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The relationship between discrimination and memory for spacing and feature changes in houses

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ABSTRACT

Adults need to discriminate between stimuli and recognize those previously seen. For faces, feature changes (e.g., different eyes) and spacing changes (e.g., distances between eyes) are important cues. In two experiments, we assessed the influence of these on discrimination and recognition of houses, a commonly used control in face studies. In both experiments, discrimination was better for feature than spacing changes. Memory for spacing changes was generally poor but aided by extra learning and intermixing change types. Conversely, memory for features was good, especially when there were few houses, and change type was blocked. Unexpectedly, memory was best for differences that might signal something about occupants (e.g., changes to garden or bins), perhaps akin to hairstyles for faces. Overall, results are consistent with previous work showing poor discrimination of spacing in non-face objects and extends them to show that, unlike for faces, spacing differences are also not well remembered.

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We can tell our friends Jane and Jim apart and tell whose coffee mug or house is whose, and this ability allows us to interact with people and objects *as individuals*. This ability applies not only to distinguishing similar items when they are present at the same time, but also to recognizing that an item is the same one that we have seen before; that is, we can both discriminate between, and remember, numerous similar items. Extensive research has been conducted to identify the cues that we use for doing this with faces; here we examine some of those same cues for discrimination and recognition of houses, a commonly used control stimulus in face studies. Doing so allows us to comment on the domain specificity of these skills, as well as compare processing for discrimination and memory tasks.

Adults use a variety of cues to discriminate and remember the identity of faces. For example, we can discriminate faces that differ only in external contour (jaw and forehead shape), only in features (e.g., eyes, mouth), or only in the spacing between features (e.g., distance between the eyes; Mondloch, Le Grand, & Maurer,

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2002). The importance of feature spacing is evident from findings that changing the spacing between features makes faces more distinctive *and* more memorable (Leder & Bruce, 1998). Feature shape is also important: We can remember which of two faces we saw previously when they differ by only one feature, even when the spacing between features has been changed (Tanaka & Farah, 1993; Tanaka & Sengco, 1997). However, accuracy in detecting the changed feature is worse when there is also a spacing change, a result again indicating some representation of spacing between features in memory (Tanaka & Sengco, 1997). All of these skills are worse for inverted (upside-down) faces (Leder & Bruce, 1998; Tanaka & Sengco, 1997; Tanka & Farah, 1993). Thus, for faces, both spacing and feature cues are important for discrimination and memory, with sensitivity refined by experience with upright faces.

Houses have been a popular comparison stimulus for face recognition studies, perhaps because, like faces, they have a shared first-order configuration (Diamond & Carey, 1986): For faces, two horizontally aligned eyes above a nose above a mouth; for houses, roof on top, door toward the bottom, windows next to the door and/or between the door and roof. This shared first-order configuration means that theoretically, as for faces, individual houses must be discriminated or remembered based on cues such as differences in the features themselves and/or their location (i.e., the spacing between features). Houses can be discriminated based on changes in individual parts or their spacing (Yovel & Kanwisher, 2008) and, as for faces, detection of changes in parts is degraded by simultaneous spacing changes (Donnelly & Davidoff, 1999). Children, at least at age 8, are worse than adults at discriminating between individual houses or faces differing only in feature spacing, a parallel suggesting a similar developmental trajectory for spacing discrimination in faces and houses (Mondloch, Maurer, & Ahola, 2006; Robbins, Shergill, Maurer, & Lewis, 2011). Memory for spacing and feature changes in houses has not been tested.

For faces, there appears to be some relationship between discrimination ability and memory. The ability to remember famous faces correlates with the ability to detect both spacing and feature changes (Rotshtein, Geng, Driver, & Dolan, 2007). For unfamiliar faces learned incidentally, memory correlates with the ability to detect spacing but not feature changes (Rotshtein et al., 2007). However, on discrimination tasks, the abilities to detect feature and spacing changes appear to be unrelated. When spacing changes are kept within natural limits, accuracy in detecting spacing changes is not correlated with accuracy in detecting feature changes, and the latter is generally higher (Mondloch & Dejarlais, 2010; Rotshtein et al., 2007; but see Yovel & Kanwisher, 2008 for a correlation when the spacing changes are increased to outside the normal population range in order to equate accuracy in the feature and spacing conditions). In addition, there is a correlation between accuracy in detecting spacing changes in faces and houses (Mondloch & Dejarlais, 2010), consistent with a domain general spacing discrimination ability (cf., Robbins, Nishimura, Mondloch, Lewis, & Maurer, 2010, Robbins et al., 2011).

No studies have addressed the kind of information that we use to discriminate and remember houses, and whether these processes use similar information. The current paper addressed those questions. Based on previous results (e.g., Robbins et al., 2011), we expected discrimination for both feature and spacing changes in houses to be quite high. The question was whether these differences would also be stored in memory, automatically or only with intentional learning, and whether the pattern of results for feature and spacing changes would be similar for discrimination and memory tests. We did not include faces as a direct comparison stimulus because there are problems in matching difficulty between faces and houses without making face stimuli unrealistic (cf., Yovel & Kanwisher, 2008), and because we wished to maximize the measurement of house processing (adding faces would have required doubling the time or reducing the number of trials).

In Experiment 1, we asked participants to discriminate between houses with feature and spacing differences with a "surprise" memory test at the end of each change-type block (i.e., participants were not instructed to remember the houses). As memory for spacing changes in Experiment 1 was poor, in Experiment 2 we aimed to boost memory performance, to ensure that any conclusions were based on the highest, not lowest, estimates of this ability. We did this by testing discrimination and memory in a between subjects design using the same stimuli for each, but increasing the number of trials overall, and allowing a standardized 10-second exposure for learning each house before an expected memory test (i.e., participants were instructed to try and remember the stimuli). Memory for spacing changes, as well as a relationship between memory and discrimination, but little or no relationship between performance for feature and spacing changes, the patterns previously found for faces, would be indicative of domain-general mechanisms.

Experiment 1: Memory task following discrimination task

In Experiment 1 we tested participants' ability to discriminate houses differing only in features or feature spacing and whether this information had been encoded in memory without instructions to learn. Participants received blocks of trials with houses differing only in features (the particular windows and doors) or only in feature spacing (the location of the windows and door) and performed a two alternative match-to-sample task. Immediately after each block, they were given a recognition memory test. Based on previous research with similar house stimuli (Robbins et al., 2010, 2011), we predicted that participants would be good at detecting both spacing and feature changes in houses but probably slightly better at feature discrimination (despite attempts to match difficulty). If similar processes are used for houses as for faces, we expected participants to also be good at remembering the houses, especially in the blocks with feature changes.

Methods

Participants

Twenty-four undergraduate students (20 females, 4 males), aged 17–24 years (mean = 18.6) completed the experiment for course credit. All had normal or corrected-to-normal vision.[1]

Design and stimuli

The experiment involved two types of change (feature changes and spacing changes); each change-type block consisted of two phases. In the discrimination phase, participants were shown a house, followed by a pair of houses, and were asked to indicate which of the pair matched the house they had seen first (see Figure 1a). In the memory phase, which immediately followed each discrimination phase, they were presented with pairs of houses (one from the discrimination phase and one never seen before) and asked to indicate which one they had seen in the discrimination phase (see Figure 1b).

Houses were presented in two counterbalanced blocks corresponding to the main conditions of interest: feature differences (different windows and doors) and spacing differences (different spacing between features). In both the discrimination and memory phases, alternatives were always from the same condition (features or spacing changes). Specifically, houses changed in spacing were always presented with other houses changed in spacing, for both the discrimination and memory phases. Similarly, houses changed in features were always presented with other houses changed in features. For each manipulation, we used a total of 15 houses (see Supplementary Material); for each participant and condition, we chose ten houses for the discrimination phase and five houses as the distractors (new items) in the memory phase, with the houses chosen as distractors in the memory phase counterbalanced across participants. At the end of the procedure, participants completed a control block with completely different houses, gauged to assess performance when there are multiple cues that the identity of the house has changed. A sub-set of the houses from the current experiment was used in Robbins et al. (2011). Figure 2 shows an example of each house-change condition; the full set for each condition is shown in Supplementary Material. All houses were presented in greyscale. In spacing and feature conditions, a single-base house was modified to create the 15 houses for that condition; for the control condition 15 different individual houses were chosen (see Supplementary Material). For feature differences, the door and all three windows from other similar houses were resized and inserted into the base house (i.e., the spacing between features was the same across the set). For spacing differences, upper windows were moved in and out, the lower window moved up and down, and the door moved left to right, with the combination of changes different for each of the 15 houses (cf., the "Jane faces" in Mondloch et al., 2002). Changes were about four

[1] Specifically, Snellen acuity of at least 20/20 -2 in each eye with up to an additional -2.0 dioptre correction, along with worse acuity with a +3 dioptre lens (to rule out farsightedness), fusion on the Worth four-dot test, and normal stereo-acuity as measured by the Titmus test.

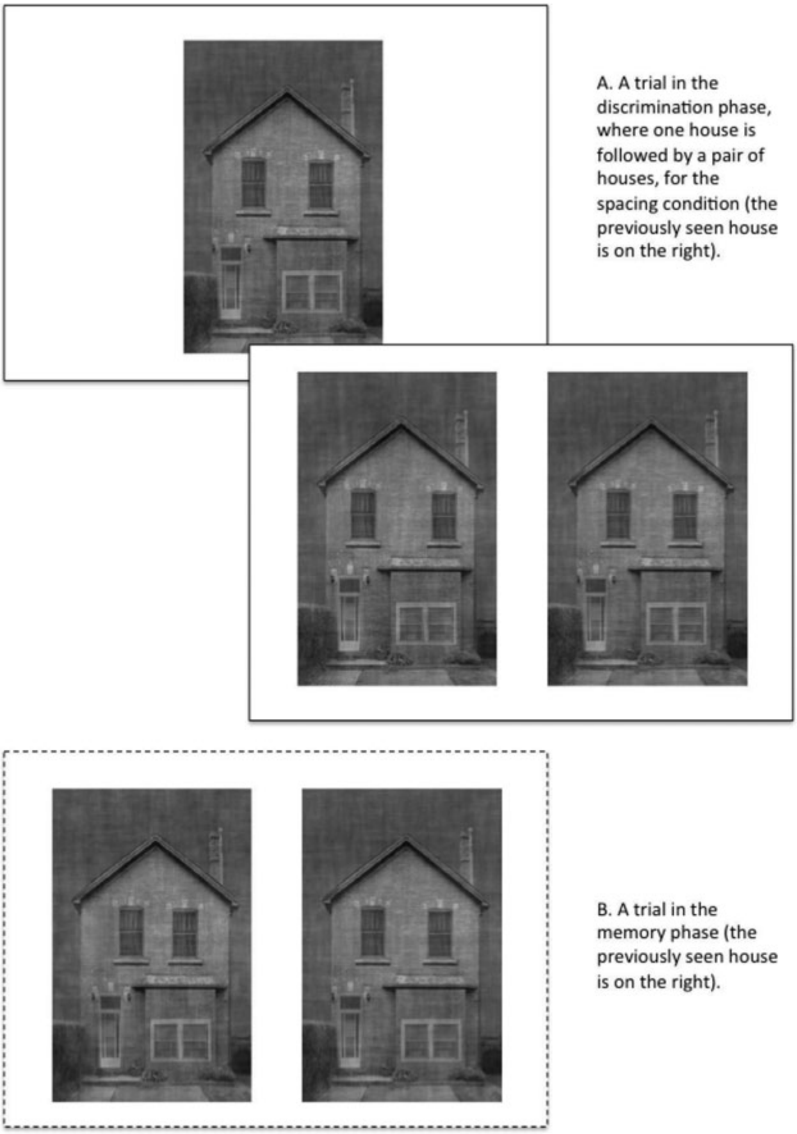

Figure 1. The trial structure of Experiment 1 showing (A) a trial from the discrimination phase in the spacing-change block and (B) the corresponding trial from the memory phase.

times larger, in absolute terms, than those made for faces in Mondloch et al. (2002), but only about twice as large when the relative size of the whole stimulus is taken into account. All houses had the spatial frequency amplitude matched by applying the average spectrum of the set to each house using MatLab (cf., Husk, Bennett, & Sekuler, 2007; Robbins et al., 2011).

Procedure and apparatus

Participants were tested individually in a darkened room. They were told that they would be tested on three blocks of houses, but were not forewarned about the memory test. The first discrimination block began with three practice trials using

Figure 2. Example houses from each condition of Experiment 1. From left to right, the house at the top differs from the house immediately below it in: Identity change (different house; control condition), Feature change (different doors and windows), Spacing change (upper windows out, lower window down). For the full set of stimuli, see the Supplementary Material.

shapes (e.g., square vs. circle). Then the participant saw a screen with examples of the 10 houses in the discrimination phase of that block, shown for as long as the participant wished. On each trial of the discrimination task, participants were presented with a fixation cross until they pushed the space bar, followed by a single house for 200 ms, and then a pair of houses until response (note that this timing is similar to previous studies with faces; e.g., Mondloch et al., 2002). The pair of houses contained the house shown first, as well as another from the set of 10 chosen for that participant, and participants were asked to indicate which of the houses they had seen first by pressing a key on the left or right side of the keyboard to indicate the left or right house, respectively. The correct answer occurred half of the time on the left and half on the right in each condition. There were 50 trials in each change-type block; the 10 houses were divided into two sets of five with all possible pairings included, and each house was shown once as the initial house in a trial (i.e., $5 \times 5 \times 2$).

After the discrimination trials, the memory phase for that condition followed immediately. On each trial of the memory phase, a fixation cross was shown until the participant pressed the space bar, followed by a pair of houses until the participant pressed the left or right response key to indicate which house they had seen before. For each pair, one of the houses had been seen previously in the discrimination phase and one was new but with the same type of manipulation (altered features or altered spacing, see Figure 1B). There were five memory trials per condition, because it was not possible to repeat distractors and have them still be novel (scheduling constraints for the Matlab procedures prevented the creation of additional houses).

Stimuli were presented with SuperLab Pro (version 1.77) on an Hp p1130 Trinitron Cathode Ray Tube monitor (21 inches diagonally) connected to a PowerMac G4 cube. Houses were 12 cm wide by 18 cm high, which at the 50 cm viewing distance corresponded to a visual angle of 13.7° by 20.4°.

Results and discussion

For each participant, we calculated the percent correct for each of the three house conditions (feature, spacing, and control), separately for the discrimination and memory tasks. As expected, participants had high accuracy for the control (different identity house) condition in both the discrimination (98.3%) and memory (91.7%) tasks, indicating that they understood the tasks. Results for spacing and feature conditions, are shown in Figure 2.

A 2 (task: discrimination, memory) × 2 (house condition: feature, spacing) repeated measures ANOVA showed significant main effects of task, $F(1,23) = 37.65$, $p < .001$, $\eta^2{}_p = .621$, and house condition, $F(1,23) = 34.45$, $p < .001$, $\eta^2{}_p = .600$, as well as a significant interaction, $F(1,23) = 11.18$, $p = .003$, $\eta^2{}_p = .327$. For the discrimination task, a t-test confirmed a significant difference between spacing and feature changes, $t(23) = 6.74$, $p < .001$, Cohen's $d = 1.41$. Importantly, both spacing and feature discrimination were also significantly above chance (50%), features, $t(23) = 53.89$, $p < .001$, Cohen's $d = 11.24$; spacing, $t(23) = 15.98$, $p < .001$, Cohen's $d = 3.33$. Thus, participants were able to discriminate houses very well that differed only in the features (windows and door; $M = 95.8\%$) or only in the spacing between features ($M = 81.1\%$), although they were still significantly better in discriminating the feature changes. For the memory task, a t-test again confirmed a significant difference between spacing and features, $t(23) = 4.85$, $p < .001$, Cohen's $d = 1.01$. However, only the feature condition was significantly above chance (50%), $t(23) = 9.4$, $p < .001$, Cohen's $d = 1.96$; spacing, $t(23) = 0.39$, $p = .702$, Cohen's $d = 0.08$. Thus, participants were able to remember very well five houses that differed only in the features ($M = 89.2\%$) but were not able to remember five houses that differed only in spacing between features ($M = 47.5\%$). Note that the five houses used as "old"/previously seen items in the memory test were counterbalanced across participants making it highly unlikely that the poor memory performance resulted from particular pairings.

There was a modest correlation between accuracy on the spacing discrimination task and the spacing memory task, $r = .376$, $p = .071$, but it was not significant on a two-tailed test. There was no relationship between discrimination and memory performance on the feature task, $r = .039$, $p = .856$, or between discrimination accuracy for features and spacing changes, $r = -.087$, $p = .685$, or memory accuracy for features and spacing changes, $r = -.272$, $p = .198$, probably because performance on the feature tasks was near ceiling for most participants.[2]

The results indicate that adults can discriminate among houses based on either featural or spacing differences but that their memory for the spacing differences when not instructed to remember the items is poor, with a group mean not different from chance. In this experiment, participants did not know that there would be a memory task (at least during the first block, which was counterbalanced across

[2] Removal of four potential outliers did not alter the results substantially: spacing discrimination and memory, $r = .205$, feature discrimination and memory, $r = .022$, discrimination for spacing and features, $r = -.113$, memory for spacing and features, $r = -.158$, all *ps* $> .05$.

participants). Therefore, it is possible that the results of Experiment 1 represent the lower, rather than the upper, bound of memory for such changes in houses (i.e., memory might have been better if participants were told to remember the houses). In addition, if the processes underlying discrimination and memory are not identical, participants may not have used the optimal strategies for remembering the houses given that they learned the houses while doing a discrimination task. As well, the small number of memory trials may not have produced reliable estimates of memory performance (with only 5 trials, participants can get only 20%, 40%, 60%, 80%, or 100%, and one wrong answer makes a large difference to overall performance). Variability in the time participants looked at the houses during discrimination before responding on each trial also may have affected the memory results. We did not record the amount of time they looked at the initial 10 stimuli. In Experiment 2, we addressed these issues to test whether spacing changes in houses are truly not remembered, or whether they are remembered in some circumstances, and how memory for spacing changes relates to memory for feature changes.

Experiment 2: Explicit memory task versus discrimination task

In Experiment 2, we tested memory and discrimination for spacing and feature differences in houses with an increased number of trials for each condition, a fixed learning time per trial, and an explicit memory task. These changes all were introduced in an attempt to improve memory for spacing changes to above chance performance so that it could be compared better to memory for features. Because of the increased number of trials, increased time, and the limited number of stimuli available, memory and discrimination tasks were tested between subjects; however, we used a yoked-design such that participant 1 in the memory task saw the same stimuli in each condition as participant 1 in the discrimination task. We also included an additional change-type comprised of changes more likely to occur frequently in the real world, namely changes such as differences in gardens or having garbage bins out. These changes are equivalent to changes in things like hairstyle for faces (i.e., things that can change, but do no alter the structure/identity). Changes to external features, such as hairstyle, contribute to the recognition of unfamiliar faces (e.g., Ellis, Shepherd, & Davies, 1979), and here we evaluated the role of such "non-structural" changes to the recognition of houses.

Methods

Participants

The final sample consisted of 20 participants in each task; 10 males and 10 females (aged 16–23 years, mean 18.8) in the memory task and 10 males and 10 females (aged 18–29 years, mean 21.1) in the discrimination task. Participants were paid $10 or received course credit for the 1-hour experiment. All participants had normal or

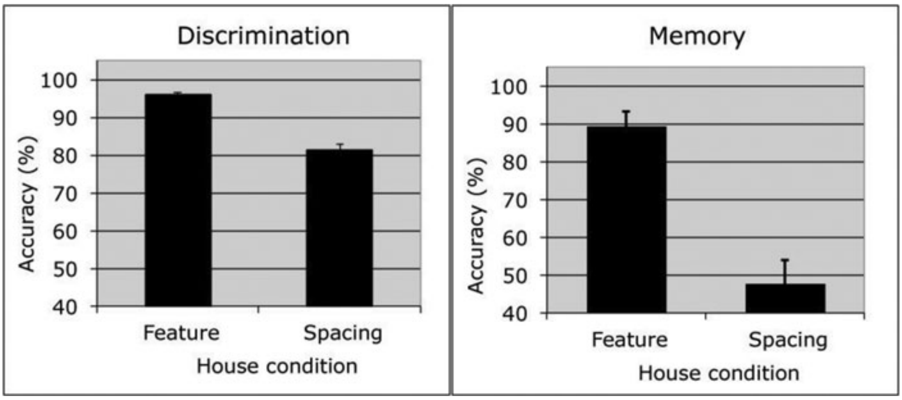

Figure 3. Mean percentage correct in Experiment 1 for the Discrimination task (left) and for the "surprise" immediate Memory task (right). In both cases, chance is 50%. Error bars represent ± 1 SEM.

corrected-to-normal vision as defined in Experiment 1. None of the participants had participated in Experiment 1.

Design and stimuli

Discrimination and memory were tested between-subject, with four change-types in each case (features, spacing, non-structural changes, control [completely different houses]). The discrimination task was a two-alternative forced choice match-to-sample task (i.e., the same structure as in Experiment 1). The memory task was a two-alternative forced choice recognition task. For the memory task, each of the 16 4-house blocks consisted of two learning phases followed by a test phase. The number of trials per block was based on pilot work. Spacing, feature, non-structural, and control trials were intermixed randomly within each block such that one of each was presented in each block of four trials.

Digitized images of 64 houses were taken with a Nikon Coolpix 5600 digital camera (resolution 6.0 megapixels), Canon Powershot S410 or similar. Some of the houses used as base stimuli had appeared in Experiment 1. Photographs were converted to greyscale to prevent the use of colour as a cue. There were four conditions in each task: feature changes (swapping windows and/or doors from a different house and thus changing one or two features, but keeping the size of the feature, and therefore the spacing, the same, as done in Experiment 1), spacing changes (moving the windows, and/or doors and/or chimneys of a house and thus changing spacing by moving one to three features), non-structural changes (a change which did not change the house itself, but which would be likely to occur to houses, for example adding or removing one item such as plants, pots, or garbage bins), and a control condition (different houses). Examples of feature, spacing and non-structural changes are shown in Figure 4.

To make a larger number of trials for the memory task of Experiment 2, we needed a larger set of houses. Rather than making somewhat arbitrary changes to the features and spacing between features of a large number of houses, while trying

Figure 4. Example houses from each condition of Experiment 2; shown from left to right for each of two houses: Original, Feature change (compared to Original, door changed in the top row, top windows changed in the bottom row), Spacing change (compared to Original, upper window and door changed in the top row, upper windows changed in the bottom row), Non-structural change (compared to Original, bins next to the steps removed in the top row, potted plant hanging from the porch added in the bottom row).

to match difficulty, we made a version of each change-type for each of the 64 houses (i.e., house 1 had a feature change version, a spacing change version, and a non-structural version, etc.). For each participant in the discrimination task, we then randomly divided the 64 houses into four sets of 16 to be presented in each of the four conditions. Our rationale was that, across participants, difficulty would then not be based on a few particularly difficult or easy houses. As discrimination and memory were manipulated between participants, we yoked participants by matching the input files across the two tasks. That is, if participant 1 in the discrimination task saw houses 1–16 in the spacing condition, so did participant 1 in the memory task. This also controlled for low-level differences between conditions.[3] Because of the larger number of houses, and all conditions being intermixed, it was not possible to show all the houses together at the start.

All editing was done in Adobe Photoshop CS (version 8.0). The houses were standardized by width and were thus a range of heights. All houses were 17 cm wide and ranged from 7 cm high to 24 cm high (or 19.3° by 8° – 27° at the 50 cm viewing distance). There was 1 cm (1.1°) between pairs of houses in the test phase.

For both tasks, on half of the trials the house presented initially was an original house, and on half the trials it was an altered house. The correct answer occurred half of the time on the left and half on the right in each condition.

Procedure and apparatus

For the discrimination task, on each trial, participants were shown a fixation cross until they pressed the space bar and were then shown a house for 5 s, followed by

3 For one of the subjects in the memory task and two in the discrimination task, a problem with the program lead to only 15 of the 16 trials being useable.

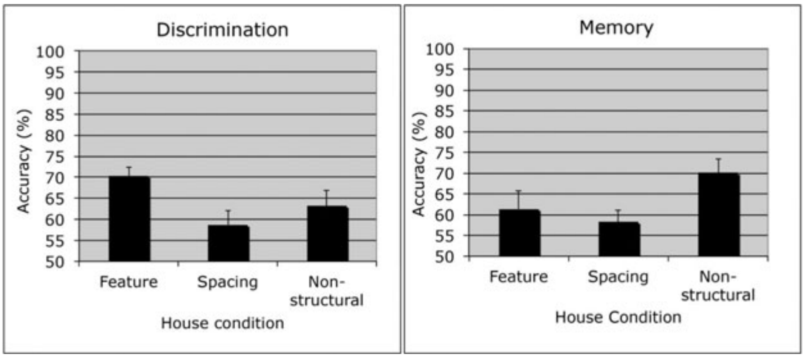

Figure 5. Mean percentage correct in Experiment 2 for the Discrimination task (left) and Memory task (right), with task tested between subjects ($N = 20$/task). Error bars show ± 1 SEM.

a pair of houses until response. One of the pair was identical to the house that they had seen previously, and one was changed in one of the four ways described above.

For the memory task, in the first learning phase, participants were shown each house for 5 s and asked to indicate how much they would like to live there from 1 ("not at all") to 5 ("would like to a lot"). In the second learning phase, which followed immediately, participants were shown the same four houses for 5 s each and asked to indicate how many people could live there (from 1–5). Thus, participants saw each house for a total of 10 s. They were told before each learning phase that they should look at the whole house and try to remember the houses for a later memory test. In the test phase, participants were presented with pairs of houses, one of which was identical to the house that they had learned and one of which was changed in one of the four ways (participants were not told what kinds of changes could occur). In each phase, a fixation cross was shown between trials, until participants pressed the space bar. Participants were given approximately a 1-min filled break between each of the 16 blocks. The breaks were filled with a variety of visual screening tasks, and a questionnaire about navigation. Before all the house blocks, there was a practice task in which participants were asked to rate pictures of bedrooms for how much they would like to sleep there. This was simply to give them practice using the rating scale.

For both memory and discrimination tasks, stimuli were presented with PsyScope X (Cohen, MacWhinney, Flatt, & Provost, 1993; http://psy.ck.sissa.it/) on a Sony Trinitron CRT monitor with a resolution of 1024 × 768, connected to a Mac-mini running OSX.

Results and discussion

For each participant, we calculated the percent correct for each condition: feature, spacing, non-structural and control. Note again that memory and discrimination were tested between-subjects. As expected, people did very well on the control condition in which the two houses were completely different (memory: 87%-100%, with most participants scoring 100%; discrimination: one person 93.75%, the rest 100%). As can be seen from Figure 5, in the other conditions, participants generally found the houses quite difficult to discriminate (left panel) or to remember accurately (right panel), even with two learning phases. For discrimination, participants were best at feature changes. However, for memory they were best at changes to things like pot-plants and garbage bins (non-structural changes) and worst at remembering the location of features (i.e., changes in spacing). We note that although relative performance for spacing and feature trials will depend on the exact stimuli used in each condition, identical stimuli were presented in the discrimination and memory tasks of the current experiment, allowing comparisons in the overall pattern of results. There were no effects of sex, *p*s > .11, and so scores were collapsed across males and females in subsequent analysis.

A 3 (house condition) x 2 (task) mixed ANOVA showed a main effect of house condition, $F(2, 76) = 6.17$, $p = .003$, $\eta^2_p = .140$ (feature = 67.4%, spacing = 58.5%, non-structural = 66.7%), but no effect of task, $F(1, 38) = 0.004$, $p = .95$, $\eta^2_p = .00$, and no interaction, $F(2, 76) = 2.58$, $p = .082$, $\eta^2_p = .064$. Although the interaction was not significant, in order to answer our a priori questions, we conducted follow-ups comparing the different house conditions for each task. Follow-up ANOVAs confirmed significant effects of house condition for both discrimination, $F(2, 38) = 4.70$, $p = .015$, $\eta^2_p = .198$, and for memory, $F(2, 38) = 4.09$, $p = .025$, $\eta^2_p = .177$.

For discrimination, t-tests showed a significant difference between spacing and feature changes, $t(19) = 3.40$, $p = .003$, Cohen's d = 0.77, as well as a marginal difference between feature and non-structural changes, $t(19) = 2.10$, $p = .049$, Cohen's d = 0.48, but no difference between spacing and non-structural changes, $t(19) = 0.99$, $p = .334$, Cohen's d = 0.23[4] . Participants were above chance in all three conditions: feature, $t(19) = 9.6$, $p < .001$, Cohen's d = 2.15; spacing, $t(19) = 2.66$, $p = .016$, Cohen's d = 0.59; and non-structural changes, $t(19) = 3.70$, $p = .002$, Cohen's d = 0.83. The worse discrimination for spacing than feature changes replicates the results for Experiment 1.

For memory, t-tests showed no significant difference between spacing and feature changes, $t(19) = 1.76$, $p = .095$, Cohen's d = 0.39, or feature and non-structural changes, $t(19) = 1.37$, $p = .187$, Cohen's *d* = 0.31. However, there was a significant difference between spacing and non-structural changes, $t(19) = 2.52$, $p = .021$, Cohen's d = 0.56[5] . In all cases the means were above chance; feature, $t(19) = 4.67$, $p < .001$, Cohen's d = 1.04, spacing, $t(19) = 2.98$, $p = .008$, Cohen's d = 0.67, non-structural changes, $t(19) = 5.98$, $p < .001$, Cohen's d = 1.34. Thus, the longer learning phase compared to Experiment 1 and explicit memory task (unlike the "surprise" memory task of Experiment 1) allowed participants to be above chance at remembering even the location (spacing) of features. As discrimination and memory were between participants, it did not make sense to correlate the two; however it is still of interest to compare spacing and feature performance on each task. For the discrimination task, there was a small, non-significant correlation, $r = .255$, $p =$

4 Note that these are *a priori*, and hence uncorrected, tests but the pattern of results is the same for a corrected alpha of .017: spacing vs. feature is significant, feature vs. non-structural is non-significant, and spacing vs. non-structural is non-significant.

5 Non-significant for a corrected alpha of 0.17.

.277. For the memory task, there was an even smaller relationship, $r = .175$, $p = .460$.

Overall, the results for this experiment are broadly consistent with those of Experiment 1 in that discrimination and memory for spacing changes in houses tended to be worse than discrimination or memory for feature changes. However, in this experiment, the difference between spacing and feature changes was not significant for memory, and memory for spacing changes was above chance. Thus, with enough practice and in anticipation of a memory task, adults can remember the location of features, such as the positions of the windows and door. In the General Discussion, we consider possible reasons for the different results across the two experiments.

Interestingly, memory was best for the kind of change which would be most likely to occur regularly for houses such as changes to potted plants and whether garbage bins are visible (those we labelled non-structural changes). Despite their prevalence, such cues are changeable and hence unreliable cues to the *identity* of houses, much like hairstyle for facial identity. Nevertheless, like our results here, hairstyle, although not reliable, is a commonly used cue for unfamiliar faces (e.g., Ellis et al., 1979). Discrimination, however, was poor for non-structural changes, and instead was best for changes to the shape of doors and windows. Here, unlike in Experiment 1, the same foils/distractors were used for the memory and discrimination tasks, and hence, the results suggest that there may be a relationship between the features used in discrimination and memory for houses. There was little to no relationship between performance on the spacing and feature trials for either task although, with only twenty participants, these results should be interpreted with caution.

General discussion

The current study is the first to compare discrimination ability with memory for houses, which are a popular comparison stimulus for faces. Our aim was to compare the pattern of results for discriminating and remembering spacing and feature changes in houses to those previously found for faces. In both Experiments 1 and 2, adults were good at *discriminating* houses that differed in features such as windows and doors, and accuracy in *remembering* the houses based on feature cues was nearly as good as discrimination performance (89.2% versus 95.8% in Experiment 1; 61.4% versus 70.4% in Experiment 2). Discrimination between houses that differed only in spacing between features was generally poorer than discrimination for features, even though we attempted to match these in Experiment 1. Memory for spacing between features was poor overall, although it did exceed chance in Experiment 2 when additional learning trials were given and the memory test was explicit. Memory for spacing changes correlated weakly with discrimination accuracy for spacing changes in Experiment 1, despite discrimination accuracy being quite high and mean memory accuracy being at chance. Thus, our results suggest there may be a relationship between discrimination and memory ability for spacing changes in non-face objects.

The current results are consistent with the findings for faces reported by Rotshtein et al. (2007), namely that discrimination accuracy for spacing changes in faces is related to memory for both familiar and famous faces. We were not able to test directly whether there was a relationship between discrimination and memory for feature changes, as participants were at ceiling on the latter in Experiment 1 and because memory and discrimination were run between subjects in Experiment 2. However, in Experiment 2, where identical stimuli were shown for discrimination and memory tasks, the relative pattern of performance for feature and spacing changes was basically the same for discrimination and memory tasks (though not significant for the latter), suggesting that the processing of these cues for discrimination and memory are similar.

Memory was best for the kind of small changes that we might often see in a familiar neighbourhood, such as a potted plant in the front yard, but which would be related to the habits of those living in a house rather than to a permanent cue to the identity of the house or location. Such changes to a familiar house are encountered more often than changes to the shape of a house's door or windows or their position, and may communicate information about the occupants of the house (e.g., away for the summer, negligent about home maintenance). It is interesting that memory for this condition was better than discrimination, and of course, the between subjects design means that some caution is needed in interpretation. It is possible that, because the changes were quite difficult to detect, the encoding was more effortful, and hence led to better overall memory. Consistent with our finding of better memory for small items within the picture than for distances between windows, adults can remember objects in indoor-scenes but not the relative distance between them (Tatler, Gilchrist, & Land, 2005). Interestingly, O'Donnell and Bruce (2001) showed that changes to hairstyle were more easily detected than changes to eyes, mouth, or chin in unfamiliar faces. For familiar faces, changes to hairstyle and eyes were both detected easily (see also Ellis et al., 1979). We would argue that such hairstyle changes are similar to those in our "non-structural" task, in that they may be relatively frequent and communicate something about the person, but by their very nature are not a stable identity cue. Thus, we have shown a new similarity between cues used for unfamiliar faces and houses, which in neither case is a reliable cue.

An important issue in studies such as this one is equating difficulty between houses and faces, or between feature and spacing changes, and whether this is an appropriate thing to do. In the current Experiment 1, feature and spacing stimulus sets were not equated for difficulty, despite our attempt to do so based on pilot work. However, we note that sensitivity to spacing on the discrimination task (81%) was similar both to our previous study for houses (77%; Robbins et al., 2011) and to previous results for faces (78%; Mondloch et al., 2002). Discrimination of feature changes was also similar to previous published results, (96% here; 98%, Robbins et al., 2011; 89% for faces in Mondloch et al., 2002). Importantly, although performance for feature and spacing in the discrimination task of the current experiment differed in Experiment 1, memory for spacing was much worse than for features. In Experiment 2, instead of trying to match performance on the discrimination task, we took the approach of using the same stimuli for the discrimination and memory tasks, so that we could better compare the pattern of results across the two *tasks*. Note that discrimination of both features and spacing was lower in Experiment 2, probably because the base house varied and conditions were intermixed, making the task harder but more like real-life.

Overall our results suggest that, as for faces varying within the normal range (e.g., Mondloch & Dejarlais, 2010; Rotshtein et al., 2007), discrimination may be easier for feature than for spacing changes. The evidence on whether memory is better for features or their location in faces is inconsistent, but may depend on methodological differences such as whether the learning time for spacing was increased (Leder & Bruce, 2000) or the discriminability of the two types of changes was equated (Rhodes, Brake, & Atkinson, 1993), again making it difficult to draw conclusions on the relative performance for feature versus spacing changes. Several studies have compared discrimination for feature and spacing changes in faces and houses. Tanaka, Kaiser, Hagen, and Pierce (2014) matched feature and spacing difficulty for both houses and for faces, which made some of the stimuli outside of normal limits. They did not also match difficulty between faces and houses, and in their task discrimination was better for faces than houses. Tanaka et al. (2014) were interested in inversion effects (as were Leder & Bruce, 2000). They found larger inversion effects (much worse performance upside down) for mouths than eyes for faces, but no region differences for houses. Yovel and Kanwisher (2008) matched upright performance on spacing and feature changes in both faces and houses (i.e., all four sets). Again their interest was in inversion effects, and they showed larger inversion effects for faces than for houses, with the largest being for feature changes. However, as previously noted, matching across all conditions meant that the spacing changes in faces, in particular, were outside the normal range.

While there are advantages to matching stimulus sets for later comparisons, it could also be argued that such matching removes any underlying differences in the tasks, as related to real-world variability in the stimuli. In the current study, we found better performance for feature than spacing changes, in both discrimination and memory, for two quite different sets of stimuli. In the only study to compare directly memory for spacing changes and feature changes in houses and faces, Leder and Carbon (2006) found that memory for spacing changes in schematic drawings of faces was worse than memory for feature changes. They found the same effect for houses, and in fact, this difference was larger for houses than faces, consistent with the difference that we found here in both experiments.

The similarities in results between previous studies of faces and our results for houses suggest that there may be a domain-general process for detecting spacing differences, in addition to a process tuned to upright human faces. Spacing detection may be possible for non-face objects but may be poorer than other cues to recognition, perhaps because it is generally less useful in non-face objects than in faces. The conclusion of a domain-general component is consistent with previous findings that the developmental trajectory for discriminating changes in spacing in monkey faces and houses is similar to that found previously for faces, at least from age 8 onwards

(Robbins et al., 2011), and that in adults, there is a significant relationship between ability to discriminate spacing in faces and houses (Mondloch & Dejarlais, 2010). Quinn, Tanaka, Lee, Pascalis, and Slater (2013) claim that the ability to discriminate spacing is domain general from as early as 3 months, with similar results for houses as they had previously found for faces. However, the consistent finding of poorer discrimination of spacing changes in inverted than in upright faces (e.g., Mondloch et al., 2002; Rhodes et al., 1993; see McKone & Yovel, 2009 for review) and the finding that the ability to discriminate spacing changes in houses and in monkey faces is preserved in patients treated for bilateral congenital cataracts, despite a deficit in discriminating spacing changes in human faces (Robbins et al., 2010), shows that there is also a face-specific component to detecting spacing changes in faces. Overall, we suggest, as we have previously (Robbins et al., 2010; Robbins et al., 2011), that there are both domain-specific and domain general mechanisms involved in face discrimination and memory.

In conclusion, we have shown that for houses, as for faces, discrimination and memory are generally better for changes to features than changes to spacing between features, keeping in mind caveats for comparing stimulus manipulations. We have shown, for the first time, that information about spacing between features is encoded in memory for houses as it is for faces, a parallel supporting some domain-general mechanism. We also found that memory was best for small changes, not relating to the form of the house, but which might be useful in real-life for knowing things like whether the people who live in a familiar house are home, and which resemble hairstyle changes in faces. Finally, we have shown that the pattern of results for discrimination and memory for changes in houses is related, consistent with shared underlying processes between the two.

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