The effect of familiarity in fusiform face area and parahippocampal place area

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Abstract

Studies have found that we might have category-specific perceptual systems for faces and places. By presenting a participant with images of faces and houses, we found fMRI BOLD response in FFA for faces and in PPA for houses. Looking for repetition suppression in these areas we tested for an effect of "familiarity" with the stimuli.

Keywords:
fMRI
FFA
PPA
Repetition suppression
Familiarity

Introduction

Is face recognition "special"? This is a question that many researchers have asked themselves (Farah, 1996; Gazzaniga, Ivry, & Mangun, 2014, p. 246). Being able to distinguish individuals as friends or enemies and extract information from a face about age, emotinal state and eye gaze, could have been of great importance for human survival. Hence, this value of face recognition is assumed to have led to the evolution of a special system for the perception of faces (Friedenberg & Silverman, 2006, p. 181; Gazzaniga et al., 2014, p. 246).

Extending the idea that evolutionary pressure has caused a category-specific system for faces, it has been argued that *places* are likewise of a significant importance for visual perception (Epstein & Kanwisher, 1998; Gazzaniga et al., 2014, p. 258).

To investigate, if these evolutionary hypotheses are worth further attention, a wide range of empirical tests have been carried out (Gazzaniga et al., 2014, p. 246). We will consider evidence from single cell recordings, neuropsychology and fMRI studies. Lastly, we will review the idea of repetition suppression in fMRI.

Faces and Places – Single cell recordings and neuropsychology

Studies, using single cell recordings in monkeys, have found that cells in an area of the monkey's inferotemporal cortex, fire selectively to faces (Baylis, Rolls, & Leonard, 1985; Desimone, 1991).

In human neuropsychology, there has been reports of patients with "Prosopagnosia", an impairment involved with the ability to recognize faces (Farah, 1996; Friedenberg & Silverman, 2006, p. 181). Additionally, there has been reports of patients with lesions in the parahippocampal gyrus, who are unable to use landmarks, such as buildings for navigating. This type of agnosia is referred to as "Landmark agnosia" (Aguirre, Zarahn, & D'esposito, 1998; Takahashi & Kawamura, 2002)

Fusiform Face Area (FFA) and Parahippocampal Place Area (PPA) – fMRI

Via functional brain imaging it is possible to investigate these proposed specialized regions for face- and place recognition in humans with a relatively good special resolution (Barron, Garvert, & Behrens, 2016).

Using fMRI, Kanwisher, McDermott, & Chun (1997) found that a specific region within the fusiform gyrus showed an extra strong response to face stimuli. Further studies have confirmed these findings, and the region has been functionally defined as the "Fusiform Face Area" (FFA) (Gazzaniga et al., 2014, p. 249).

Russel Epstein and Nancy Kanwisher (1998) found that the BOLD signal in one region of the parahippocampus was extra strong when viewing pictures of scenes such as landscapes and stronger for buildings and landmarks than common objects. Subsequent studies found the same area responding strongly to stimuli of a place-like character and the area has been named "Parahippocampal Place Area" (PPA) (Gazzaniga et al., 2014, p. 258).

Extending on the study by Epstein et al., it was investigated what the function of PPA might be. A decrease in BOLD fMRI signal in PPA was found between a novel place-stimulus and the repetition of this image (Epstein, Harris, Stanley, & Kanwisher, 1999). A phenomenon referred to as repetition suppression (Grill-Spector, Henson, & Martin, 2006), which will be further explained in next section. In contrast, when repeating stimuli of places already familiar to the participant, no such decrease was found. It was argued that these findings, explicitly explained that PPA is more involved with encoding of novel places than with the recognition of familiar places (Epstein et al., 1999).

Repetition suppression (RS)

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The reduction of neural activity when a stimulus is repeated, has been widely studied on multiple spatial levels (Grill-Spector et al., 2006). Stimulus specific repetition suppression (RS) on neural level, measured using single cell recordings in monkeys, has been found to be a highly robust phenomenon (Desimone, 1996; Grill-Spector et al., 2006). The neurocomputational mechanisms behind this effect are controversial though (Grill-Spector et al., 2006).

Some researchers argue that repeating a stimulus will result in a sparser neural representation of that stimulus, referred to as the *sharpening model* (Desimone, 1996; Wiggs & Martin, 1998). This idea considers RS as an automatic, "bottom up" effect and as the neural correlation of the behavioural phenomenon "priming" (Desimone, 1996; Wiggs & Martin, 1998).

It has been suggested that a parallel to RS on neural level can be drawn to the decrease in the haemodynamic response to a repeated stimulus in fMRI (Grill-Spector et al., 2006; R. N. Henson, 2016).

RS in fMRI studies is anticipated to be specifically useful as a mean to tell more about functional properties of cortical neurons (Malach, 2012). As was the aim in the described by Epstein and colleagues (1999). This can be done by repeating a specific stimulus to find a baseline of RS, then changing the stimulus on one dimension for a subsequent comparison with the baseline (Grill-Spector et al., 2006).

In our fMRI study, we wanted to test if we could find an effect of RS for faces and houses as the participant get more familiar with the stimuli across repetitions. We furthermore tested the hypothesize that the house-stimuli would cause activation in PPA and face-stimuli would show activation in FFA.

Materials and Methods

Participant

One participant took part in the fMRI experiment. The participant was a 22-year old Danish male (right handed) recruited at Cognitive Science at Aarhus University.

Stimuli

The stimuli consisted of 24 different images of animated faces and 24 different images of animated houses. The faces were divided into an equal amount of young and old and males and females.

The stimuli (Figure 1 and Figure 2) were created by the researchers using the pc game “Sims 4”. Using this game platform made it possible to create images with approximately the same graphics and light intensity. All images were presented in an oval shape on a black background in a 361 x 433-pixel format.

Figure 1: Example of face stimulus

Figure 2: Example of house stimulus

This allowed for an unfamiliarity condition where all stimuli were novel to the participant and a familiarity condition consisting of a repetition of the images from the unfamiliarity condition. This way, the design contrasted with other experiments where the effect of showing novel stimuli is compared to showing stimuli that the participant would know beforehand, e.g. famous people and places (R. N. Henson, 2016). By using the same images in both conditions, the only variable that changes when the effect of familiarity is measured, is that the stimuli has been shown before meaning that every other variable is controlled.

Given that confounding variables have already been reduced, a choice was made to present the stimuli in colour – as opposed to the more controlled black and white – since it simulates real-life perception of faces and houses more closely. At the same time, it ensures that the faces and houses have recognisable features and consequently that the targeted effect is not eliminated through an excessive attempt to control the experiment.

Procedure

In the beginning of the experimental paradigm, the participant was presented with instructions on the paradigm and the behavioral task visually on the screen implemented in the scanner.

The fMRI scanner used in this experiment was a Siemens Trio 3 Tesla with an interscan interval of 2 seconds.

The experiment consisted of 48 images – divided in 24 houses and 24 faces. Each image was repeated 3 times, giving a total of 144 trials. The presentation of initial and repeated faces and houses

was randomized across trials, so the participant did not know if the next stimulus would be a house or a face and whether it would be a repeat or a novel image.

The images were shown for 700 ms, separated by a fixation cross of random duration (ranging from 2.05 seconds to 6.15 seconds with an overall meantime of 4.1 seconds) to make the time interval less predictable for the participant. The experiment lasted for 12 minutes which is referred to as one session. To get more data, the participant did the experiment twice. Furthermore, he participated in another independent experiment between the two sessions. Thus, this report contains data from one participant with six repetitions of every house and face stimuli over time to investigate the effect of familiarity. The experiment was event-related and had a two by six repeated measures factorial design.

Analysis of behavioural data

During the experiment the participant performed a behavioural task having to press a button with his index finger whenever he saw a house and with his middle finger whenever he saw a face. This task primarily served to verify that the participant had been attentive throughout the entire experiment, however the reaction times were also recorded.

For both types of stimuli, an analysis showed that there was only a minor variation in the reaction times across the repetitions (Figure 3).

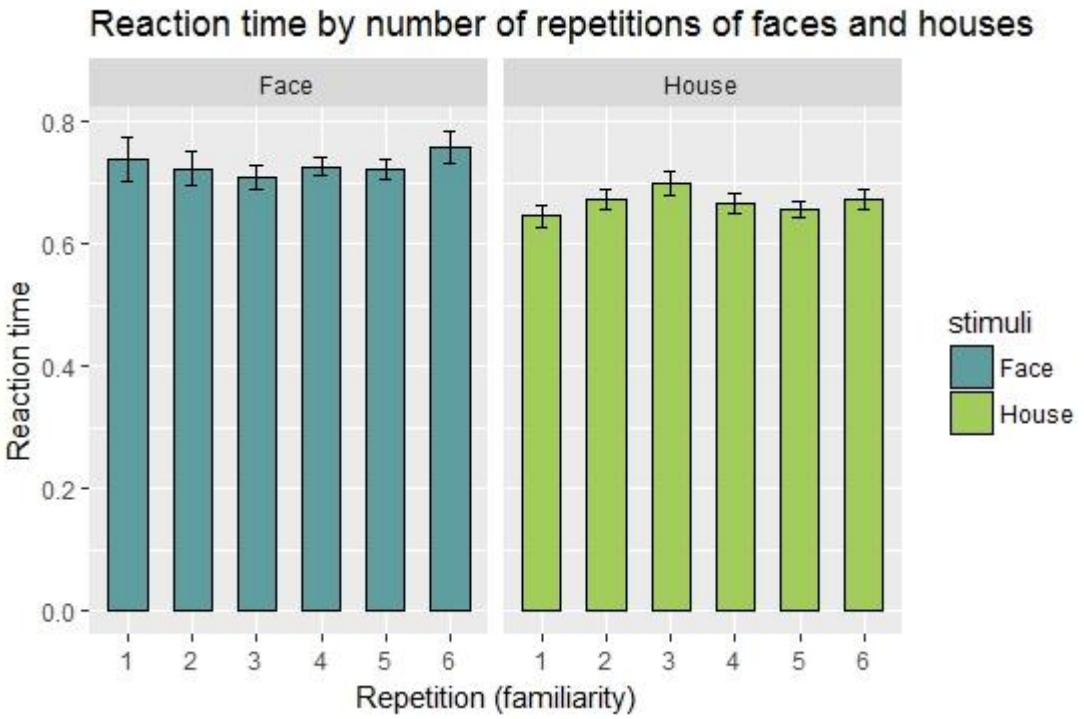

Figure 3: Reaction times across conditions and repetitions

However, the reaction times for the house stimuli were significantly lower than for the face stimuli, $t(248.77) = 5.00$, $p < .05$, but this difference can most likely be ascribed to the fact that the participant responded using his index finger in the house trials facilitating a systematic difference in reaction time (Goodman, Franks, & Wilberg, 1985, p. 165). On average, the participant answered correctly on 98% of the trials.

Analysis of fMRI-data in SPM

Preprocessing of the scanning data from the two sessions of the experiments was carried out using SPM12 in Matlab. All the functional scan images were realigned, resliced, co-registered with the structural image, segmented, normalized and smoothed using an 888 Gaussian kernel.

To analyze the data, we set up several contrasts to discover any effects of the face and house stimuli as well as the familiarity hypothesis. Hence the following t-contrasts were performed; all house stimuli alone, all face stimuli alone, face stimuli minus house stimuli, house stimuli minus face stimuli and the following f-contrasts; the effect of only the house stimuli over time and the effect of only face stimuli over time. Furthermore, we performed a contrast to explore the familiarity hypothesis within only the first session, hence analyzing this part as a two by three factorial design.

MNI-coordinates

The t-contrasts showed the areas that differed for face stimuli and house stimuli respectively. To ensure that the BOLD-activation was in the FFA and PPA, we compared our MNI coordinates to coordinates found in previous studies with more participants.

Axelrod & Yovel (2015) placed the FFA at MNI-coordinates: left: (-41, -53, -18) and right: (39, -52, -16) by averaging over 13 participants.

For our participant, the activation was significant in MNI coordinates (-42, -61, -22), which we conclude to be the FFA, as all brains are anatomically different and it is close to the average coordinates.

Park & Chun (2009) placed the PPA at MNI-coordinates: left: (-27, –46, –15) and right: (30, -44, -14) by averaging over 10 participants. For our participant, the activation was significant in MNI coordinates (-27, -49, -7), which we conclude to be the PPA for the reasons mentioned above.

Results

Activation in FFA and PPA (hypothesis 1):

A main effect of seeing faces elicited increased BOLD-activation in the FFA (MNI coordinates -42, -61, -22) doing a family wise error corrected analysis, $t(1, 684) = 4.89$, $p < 0.05$.

For illustrational purposes the following figure shows the uncorrected effect:

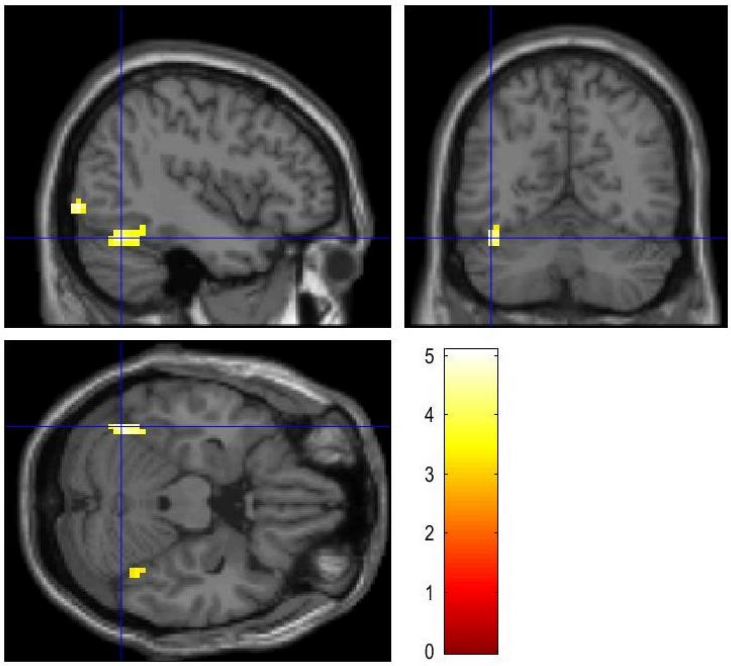

Figure 4: BOLD-signal in FFA with face stimuli

A main effect of seeing houses elicited increased BOLD-activation in the PPA (MNI coordinates -27, -49, -7) doing a family wise error corrected analysis, $t(1, 684) = 7.18$, $p < 0.05$.

For illustrational purposes the following figure shows the uncorrected effect:

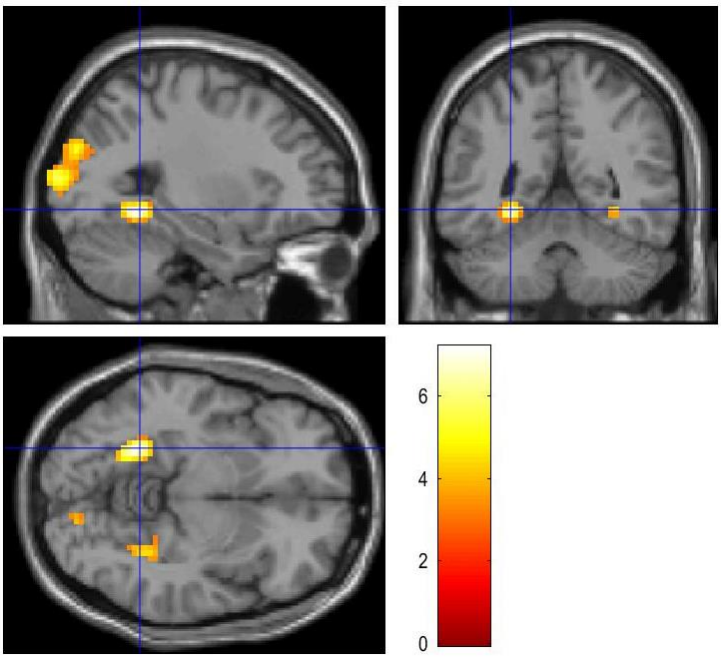

Figure 5: BOLD-signal in PPA with house stimuli

Effect of repetition (hypothesis 2):

A contrast of the fMRI signal difference between the 1st and 2nd, 2nd and 3rd, 3rd and 4th, 4th and 5th and 5th and 6th repetition of stimuli showed no significant effect of repetition in either condition (faces or houses).

The following two plots show the BOLD-signal development in the FFA and PPA respectively. The error bars are thus showing the 90% confidence interval for the signal strength and not the contrast between repetitions. This is to illustrate the nonsignificant development in signal strength over repetitions.

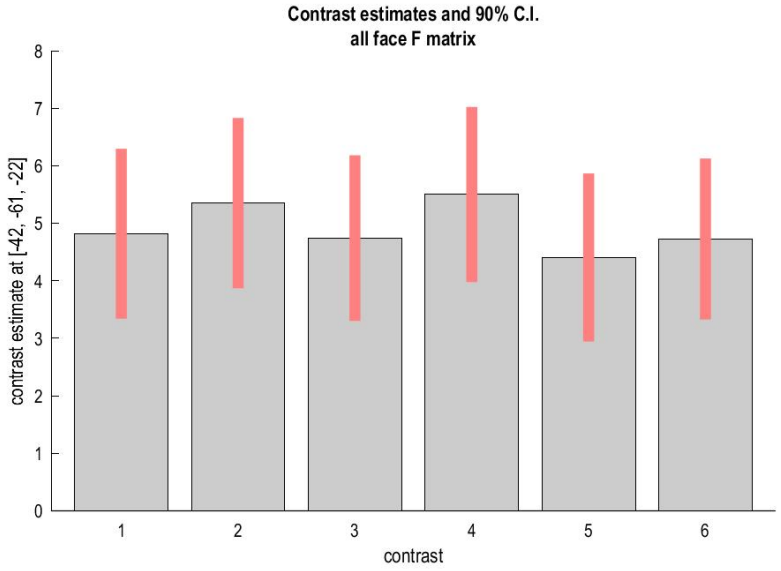

Figure 6: BOLD-signal in FFA across repetitions

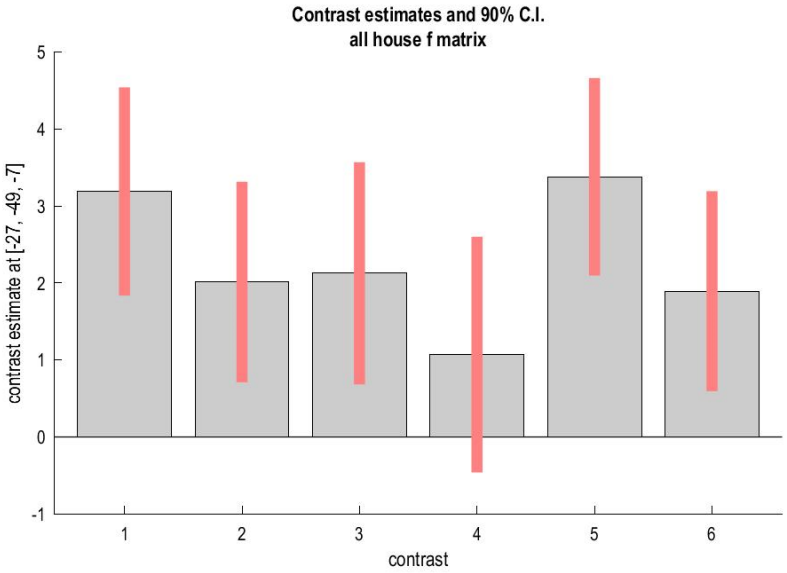

Figure 7: BOLD-signal in PPA across repetitions

As it can be problematic to compare over two sessions due to the difference in signal strength, we have also done the analysis of the effect of time within the two sessions separately (first 3 repetitions only and last 3 repetitions only). This contrast did not show a significant effect of repetition in either condition or session either.

Discussion

This study investigated the activation in the brain areas FFA and PPA and an effect of RS for face- and place stimuli in the corresponding brain areas.

The findings showed significant activation in FFA for face-stimuli and PPA for house-stimuli. We did not find a decrease in activation in FFA and PPA upon repetitions of the stimuli.

Method evaluation

The stimuli used in this fMRI paradigm was of the same size and approximately same colour intensity. Furthermore, the participant answered accurately 98% of the time in his behavioural task. Thus, we expect that differentiated attention, or no attention towards the stimuli at all, were not significant confounds in this experiment.

There was an independent experiment running between the two sessions of our paradigm. In some studies, it has been found that too much intervening stimuli between repetitions disturbs the effect of RS (Barron et al., 2016), which could have been the case in our study. Additionally, the number of repetitions seem to effect RS. Epstein and colleagues found that there was no effect of RS in PPA within the first 5 repetitions (1999), indicating that more than 6 repetitions might have been a better choice for our paradigm. More importantly, we would need data from more participants to be able to generalize the findings.

Considering that fMRI RS has been tied to the robust phenomenon of RS in single cell recordings, it should be considered, if a direct comparison of the two is justifiable (Barron et al., 2016).

Neural RS has been found to occur very rapidly after a repeated stimulus (R. Henson, Shallice, & Dolan, 2000). The method of fMRI is dependent on hemodynamic changes integrating over seconds (Gazzaniga et al., 2014, p. 110), this poor temporal resolution results in an uncertainty of the degree of activation right after the stimulus representation. If we are to comprehensively use RS in fMRI studies, it would be relevant to establish a better understanding of the neural mechanisms behind the phenomenon (Grill-Spector et al., 2006). Is it for instance sufficient to describe RS as an automatic, priming-like phenomenon, as is the idea behind the sharpening model?

FFA and PPA

Even though a BOLD response was found in FFA and PPA for faces and houses respectively, this does not conclude the causation that the areas are selectively handling face- and place-stimuli. Neither does the results tell us about the specific function of the areas. It has been suggested that the function of FFA has to do with the level of expertise towards a stimulus, rather than faces specifically (Gazzaniga et al., 2014, p. 252). Hence, another reason why it can be that faces cause activation in FFA, can be ascribed to the effect of humans being experts in face-perception.

Evolutional hypotheses suggest that there is something special about the recognition of faces and places. Evidence from neuropsychology, single cell recordings and fMRI studies supplement the hypotheses. The exact neuronal function of PPA and FFA remains a topic for further investigation.

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