The Influence of Within-Category Structure on Stimulus Similarity and Stimulus Generalization

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Abstract

In Exp. 1, the authors report an influence of temporal contiguity in stimulus exposure on later judgments of similarity. Exposure to transformational information – that is, information that 'connects' two similar, but perceptually distinct stimuli – was found to have no influence on later judgments of similarity. In Exp. 2, exposure to transformational information was also found not to influence later property generalization; however, exposure to within-category structure that promoted a sense of 'surprise' (i.e., contained clear discontinuity) led to a reduction in later property generalization between two similar, but perceptually distinct stimuli. This latter effect was confirmed in Exp. 3 while ruling out any influence of temporal factors.

Keywords: Spontaneous categorization; within-category structure; similarity; generalization; transformational knowledge; temporal dynamics; perceptual learning; sensory preconditioning.

Introduction

Similarity and categorization are intimately intertwined: stimulus similarity is assumed to form the basis for many of our natural categories (Hampton, 2001), but categorization can also alter perceived similarity (Harnad, 1987). When taught that stimuli are members of the same category, participants will perceive these stimuli to be more similar than participants who are not (e.g., Livingston, Andrews, & Harnad, 1998). The reverse is also true: when taught that stimuli are members of contrasting categories, participants will perceive these stimuli to be more different (e.g., Goldstone, 1994). Moreover, given the lawful relationship that exists between similarity and stimulus generalization (Shepard, 1987), it is not surprising that many studies have shown that stimulus generalization is directly influenced by the 'classificatory status' of stimuli: when stimuli are 'classified together' (or acquire equivalence), increased levels of stimulus generalization are found between these stimuli. In contrast, when stimuli are 'classified apart' (or acquire distinctiveness), decreased levels of stimulus generalization are found between them (see Honey, Close, & Lin, 2010). In other words, categorization can warp psychological similarity space (Nosofsky, 1989).

While interesting, almost all studies to date that have indexed an influence of categorization on later judgments of similarity and stimulus generalization (commonly termed *categorical perception* (CP)) have employed supervised training procedures (but see Gureckis & Goldstone, 2008). Consequently, as Gureckis and Goldstone have noted, "it remains a somewhat opaque question if learned CP effects are restricted to cases where subjects make a differential response to each category or if other aspects of category organization, such as the similarity structure or distribution of items within a category, may also exert an influence on perception" (2008, p. 1876). This is important because although one may presume that the mechanisms of supervised categorization drive all classification, evidence has shown that this is unlikely to be the case (Pothos & Chater, 2002). To fully assess categorization's influence on later behavior, therefore, one needs to look to unsupervised categorization – that is, categorization that occurs in the absence of any external feedback.

Fundamentally, unsupervised categorization tasks afford an assessment of the principles that underlie categorization in an unconstrained manner, allowing greater insight into people's natural categorization biases (or preferences). However, much of the unsupervised categorization that occurs in the laboratory has been considered very different to that which occurs naturally (see Clapper & Bower, 1994; Love, 2002). Crucially, whereas any natural unsupervised category formation will have unlikely been the primary purpose of an interaction (meaning that any category formation is incidental), in laboratory investigations of unsupervised categorization, explicit instruction to categorize is generally given, meaning that any category formation is intentional (Love, 2002). Unlike the majority of laboratory-based unsupervised categorization, then, natural incidental categorization requires that a person first realize there is some structure present, and then utilize this structure to guide their classifications[1]. The experiments presented in this paper, therefore, sought to assess how the similarity structure (i.e., the distribution of items) within a category influences incidental categorization, as indexed by the later perceived similarity of category items, and the level of generalization between category items.

What aspects of within-category structure might influence whether stimuli are incidentally classified together or apart? Zaki and Homa (1999) have proposed that the acquisition of an object concept will be facilitated by exposure to that object's successive changes (that is, exposure to transformational information). Based on this hypothesis, it seems plausible to suppose that transformational information should encourage the incidental 'classification together' of similar, but distinct stimuli (but see the categorical perception effects of Newell & Bülthoff, 2002). Another factor that might also encourage the 'classification together' of stimuli is temporally contiguous stimulus exposure (see, e.g., Bateson & Chantrey, 1972). Empirical investigation into the phenomenon of perceptual learning has shown that the temporal dynamics of stimulus exposure influence whether an increase or decrease in later perceived stimulus similarity (and stimulus generalization) is found (see Goldstone, 1998; Hall, 1991). More specifically, when two similar stimuli are exposed in close temporal contiguity, the perceived similarity of (and the level of generalization between) these stimuli should increase, relative to situations where no stimulus exposure is given and where stimulus exposure is not particularly temporally contiguous (see Bateson & Chantrey, 1972; Bennett & Mackintosh, 1999). Finally, a number of theories of spontaneous category learning link the formation of new categories (or clusters) to unexpected changes in stimulus structure. For example, Clapper and Bower (1994, 2002; see also SUSTAIN, Love, Medin, & Gureckis, 2004) propose that if a novel stimulus is perceived as sufficiently 'surprising' (sufficiently dissimilar) to previously stored stimulus encounters, then a new category (cluster) will be invented to accommodate that stimulus. Consequently, if a strong set of norms has been established about, for example, Category A membership (i.e., through a number of exposures to Category A exemplars), then it is more likely that a Category B exemplar will be accommodated in a newly invented category (cluster). Exposure to only a single Category A exemplar before exposure to a Category B exemplar, by contrast, will likely not lead to these stimuli being 'classified apart' (Clapper & Bower, 1994, 2002; Love et al., 2004).

In summary, much evidence has shown that categorization (using supervised training procedures) can alter the perceived similarity of stimuli, and concomitantly, the level of generalization between stimuli. While there is some preliminary evidence that similar alterations in perceived stimulus similarity can be found following unsupervised categorization (Gureckis & Goldstone, 2008), little research has directly assessed how the similarity structure (i.e., the distribution of items) within a category influences incidental categorization. Moreover, the discrimination based studies that have indexed an influence of categorization on stimulus similarity and stimulus generalization have typically employed designs in which participants engage in hundreds of experimental trials. However, it seems reasonable to suppose that people's sensitivity to category structure (if sufficiently obvious) should be immediate. This means that under certain conditions, incidental categorization should be a rapid process that can occur following only minimal stimulus exposure.

[1] This contrasts with laboratory-based unsupervised categorization where the explicit instruction to categorize will likely promote a belief in participants that their task is to find some experimenter defined category structure.

Experiment 1

In Exp. 1, we were interested in investigating those factors that should encourage incidental 'classification together' under conditions of minimal stimulus exposure. Specifically, we sought to test the hypotheses that transformational information and temporally contiguous stimulus exposure should encourage the 'classification together' of two similar, but distinct stimuli, as indexed by a later increase in their perceived similarity to one another.

Method

Participants 48 Cardiff University undergraduate students took part either for partial fulfillment of course credit or a small payment of £2, with 16 participants in each condition (see Table 1).

Table 1: The three conditions employed to assess within-category structure in Exp. 1.

Condition	Preexposure	Test
Baseline	A / - / - / - / - / F	A - F
Sys_trans	A / B / C / D / E / F	A - F
Contiguous	A / F	A - F

Stimuli The stimuli were individually rendered images taken with permission from Hahn, Close and Graf (2009). They were basic level objects from six biological categories (bird, fish, head, mushroom, starfish, turnip) and one artifact category (light bulb; see Figure 1). For every category, two objects formed the endpoints of each morph continuum (the 1% and 100% morph stimuli), from which 20%, 40%, 60% and 80% morph images were rendered (here, the 1%, 20%, 40%, 60%, 80% and 100% images are referred to as A, B, C, D, E and F, respectively). All morph images had a size of 256 × 256 pixels and were presented in gray scale on a 15-in.

computer monitor. Participants were seated approximately arms length from the monitor for the duration of the experiment.

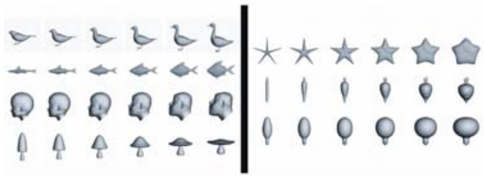

Figure 1. Illustration of the morph stimuli employed. The stimuli shown here are the 1%, 20%, 40%, 60%, 80%, and 100% morph images, respectively.

Design and Procedure Exposure condition was manipulated as a between-participants factor and participants in all conditions were exposed to the seven different object categories. On a given trial, participants were sequentially preexposed to a set of morph stimuli from one of the object categories. Within each of the three exposure conditions, half of participants received presentations of the morph stimuli in the order A to F, and half of participants received presentations of the morph stimuli in the order F to A. Each stimulus was presented for 3000 ms, and the temporal spacing between presentation of stimulus A and stimulus F was held constant in the Baseline condition and condition Sys_trans by introducing a fixation cross when no morph (object) stimulus was scheduled to be presented in the Baseline condition, relative to condition Sys_trans. Following stimulus preexposure, a 1000 ms inter-stimulus interval (blank screen) separated presentation of the test screen, on which was presented stimulus A and stimulus F. Within the subconditions created in each exposure condition following the previous counterbalancing operation, half of participants saw stimulus A surrounded by a red border on the test screen, and half of participants saw stimulus F surrounded by a red border on the test screen. Within each of the subconditions created by the previous counterbalancing operations, half of participants received presentations of stimulus A on the left-hand side of the test screen and presentations of stimulus F on the right-hand side of the test screen, and half of participants received the reverse. On the test screen, participants were simply asked to rate how similar they thought the object framed in red was to the object not framed in red, using a 1 (very dissimilar) to 9 (very similar) rating scale presented at the bottom of the test screen. Responses were made using the keys "1" through "9" on a standard keyboard. Following a response, a 1000 ms inter-trial interval (blank screen) separated participants' exposure to the next object category. Exposure to the seven object categories was random for all participants in each of the three exposure conditions.

Results

For the purpose of analyses, participant similarity judgments were averaged over the seven object categories. Figure 2 displays the results of interest: participants' overall mean similarity rating, split by preexposure condition. Inspection of this figure reveals that similarity ratings in condition Contiguous were higher than in the Baseline condition and condition Sys_trans. Similarity ratings in condition Sys_trans differed little from those in the Baseline condition. A one-way ANOVA revealed a significant effect of exposure condition, $F(2, 45) = 7.31$, $p < .003$, $\eta^2 = .25$. Tukey HSD post-hoc tests revealed that, overall, participants in the Contiguous condition reported significantly higher ratings of similarity than participants in the Baseline condition ($p < .05$) and Sys_trans condition ($p < .002$). Overall similarity ratings did not differ significantly between the Baseline and Sys_trans conditions ($p > .05$).

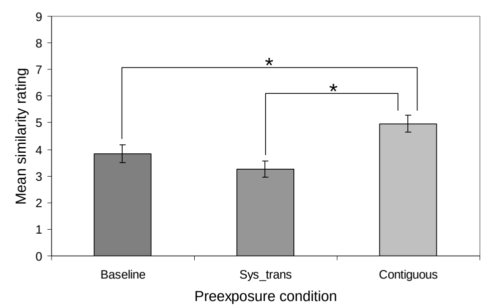

Figure 2. Results of Exp. 1: overall mean similarity rating, plotted by preexposure condition. Error bars indicate the standard error.

Discussion

In Exp. 1, the perceived similarity of stimuli A and F was influenced only by the temporal contiguity of preexposure to these stimuli. One interpretation of this result is that only the Contiguous condition was sufficient to encourage the 'classification together' of stimuli A and F. This 'classification together' can be conceptualized in a number of ways: one way of conceptualizing such is in terms of the formation of a blended representation of stimulus A and stimulus F (i.e., AF; see Hall, 1991). Alternatively, an account can be considered with respect to the assumption that temporally contiguous stimulus exposure provides the optimal conditions under which an excitatory association can form between two similar stimuli (Hall, 1991). Formation of such an A–F association would dictate that stimulus A will evoke a representation of stimulus F, creating a situation in which these stimuli will come to be perceived (somewhat) equivalently. Such *acquired equivalence* would lead to a concomitant increase in the perceived similarity of stimuli A and F (see Hall, 1991).

Interestingly, the results of Exp. 1 do not support the proposal of Zaki and Homa (1999). A number of possibilities exist for this failure: first, Zaki and Homa's (1999) proposal may simply be wrong. Second, the within-category similarity structure of condition

Sys_trans may have resulted in both associationistic and comparator processes operating (Honey, Bateson & Horn, 1994). If one assumes that the influence of these two processes was relatively balanced in condition Sys_trans, then this would have resulted in little change in the perceived similarity of stimuli A and F, relative to their baseline similarity.

In Exp. 2, we sought to further assess the influence of within-category structure using a property generalization task at test. Here, we were interested in investigating whether we could find evidence for 'classification apart' – driven by a surprise-driven category invention mechanism (Clapper & Bower, 1994, 2002) – under conditions of minimal stimulus exposure. To this end, we compared a skewed stimulus structure (condition Surprise) to the Baseline and Sys_trans conditions of Exp. 1, and a further scrambled transformational information condition (condition Scram_trans).

Experiment 2

In Exp. 2, we sought to assess the hypothesis that the Surprise condition – in which participants were exposed to a skewed stimulus structure – would lead to the 'classification apart' of stimuli A and F, as indexed by a later reduction in the level of property generalization between them. Such a finding would provide support for a surprise-driven category invention mechanism operating in incidental categorization (Clapper & Bower, 1994, 2002).

Method

Participants 64 Cardiff University students took part for partial fulfillment of course credit, with 16 participants in each condition (see Table 2).

Table 2: The four conditions employed to assess within-category structure in Exp. 2.

Condition	Preexposure	Conditioning	Test
Baseline	A / - / - / - / - / F	A+	F
Surprise	A / B / C / - / - / F	A+	F
Sys_trans	A / B / C / D / E / F	A+	F
Scram_trans	A / E / C / D / B / F	A+	F

Stimuli, Design and Procedure The same stimuli used in Exp. 1 were employed. As for Exp. 1, on a given trial, participants were sequentially preexposed to a set of morph stimuli from one of the object categories. Within each of the four exposure conditions, half of participants received presentations of the morph stimuli in the order A to F, and half of participants received presentations of the morph stimuli in the order F to A. Each stimulus was presented for 3000 ms, and the temporal spacing between presentation of stimulus A and stimulus F was held constant across conditions by introducing a fixation cross when no morph (object) stimulus was scheduled to be presented, relative to conditions Sys_trans and Scram_trans. Within the subconditions created by the previous counterbalancing operation applied in each preexposure condition, following a 1000 ms inter-stimulus interval (blank screen), half of participants were then presented with stimulus A, and half of participants were then presented with stimulus F. Situated above the stimulus was a sentence that informed participants about a particular property that the stimulus had: for example, "This person comes from a small, remote island in the Pacific Ocean". This information remained on the screen until the space bar was pressed, at which point participants were immediately presented with the test screen. On the test screen, participants were simply asked to rate on a scale from 1 (very unlikely) – 9 (very likely) how likely they thought it was that the stimulus now presented to them shared the property of the previously seen stimulus. If participants had previously been presented with stimulus A, then at test, they were presented with stimulus F, and if they had previously been presented with stimulus F, then at test, they were presented with stimulus A. The 1 – 9 rating scale was continuously presented beneath the test stimulus, and responses were made using the 1 – 9 keys on the top of a standard computer keyboard. A 1000 ms inter-trial interval (blank screen) separated participants' likelihood ratings and their exposure to the next object category. Exposure to the seven object categories was random for all participants in each of the four preexposure conditions.

Results

Again, for the purpose of analyses, participant similarity judgments were averaged over the seven object categories. Figure 3 shows the results of the generalization test: the overall mean likelihood ratings that the test stimulus shared the property of the previously seen stimulus, split by preexposure condition. Inspection of this figure reveals that participants in the Surprise condition reported lower mean likelihood ratings than participants in the other three preexposure conditions; likelihood ratings in the other three conditions were all very similar.

A one-way ANOVA[2] confirmed that there was an overall effect of preexposure condition, $F(3, 40.51) = 2.85$, $p < .05$, $\eta^2 = .12$. Dunnett T3 post-hoc tests (equal variances not assumed)[3] revealed that, overall, participants in the Surprise condition reported significantly lower mean likelihood ratings than participants in the Baseline condition ($p < .05$, $r = .35$). No other post-hoc comparisons were significant (all ps > .05).

[2] Due to a lack of homogeneity of variances between conditions, the Brown-Forsythe correction was applied.

[3] Tukey HSD post-hoc tests were not performed (as in Exp. 1) due to the lack of homogeneity of variances between conditions.

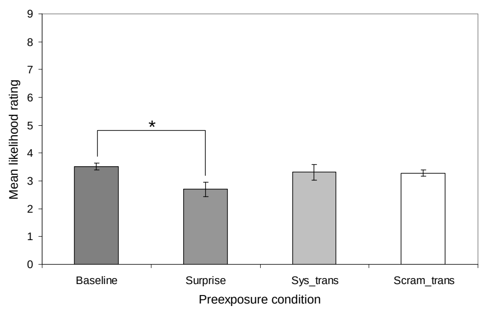

Figure 3. Results of Exp. 2: overall mean likelihood ratings, plotted by preexposure condition. Error bars indicate the standard error.

Discussion

The results of Exp. 2 are broadly consistent with the predictions of a surprise-driven category invention mechanism operating in incidental categorization (Clapper & Bower, 1994, 2002; also Love et al., 2004). This assumes that only the within-category similarity structure of the Surprise condition encouraged participants to invent an extra category (cluster) in which to accommodate the lone distinct stimulus, meaning that stimuli A and F were 'classified apart'. As a consequence of this, property generalization between A and F in the Surprise condition was reduced (Harnad, 1987).

In line with the results of Exp. 1, it is apparent that transformational information did not encourage the 'classification together' of stimuli A and F and a concomitant increase in the level of property generalization between A and F (condition Baseline vs condition Sys_trans). Moreover, there is no evidence to suggest that systematic transformational information influenced participants' response behavior differently to non-systematic transformational information (condition Sys_trans vs condition Scram_trans; cf. Zaki & Homa, 1999).

What aspect of the within-category structure of the Surprise condition encouraged the assumed 'classification apart' of stimuli A and F? Inspection of this structure reveals that not only does it have a similarity structure likely to engage a surprise-driven category invention mechanism, but also a distinct temporal structure. That is, while the three stimuli with the highest perceptual similarity were presented in a temporally contiguous manner, a temporal gap of six seconds separated presentation of the distinct stimulus from the highly similar stimuli. It is possible, therefore, that it was this temporal discontinuity, rather than the perceived perceptual discontinuity, that engendered the assumed invention of a new category (cluster) in which to accommodate the distinct stimulus.

Experiment 3

Exp. 3 replicated Exp. 2 with one exception: in order to determine if the temporal discontinuity contained within the Surprise condition of Exp. 2 was critical in producing the significant difference between the Baseline and Surprise conditions, the stimuli in condition Surprise_2 were preexposed with even temporal spacing.

Method

Participants 32 Cardiff University students took part for a small payment of £2, with 16 participants in each condition (see Table 3).

Table 3: The two conditions employed to assess within-category structure in Exp. 3.

Condition	Preexposure	Conditioning	Test
Baseline	A / - / - / - / - / F	A+	F
Surprise_2	A / B / C / F	A+	F

Stimuli, Design and Procedure The only difference to Exp. 2 was that during the preexposure phase of the Surprise_2 condition, presentations of the morph stimuli were separated by a 2000 ms long fixation cross. This maintained the equivalent temporal spacing between presentations of the object category endpoints (A and F) across the two conditions.

Results

Figure 4 shows the results of interest: the overall mean likelihood ratings split by preexposure condition. Inspection of Figure 4 shows that, overall, participants in the Surprise_2 condition reported significantly lower likelihood ratings than participants in the Baseline condition, $F(1, 30) = 6.14$, $p < .02$, $\eta^2 = .17$[4].

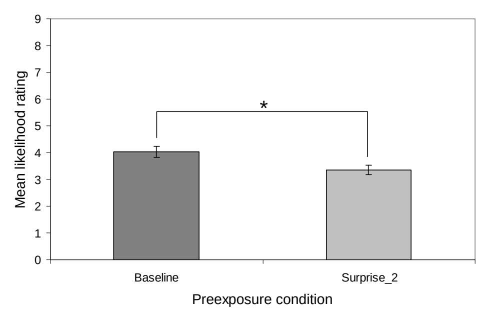

Figure 4. Results of Exp. 3: overall mean likelihood ratings, plotted by preexposure condition. Error bars indicate the standard error.

General Discussion

The method of these studies provides a fast and effective way of assessing the influence of within-category structure (i.e., the distributional properties of the stimuli)

[4] Due to a violation of normality in the data (Shapiro-Wilk test of normality, $p < .007$), we confirmed this result using the non-parametric Mann-Whitney U test, $U(16, 16) = 56.50$, $p < .008$, $r = .49$.

on people's incidental categorization behavior, as indexed by their later judgments of stimulus similarity and stimulus generalization. Indeed, one particularly notable feature of the designs of Experiments 1 – 3 is that participants only received a single presentation of each scheduled stimulus during preexposure.

Two main findings were made: First, transformational information did not encourage 'classification together', which would have resulted in a later increase in the perceived similarity of stimuli A and F (Exp. 1) and an increase in the level of property generalization between these stimuli (Exp. 2). Second, when perceptual discontinuity existed in the presented within-category structure, this resulted in a reduction in the level of later property generalization between stimuli A and F (Exp. 2 and Exp. 3). This result is consistent with the assumption of a surprise-driven category invention mechanism operating in human incidental categorization (Clapper & Bower, 1994, 2002; also Love et al., 2004), and supports previous work by Gureckis and Goldstone (2008). Importantly, the results of Exp. 2 demonstrate that this reduction in stimulus generalization was not simply a product of the amount of stimulus preexposure.

In conclusion, the present results support the idea that perceived discontinuity in the environment (be this temporal or perceptual) guides people's incidental categorization behavior, as indexed by their later judgments of stimulus similarity and stimulus generalization (Anderson, 1991; Rosch & Mervis, 1975). Finally, one of the particularly nice aspects of the design of Exps 2 and 3 is that it can be readily transposed to assessments of incidental categorization in nonhuman animals and prelinguistic children.

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