would also fail to show a novelty preference, whereas, in fact, they did. An alternative explanation is that the label overshadows the processing of the visual stimuli in line with the Robinson and Sloutsky (2004) account, precluding the formation of any categories and resulting in failure to demonstrate a novelty preference. At first glance, the overshadowing hypothesis would seem to lack parsimony as it fails to account for the pattern of findings in the other experiments. However, a closer analysis of infant behaviour in the one label, Broad condition experiment reveals why under some circumstances infants may fail to show category formation whereas an apparently minor adjustment to the stimuli (removing the label) reinstates category formation.

Plunkett et al. (2008) demonstrated that infants look longer during familiarisation in the Broad condition (Experiment 1) than in the Narrow condition (Experiment 2). Gliozzi et al. (in press) showed how this could be explained in terms of the length of the Euclidean pathways infants must traverse when viewing the sequence of familiarisation objects—the longer the pathway, the longer the looking time. Now suppose we examine in detail the Euclidean distances traversed by each infant in Experiment 1 as a function of their novelty preferences in the test phase of the experiment as shown in Figure 4. Keep in mind that

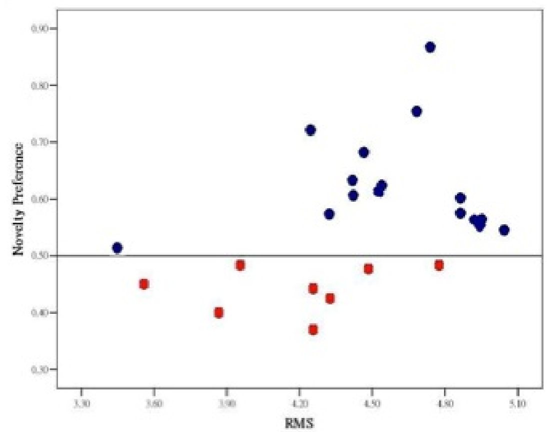

Figure 4. Novelty preference for modal stimuli as a function of Euclidean distance in Broad condition (Experiment 1) of Plunkett et al. (2008)

each infant is likely to traverse different Euclidean distances during familiarisation because they are exposed to different sequences of the same set of 8 objects. Overall, in Experiment 1, infants show a novelty preference (above 0.5) for the modal stimuli. Figure 4 shows that almost all the infants who prefer the modal stimuli have long Euclidean pathways whereas the rest of the infants are quite varied in RMS values. In other words, the infants who showed a novelty effect at test tended to experience the greatest perceptual shifts during familiarisation. Figure 5 shows the same type of analysis for the infants in the single label, Broad condition experiment. Now the pattern is reversed. Overall, the infants in this experiment failed to show any systematic preference. However, all the infants who failed to show any novelty preference for the modal stimuli were exposed to high Euclidean pathway sequences. This pattern of results suggests that hearing a label and experiencing large perceptual shifts during familiarisation is detrimental to category formation.

This contrasting pattern of results can be explained in terms of a perceptual load hypothesis. For simplicity, let us assume that only two factors contribute to the variability in the perceptual load on infants in these experiments: The first factor is the label such that the presence of a label increases perceptual load. The second factor is the Euclidean pathway traversed by the infant during familiarisation such that longer pathways increase the perceptual load. Finally, assume that category formation and novelty preference is sensitive to perceptual load according to an inverted U-shaped function, the Goldilocks Principle: You've got to get it just right—too much perceptual load interferes with categorisation but so does too little. Infants who showed a novelty preference in Experiment 1 experienced

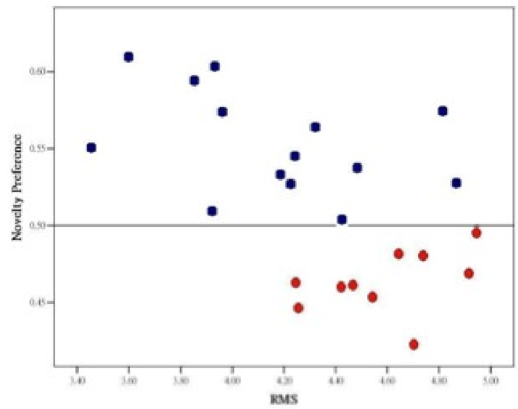

Figure 5. Novelty preference for modal stimuli as a function of Euclidean distance in single label, Broad condition of Hu (2008)

large Euclidean distances placing them near the peak of the inverted U-shaped function (see Figure 6). However, infants who heard a label and experienced large Euclidean distances were under heavier perceptual load and so were less likely to show a novelty preference.

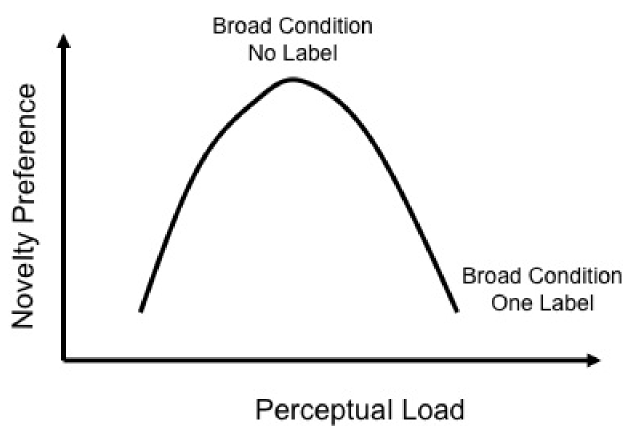

Figure 6. Inverted U function of infant novelty preference as a function of perceptual load.

The perceptual load hypothesis therefore predicts that labels can interfere with categorisation when infants are already under demanding processing conditions. This is not the same as the overshadowing hypothesis which predicts that novel labels will always interfere with visual processing. In contrast, the perceptual load hypothesis predicts that labels will facilitate categorisation if the visual processing load is reduced, e.g., by using short Euclidean pathways. The perceptual load hypothesis might therefore be able to resolve the conundrum whereby auditory stimuli sometimes appear to overshadow the processing of visual stimuli and at other times facilitate visual processing and categorisation. Note that virtually all of the experiments on categorisation performed by Waxman and colleagues involve visual objects that are likely to be quite familiar to infants. The visual perceptual load resulting from object processing will therefore be low and novel labels can enhance processing to the peak of the inverted U-shaped function, resulting in categorisation and the expression of a novelty preference. In contrast, the experiments conducted by Sloutsky and colleagues involve entirely novel objects and therefore high perceptual load, so that the addition of a novel label results in perceptual overload and failure to categorise.

Under the perceptual load hypothesis, category formation is not just the result of the computation of statistical correlations across the cross-modal stimuli. The outcome of these computations will also depend on the load that individual stimuli place on the perceptual system. Therefore, there is no simple answer to the question as to whether labels facilitate or interfere with infant categorisation. The answer must be that it all depends on the status of infants current mental representations of the experimental stimuli. Thus, Sloutsky and Robinson (2008) did not find overshadowing effects when infants were pre-familiarised to the auditory stimuli in their experiments, presumably because pre-exposure decreases the perceptual load.

Names or Features? A Reprise

Unsupervised feature-based approaches, supplemented by a consideration of perceptual load effects, can offer an explanation for a wide variety of experimental findings relating to the impact of labels on infant visual categorisation. Labels do not need to be names to influence the categorisation process. However, this does not mean that labels are not special to the infant. Just as some visual features of an object, such as its shape, may assume a special role in object categorisation, so may certain types of auditory signals, such as those phonotactically legal sequences which emerge from the mouths of socially significant others, act as salient features in directing categorisation. Socially significant auditory signals, such as words, may acquire salience even for the young infant and salient stimuli might be particularly useful in driving statistical computations across features. Fulkerson and Waxman (2007) report that words but not tones facilitate categorisation in young infants, suggesting that words have achieved some special significance by 6-months of age. Such findings are consistent with an unsupervised feature-based approach to infant categorisation.

Is there any role for a supervised name-based approach to infant categorisation? We know that young infants are able to demonstrate an appreciation of familiar label-object associations (Tincoff & Jusczyk, 1999) and are able to learn novel label-object associations (Pruden et al., 2006). It is unclear whether these early labels should be considered as names since they may not be referential in character and may be limited in scope of generalisation. Irrespective of the referential nature and generalisability of early words, the formation of label-object associations might impact categorisation in a manner that goes beyond the statistical role ascribed to labels in the unsupervised feature-based approach. However, this may be difficult to demonstrate. Even studies of concept formation in adults are equivocal about the mechanism by which labels impact the categorisation process. For example, Yamauchi and Markman (2000) have demonstrated that labels function in much the same fashion as ordinary perceptual features in a straightforward classification task, but that labels differ from other perceptual features when Ss are required to make inferences: Inferences based on feature information are governed by perceptual similarity whereas inferences based on knowledge of labels are more categorical. Nevertheless, Yamauchi and Markman (2000) acknowledge that "category labels can be viewed as reliable pointers to systematic knowledge structures that may provide a basis for making predictions about unknown features" (p.793) suggesting that it may be the predictive reliability of labels rather than their status as names that is driving the asymmetry between linguistic and non-linguistic features in adult categorization experiments.

Lupyan, Rakison, and McClelland (2007) have also shown that labels can facilitate categorization even when the labels are redundant to task success. Furthermore, they showed that categorization performance correlated positively with verification performance (akin to Yamauchi and Markman's 2000 classification task), indicating that Ss who were best at identifying names of training items also performed best at categorizing them. This result can be interpreted as evidence for name-based categorization. However, the authors note that their findings are compatible with "a general account that naming a category causes items within that category to cohere because the name serves as a reliable cue to class membership" (p. 1082). In other words, even these adult findings are compatible with an unsupervised feature based account of categorization but where labels have the status of particularly reliable predictors, presumably as a result of a lifetime of use. Of course, separating the contributions of name-based and feature-based approaches to categorisation is complicated by the fact that former involves the latter: Names are reliably correlated with category membership. Should we therefore abandon any attempt to resolve this issue? I think not. Names refer. Features do not refer. One might reasonably suppose that the cognitive mechanisms that underpin the referential use of labels are separable from the mechanisms that exploit labels as perceptual features. The identification of these mechanisms and perhaps their neural instantiation promises to provide insights into the manner by which labels impact the process of categorisation in both infants and adults.

References

Balaban, M. T., & Waxman, S. R. (1997). Do words facilitate object categorization in 9-month-old infants? *J Exp Child Psychol*, *64*(1), 3–26.

Behl-Chadha, G. (1996). Basic-level and superordinate-like categorical representations in early infancy. *Cognition*, *60*(2), 105–141.

Clark, E. V. (1973). What's in a word? on the child's acquisition of semantics in his first language. In T. E. Moore (Ed.), *Cognitive development and the acquisition of language.* New York: Academic Press.

Eimas, P. D., & Quinn, P. C. (1994). Studies on the formation of perceptually based basic-level categories in young infants. *Child Dev*, *65*(3), 903–917.

Fulkerson, A. L., & Waxman, S. R. (2007). Words (but not Tones) Facilitate Object Categorization: Evidence from 6- 12-Month-Olds. *Cognition*, *105*, 218–228.

Gliozzi, V., Mayor, J., Hu, J.-F., & Plunkett, K. (in press). Labels as features (not names) for infant categorisation: A neuro-computational approach. *Cognitive Science*.

Golinkoff, R., Hirsh-Pasek, K., Cauley, K., & Gordon, L. (1987). The eyes have it: lexical and syntactic comprehension in a new paradigm. *Journal of Child Language*, *14*, 23-46.

Hu, J. F. (2008). *The Impact of Labelling on Categorisation Processes in Infancy*. Unpublished doctoral dissertation, Department of Experimental Psychology, Oxford University, UK.

Kohonen, T. (1988). An introduction to neural computing. *Neural Networks*, *1*(1), 3–16.

Lupyan, G., Rakison, D. H., & McClelland, J. L. (2007). Language is not just for talking: redundant labels facilitate learning of novel categories. *Psychological Science*, *18*(12), 1077–1083.

Mareschal, D., & French, R. (2000). Mechanisms of categorization in infancy. *Infancy*, *1*(1), 59–76.

Plunkett, K., Hu, J.-F., & Cohen, L. B. (2008). Labels can override perceptual categories in early infancy. *Cognition*, *106*(2), 665–681.

Pruden, S. M., Hirsh-Pasek, K., Golinkoff, R. M., & Hennon, E. A. (2006). The birth of words: Ten-month-olds learn words through perceptual salience. *Child Development*, *77*, 266–280.

Robinson, C. W., & Sloutsky, V. M. (2004). Auditory dominance and its change in the course of development. *Child Development*, *75*, 1387–1401.

Robinson, C. W., & Sloutsky, V. M. (2007). Visual processing speed: effects of auditory input on visual processing. *Dev Sci*, *10*(6), 734–740.

Schafer, G. (2005). Infants can learn decontextualized words before their first birthday. *Child Development*, *76*(1), 87–96.

Sloutsky, V. M., & Robinson, C. W. (2008). The Role of Words and Sounds in Infants' Visual Processing. *Cognitive Science*, *32*(2), 342–365.

Tincoff, R., & Jusczyk, P. W. (1999). Some beginnings of word comprehension in 6-month-olds. *Psychological Science*, *10*(2), 172–175.

Waxman, S. (2003). Links between object categorization and naming: Origins and emergence in human infants. In D. H. Rakison & L. M. Oakes (Eds.), *Early category and* *concept development: Making sense of the blooming, buzzing confusion* (pp. 213–241). London: Oxford University Press.

Waxman, S., & Booth, A. (2003). The origins and evolution of links between word learning and conceptual organization: New evidence from 11-month-olds. *Developmental Science*, *6*, 128–135.

Waxman, S., & Markow, D. B. (1995). Words as invitations to form categories: Evidence from 12- to 13-month-old infants. *Cognitive Psychology*, *29*, 257–302.

Yamauchi, T., & Markman, A. B. (2000). Inference using categories. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *26*(3), 776–795.

Younger, B. (1985). The segregation of items into categories by ten-month-old infants. *Child Development*, *56*, 1574-1583.

Younger, B., & Cohen, L. (1986). Developmental change in infants' perception of correlations among attributes. *Child Development*, *57*, 803-815.