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Author

Hampton, James A.

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Perceptual contrast and response assimilation in sequential categorization without feedback

James A. Hampton (hampton@city.ac.uk)
Department of Psychology, City, University of London
Northampton Square, London EC1V OHB

Abstract

Sequential categorization of perceptual stimuli typically shows contrast from one trial to the next. Using familiar categories of animals and faces, contrast effects were dissociated from assimilation effects. Two independent main effects were observed: contrast to the preceding stimulus, and assimilation to the previous response. It is argued that contrast and assimilation may reflect different processes in categorization.

Keywords: categorization, contrast, assimilation

Introduction

Learning to categorize stimuli along a perceptual dimension (e.g. the pitch of a tone) would appear to require the establishment of a criterion value against which each stimulus can be judged. Above the criterion stimuli fall in one category, and below in the other (Ashby & Gott, 1988). However Stewart, Brown, and Chater (2002; 2005) argued that people may be unable to keep a consistent criterion in mind through the course of a sequence of such decisions. It is well known from the literature on absolute identification (where each value on the dimension must be identified separately) that learning to make such judgments is very difficult and prone to bias (Garner, 1953; Baird, Green, & Luce, 1980). In the same way, Stewart et al. (2002) argued, learning and retaining a given boundary on a perceptual dimension such as the pitch of a tone, will also be hard. Instead of making a judgment relative to an absolute value held in memory, people may instead rely on the difference between the current stimulus and the previous one. Since in a categorization task, feedback is normally provided on every trial, people can use the feedback on the previous trial, together with the direction and degree of change between the previous and the current stimulus to arrive at a reasonably accurate judgment. Stewart et al. referred to this way of doing the task as a MAC, or Memory and Contrast, strategy. Such strategies can lead to reasonable accuracy in the task, without recourse to the representation of absolute values in memory.

In this and subsequent research (Stewart & Brown, 2004, 2005; Stewart, Brown & Chater, 2005; Stewart & Morin, 2007), Stewart and colleagues have shown that the use of MAC strategies produces a category contrast effect between one trial and the next. If a sequence of ten tone stimuli is divided into two categories #1 to #5 as “low” and #6 to #10 as “high”, then a given stimulus next to the borderline (e.g. #5) will be more likely to be correctly called “low” if preceded by a clearly high case (e.g. #10) than by a clearly low case (e.g. #1).

Stewart and Brown (2005) proposed that the category contrast effect could be part of a pair of heuristics in which the similarity and dissimilarity of a stimulus to the preceding stimulus is used to inform its categorization. In their Similarity-Dissimilarity (SD-GCM) adaptation of Nosofsky’s Generalized Context Model (GCM) (Nosofsky, 1986), they proposed that categorization takes account not only of similarity to the exemplars of a class, as in the GCM, but also dissimilarity. Adopting Nosofsky and Palmeri’s (1997) proposal that recently classified exemplars will have greater influence on the decision, the SD-GCM proposes that when a stimulus is very *similar* to one on the preceding trial or trials, then it should tend to be put in the same category, while when it is very *dissimilar*, it will tend to be put in the opposite category. The model thus predicts a contrast effect that increases with the dissimilarity between neighbouring stimuli in a sequence, and turns into an assimilation effect as the two become increasingly similar. Jones, Love and Maddox (2006) describe this prediction in terms of a generalization curve from one trial to the next that is positive for similar items (assimilation), but negative for highly dissimilar items (suppressing categorization, and thus generating contrast).

Evidence for the SD-GCM was also found in a series of studies by Hampton, Estes and Simmons (2005). In their paradigm, pairs of ambiguous stimuli were presented simultaneously and participants judged whether both, just one, just the other, or neither were in a category. A strong contrast effect was observed, seen as a bias to judge that just one stimulus was in the category, rather than both or neither.

The aim of the current study is to investigate contrast and assimilation in sequential judgments empirically. To provide a clear picture of the effect of the previous trial however, it is important to be able to separate out the effects of the previous stimulus from the previous feedback (category membership). Jones et al. (2006) pointed out that Stewart et al.’s (2002) procedure of providing correct feedback on every trial means that the two effects are confounded. To remove this confounding, Jones et al. introduced probabilistic category feedback, with the likelihood of a stimulus being categorized in a given category ranging from 90% to 10% across the range of stimuli. With this task, it was possible to separate out the effect of the previous stimulus – which they argued would be based on perceptual contrast – from the effect of the previous feedback, which would be a decisional effect. In their study they found that the previous stimulus produced a perceptual contrast effect, while the previous feedback produced assimilation when stimuli were similar, and contrast when they were very different. The heuristics proposed by the SDGCM were therefore supported by the decisional contrast and assimilation observed, while in addition the effect of one stimulus was shown to lead to contrast with the next. Looking at the parametric properties of these two effects, they suggested that Stewart et al.'s original category contrast effect was probably perceptual in origin, since the decisional contrast only appeared at extreme distances.

The present study aimed to extend the method used by Jones et al. (2006) by differentiating the effects of the stimulus and the prior category in a simpler way. One problem with probabilistic category feedback is that participants may develop higher order models of the task. For example, if the most typical member of Category A is actually categorized by feedback as a B on 10% of trials, (non-modal feedback) the participant may develop a justified belief that the feedback is erratic and sometimes gives the wrong answer. They may even believe that the stimulus-response mapping has changed (Berg, 1948). Non-modal feedback is thus likely to cause disturbance to the current response strategy. Indeed, the reported results (Jones et al., 2006, Figure 5) are consistent with this suggestion. When the previous trial gave modal ("correct") feedback, the response curve rose smoothly with position along the physical dimension, asymptoting near 0.95 for the last two or three stimuli. When the previous trial's feedback was non-modal however, the data showed a pattern of similarity based responding, with generalisation of the same category response to similar stimuli, but also a tendency to reverse categorization for distant stimuli, thus leading to the negative generalisation or contrast for large shifts in stimulus values.

Given the possibility of different interpretations of Jones et al.'s results, it is therefore important to find other means of separating the effects of the prior stimulus and feedback to test the generality and reliability of their result. To do this, a categorization task was used in which, because the categories are well known prior to the experiment, no feedback is needed. Hampton, Estes and Simmons (2005) used a categorization task in which 7 images were shown varying along a dimension in which an image of a cat was morphed into that of a dog (see Figure 1). The task was simply to categorize the images as cats or not cats. Since responses to stimuli in the middle of the range will be probabilistic it is possible to break the data down as a function not only of the previous stimulus, but also of the previous response. While this feedback-free procedure has been used in absolute identification (e.g. Mori & Ward, 1995) it has not been attempted before for categorization.

Based on the results of Jones et al. (2006), assimilation to the previous response/category was predicted, that is, a bias to place a stimulus in the same category as the previous stimulus. Second, this bias should be stronger when the two stimuli are similar, and may even reverse to a contrast effect if they are very dissimilar. Third, it was predicted that there would be a perceptual contrast effect, such that, holding the previous response constant, then a current stimulus would be more likely to be placed in the opposite category to the previous one.

Experiment 1

Method

Participants. Nineteen students from City University London (10 males) took part in the study.

Materials. Seven images (see Figure 1) were taken from Hampton et al. (2005, with thanks to Vladimir Sloutsky). They ranged from a clear picture of a kitten (#1) through to a clear picture of a puppy (#7), with equal morphed steps in between. Each image was 200 x 200 pixels, measuring 6.6 cm square on the display screen.

Figure 1: Stimuli used in Expt 1

Apparatus. A Dell PC with a 15-inch CRT was programmed in Microsoft Visual Basic.

Design. A repeated measures factor of Preceding Stimulus with 7 levels corresponded to the stimulus (#1 to #7) on the preceding trial. For analysis, this was converted to a measure of Relative Distance between the current and preceding stimulus. A post hoc factor of Response differentiated trials on the basis of the response given on the previous trial. The trial sequence provided a balanced pseudo-random sequence maximizing the number of useful trials. There were 6 blocks of 42 trials each. The 3 central images (#s 3, 4, and 5) where responding would not be at floor or ceiling were taken as "target" stimuli, and even-numbered trials always featured one of these three. Within a block of 42 trials, each target was preceded on odd-numbered trials by each of the 7 images (including itself and the other target stimuli), and the transition from one trial to the next was balanced as in Table 1. Note that there were no transitions between non-target stimuli. Across blocks, the full transition matrix had 6 times as many trials in each cell as in Table 1. Self-terminated breaks occurred after the second and fourth blocks, and filler trials were introduced at the beginning of the experiment and after each break to provide the starting context for the next set of trials.

Procedure. Instructions were displayed below the 7 images ranked from #1 to #7. A trial began with the display of an image below which appeared two response boxes labeled CAT and DOG. The image remained on screen until a response was made with the mouse. A centrally located NEXT button then appeared and had to be clicked, to reduce response perseveration due to mouse position. On each trial the mouse pointer was moved from the same central starting location. To reduce image persistence, and hence the possibility of detecting small changes from trial to trial, the images were displayed alternately to left and right of center.

Table 1: Transition frequency from one trial to the next within each of the 6 blocks of 42 trials. The shaded area shows the critical trials involving a decision about one of the target borderline images.

	Stimulus on Current Trial							
Trial Before	1	2	3	4	5	6	7	Sum
1			1	1	1			3
2			1	1	1			3
3	1	1	2	2	2	1	1	10
4	1	1	2	2	2	1	1	10
5	1	1	2	2	2	1	1	10
6			1	1	1			3
7			1	1	1			3
Sum	3	3	10	10	10	3	3	42

Results

Preliminary data processing was required to clarify the results. First, one participant chose "cat" on only 6 of the 180 target trials, and was excluded. Next, the rate of responding "cat" to each stimulus was calculated to check for range effects. The cat/dog boundary was not quite at the center of the scale, but lay between #3 and #4 on the CAT side of the center. As a result, almost all responses to #5 were "dog". Since #5 would therefore show a floor effect, this stimulus was not used as a target, leaving #3 and #4 as the target stimuli. The proportion of "cat" responses given to each of these was calculated as a function of the response given on the previous trial, and the relative distance of the previous stimulus from the current target. Two participants lacked data for just one cell each, and missing values were replaced with the relevant mean group.

Figure 2 shows the proportion of "cat" responses to the current target stimulus, averaged over the two target stimuli #3 and #4. The top line shows trials where the preceding response was "cat", and the lower shows trials where it was "dog". The horizontal axis shows the relative distance of the current target from the previous stimulus. Thus CAT+2 represents the case where the preceding trial was 2 steps more cat-like than the target and DOG+3 shows the case where the preceding stimulus was 3 steps more dog-like. TARGET represents the case where the preceding stimulus was the same as the current target stimulus. Note that no data are shown for CAT+3 because target #3 could only have a previous stimulus (#1) two steps more cat-like. In addition, two other points are missing from the graph because there were too few data points to estimate the mean. These points corresponded to the prior stimulus three steps more dog-like (DOG+3) being called a "cat", and the prior stimulus two steps more cat-like (CAT+2) being called a "dog".

Figure 2 shows two main effects. First, when the previous response was "cat" (the top line), the current target stimulus was more likely to be called "cat" than when the previous response was "dog" (the lower line). Thus there was an assimilation to the previous stimulus showing up as a perseveration of the previous response. Regardless of the distance on the scale between the current target and the previous stimulus, there was a bias to repeat the same response.

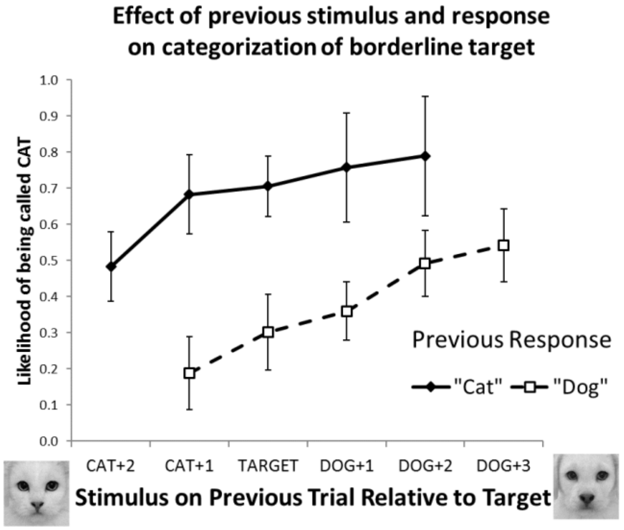

Figure 2: Categorization probabilities for Experiment 1

Second, the lines rise from left to right, indicating a contrast from the previous stimulus. As the prior stimulus became more like a dog (moving from left to right along the axis) so the probability of the current target being called "cat" increased in a linear fashion. For example, consider the lower dotted line in the figure where the previous response was "dog"; the same target was called "cat" only 20% of the time if following the stimulus CAT+1 – a stimulus one step more cat-like – but it was called "cat" over 50% of the time if following stimulus DOG+3 – where the previous stimulus was 3 steps more like a dog.

The data were submitted to ANOVA with factors of Previous Response (Cat, Dog), and Relative Distance of previous stimulus (four levels for which full data were available: CAT+1, TARGET, DOG+1, DOG+2). Both main effects were highly significant: Previous Response, $F(1,17) = 76.3$, $p < .001$, and Relative Distance, $F(3,51) = 5.36$, $p < .005$, and there was no interaction ($F(3,51) = 1.4$, $p > .2$). Relative Distance had a significant linear trend ($F(1,17) = 14.7$, $p < .001$).

Before discussing the implications of the results, a replication will be described using the same procedure but a different set of stimuli.

Experiment 2

Method

Participants. Participants were 23 students (3 male) from City University, London.

Materials. The stimuli used were a set of morphed images created between two celebrity faces, one of Eva Longoria and the other of Victoria Beckham (see Figure 3). Pilot testing established the necessary gradations to achieve a range of ambiguous images.

Apparatus and Procedure. The same apparatus and procedure was employed as in Expt 1. In addition, in a first phase, participants were shown a sheet of images with 18 morphs changing from Eva to Victoria, and were asked to select the image that they felt was the closest to the 50:50 boundary between the two end images. This image was then used as the central target (#4) in the sequence for that participant with stimuli #1 to #7 in equal steps either side. The same sequence of trials was presented as in Experiment 1, with the question “Is this picture more like Eva or Victoria?” and a mouse response. Data were scored as the probability of categorizing the image as Eva.

Figure 3. Morphed Images of Eva Longoria and Victoria Beckham From the Range of 18 Morphs in Experiment 2

Results

The mean likelihood of responding “Eva” was calculated for the three borderline target faces, as a function of the relative scale position of the previous face, and the response made to the previous trial. As in Experiment 1, there were two clear effects on the probability of choosing the “Eva” response, over and above the effect of the target face itself. First, the previous response had an assimilation effect – when the previous response was “Eva” there was an increase from 0.40 to 0.61 in the probability of the current response being “Eva” regardless of the target or the previous stimulus. Second, as in Experiment 1 the effect of the previous stimulus was to produce a contrasting shift in the response.

Because the range of borderline faces was narrower than in Experiment 1, there were insufficient trials in which an ambiguous target followed another ambiguous face. (These trials are critical to applying the method of analysis used in Study 1).

A different method of analysis was therefore used. The effect of the previous response was calculated for the three images in the middle of the scale 3-5, where there were sufficient responses of each type. A 2 (Previous response) x 3 (Previous Image) x 3 (Target face) repeated measures ANOVA showed a highly significant effect of the Previous Response, ($F(1,22) = 32.3$, $p < .001$.)

To assess the contrast effect, for each participant, target face, and previous response, the correlation was calculated between response probability of saying “Eva” and the scale value of the previous stimulus. For example, for face #4 in Figure 3, the rate of responding “Eva” was calculated based on which of the 7 faces had been presented on the previous trial. A correlation was then calculated to determine whether the rate was increasing or decreasing as the previous stimulus changed. Six correlations were calculated for each participant, based on the 3 target faces (3, 4, 5) and two previous response possibilities.

Positive correlations indicated a contrast effect. A higher scale value for the preceding stimulus means it is more like Victoria, so that a contrast effect would see a higher probability of saying “Eva” following face #7, than following face #1. The correlations were transformed to Fisher Z and t-tests were run across the participants for each of the 3 targets (3, 4, 5) and 2 previous responses. Eva responses to Target 3 following an Eva response, and to Target 5 following a Victoria response both showed a range effect (the first being towards ceiling and the latter at floor). For the other four conditions, the average correlation ranged from .35 ($p < .05$) to .49 ($p < .002$) all showing a strong positive contrast effect of the previous stimulus.

Discussion

This study set out to separate the effects of the preceding response and stimulus by using a set of images with a vague borderline region that was wide enough to provide trials where a given prior stimulus could be categorized either way.

First, the results clearly demonstrated strong assimilation to the previous response, in line with the findings of Jones et al. (2006). For the central stimuli where sufficient responses of each kind were available, there was a bias of around .20 to .30 in the probability of a given categorization in the direction of the previous response, regardless of the previous stimulus. Unlike Jones et al. however there was no reduction in the response assimilation effect as the stimuli became more different. There are two likely explanations for this effect. First, in paradigms where feedback is provided, people tend to repeat whatever response was reinforced on the previous trial (Jones & Sieck, 2003), similar to the situation with probability learning (Edwards, 1961, Jarvik, 1951), and consistent with theories of conditioning (Rescorla & Wagner, 1972). Even though no feedback was provided (the participants in the present study decided for themselves where the boundary lay) they could nonetheless have treated their previous response as an anchor on which to base the next. This is what Mori and

Ward (1995) reported for an absolute identification task when feedback was omitted. A second explanation would be in terms of instability in the classification criterion adopted by participants over the course of the experiment leading to autocorrelation of responses. If the criterion is sometimes set low, then most stimuli will be "cats", and if it then drifts high, they will mostly be "dogs", yielding a greater preponderance of repeated category responses than expected. (Note that this explanation does not work on the basis of participants having different criteria since response rates were calculated separately for each participant before averaging.)

The failure to show a reduction in response assimilation as the stimuli became less similar may be a function of the design. Trials focused on given borderline targets, preceded by different context stimuli. Thus there were no transitions from one extreme of the scale to the other, which is where Jones et al. observed the response-based contrast effect. There was little point in including such trials as almost all responses to the extreme images were at floor or ceiling. As described in the introduction it is uncertain whether the decisional contrast effect reported by Jones et al. (2006) is genuine evidence for negative generalization of the previously reinforced category (as they argue). When non-modal feedback was provided (i.e. "false" feedback) performance on the next trial was disturbed, and this could have several alternative explanations. Since the argument for negative generalization depends on the use of invalid feedback, it must be treated with caution.

Once the data were analyzed separately depending on both the stimulus *and the response* on the previous trial, a contrast effect was also seen, confirming Jones et al.'s report of a perceptual contrast effect between neighboring stimuli, independent of the previous response (or in their case feedback). Unlike Stewart et al.'s (2002) contrast effect, the effect here is unlikely to reflect a MAC strategy.

In comparison with previous research using simple tones or rectangles, participants showed little evidence of noticing when a stimulus changed from the previous trial, and if so in what direction. Our procedure of shifting the image left and right between trials may have made it harder to notice when a stimulus had changed from trial to trial and in what direction. For example, if participants had recognized that a stimulus had been repeated, (the point labeled TARGET in Figure 2) then one would naturally expect the previous response to also have been repeated, leading to extreme response rates of 0 if the previous response was Dog and 1 if the previous response was Cat. The data in Figure 1 show no evidence for this strategy. Similarly, if people noticed the direction of change from trial to trial, extreme responding should have been found when the direction of change was further towards the category previously chosen (the Monotonicity Constraint identified by Hampton et al., 2005). If I have just called something a Cat, and this new image is even more cat-like, I would not now call it a dog. In that case, for example, in Figure 1, the rightmost two points on the top filled line should be at 1, since here the participant has said that DOG+1 or DOG+2 looks like a cat, and they are now faced with a more cat-like target. This type of behavior was not seen in the data. It is striking that even though participants appeared to make no use of how the stimuli changed from trial to trial, they were still more likely to judge the current borderline image as a cat, when preceded by a more dog-like image, and vice versa, *regardless* of how they classified that previous image. Perceptual contrast effects such as this can be explained as adaptation level effects (Hampton et al., 2005; Helson, 1964; Treisman & Williams, 1984). Treisman and Williams proposed a tracking process, whereby category criteria may adjust themselves towards the average of the current stimulus environment, to maintain maximum sensitivity to change, and thus leading to contrast.

The contrast and assimilation effects built in to Stewart and Brown's (2005) SD-GCM may therefore be operating at different levels, something that previous research has not considered. Contrast – the tendency to see one stimulus as more likely to be in the category opposite to the preceding stimulus – comes out as primarily perceptual in the present experimental set up, showing up regardless of how the previous stimulus was categorized. The fact that pairs of trials where a stimulus was repeated showed no increased tendency to repeat the previous response is clear evidence that participants were not using a MAC strategy in this case. Recall that the MAC strategy explains contrast in terms of a participant judging the sign (and possibly magnitude) of the change in the stimulus presented from one trial to the next. A large shift away from the category of the previous stimulus will give rise to contrast.

Assimilation can also have two sources. According to the SD-GCM it is the similarity of two sequential stimuli that leads to perseverance of the response, and hence to assimilation. If you choose to call one stimulus a cat, and the next stimulus is hardly any different, then you call the next stimulus a cat as well. This type of assimilation should then be sensitive to the distance between the two stimuli. Only when a pair of stimuli are highly similar should you get assimilation.

The assimilation observed here was quite different in character. There was no good evidence in the lines in Figure 1 of the slope flattening out or becoming negative as the previous stimulus approached the target. The large assimilation effect was entirely associated with the effect of the previous response. Having called one stimulus a cat or dog, there was an inertia in the response, leading to a constant bias to place the next stimulus in the same category, regardless of the distance between them.

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