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Title: Comparing Face and Object Processing in Perception and Recognition

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Highlights:

- Face processing is different from object processing.
- This difference may be present in various levels of processing but in distinct ways.
- The distinctions in amplitude, onset, and peak latency were examined in this study.

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Abstract

Faces can be speedily processed, although they convey an immense amount of information. Hence, in psychophysiological experiments, human faces constitute very special stimuli! Numerous studies have investigated the electrophysiological correlates of face processing, showing the existence of multiple event-related components. Nevertheless, dissimilarities in various levels of processing are still controversial. In this present study, we used magnetoencephalography (MEG) to examine how facial processing is different in perception and recognition from object processing and also determined 95% confidence interval for the onset and peak time of the effects we found. Our results confirm the face-selectivity for the M170 component, but not always for the M100 component. Additionally, we observed a unique speed pattern for the M170 component in perception and recognition both at the onset and the peak time.

Keywords: Face processing, magnetoencephalography, event-related field

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Introduction

The face is a special dominant stimulus! There are a variety of reasons behind this fact including quick speed of processing, conveying an immense amount of information at a glance, and its extensive familiarity to human being (Rossion 2014).

To study how the brain activities change when confronted with face stimuli, there is an ample number of ways. One of the most prevalent approaches in studying brain functions is using event-related activities. Event-related activity is a powerful measurement to inspect time-locked events (Rossion 2014, Besson, Barragan-Jason et al. 2017). To record event-related activities, a well-accepted modality is magnetoencephalography (MEG). MEG has high temporal resolution and an acceptable spatial resolution which provides us the opportunity to track momentary changes in brain dynamic (Singh 2014).

Inspecting the electrophysiological correlates of facial processing, multiple studies have found a face-selective component around 170ms after stimulus onset (for a review see Yovel 2016). This component is known as M170 for faces. Beside from faces, in visual inspection of objects, a negative event-related component known as N1 (M1 in MEG) occurs with similar latency to M170 (Rossion and Caharel 2011). However, in comparison to N1, the M170 component has a larger peak and most conspicuous over the occipitotemporal parts of the human brain (Rossion and Jacques 2008).. The M170 component is believed to represent the early structural encoding of faces (Bentin and Deouell 2000, Eimer 2000) and sometimes even containing some information about the identity (Jacques and Rossion 2006, Vizioli, Rousselet et al. 2010).

An earlier component peaks about 100ms after the starting time of stimulus presentation and is called M100 or P1 (Linkenkaer-Hansen, Palva et al. 1998, Rivolta, Palermo et al. 2012). The M100 component reflects low-level properties in visual stimuli including features like the luminance and the size (Negrini, Brkić et al. 2017) and it is also an important attentional component (Luck, Heinze et al. 1990, Mangun and

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Hillyard 1995). The M100 component is sometimes considered as a face-selective component and some studies have reported a larger M100 peak in response to face stimuli in comparison to objects (Goffaux, Gauthier et al. 2003, Itier and Taylor 2004, Itier and Taylor 2004). Contrary to this, some studies have stated that the M100 is not a face-selective component (Boutsen, Humphreys et al. 2006).

Although previous studies have shed light on the importance of the M100 and M170 component in the context of the face as well as to object processing, the existence of significant effects in these components during different levels of facial processing as well as the onset and peak time of these components are still controversial. The onset time of an effect is important because it determined the speed at which the distinction between various stimulus pairs takes place in the human brain. Additionally, the time point at which the maximum difference between the two conditions happens clarifies the maximum separability between those conditions. In the present study, we examined the M100 and M170 components in perception and recognition levels of facial and object processing. Additionally, we did not confine facial processing to human face stimuli, but also extended it to another species face stimuli and sought for the probable difference in any of the mentioned processing levels.

Materials and Methods

Participants

In our study, twenty-two healthy individuals with an average age of 24 ± 5 years old participated. Participants included 21 males and 20 right-handed. Written informed consent was acquired from all individuals. All procedures were in agreement with the Code of Ethics of the World Medical Association (Declaration of Helsinki) and approved by the Oxford Research Ethics Committee B (Ref. 07/H0605/124).

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Experimental procedure and Data Acquisition

Images were static and grey-scale acquired from FERET open-source database (Phillips, Wechsler et al. 1998). Each image was displayed for 200 ms. All images were standardized for size (subtended 8x6 degree at the eye) and luminosity (42 ± 8 cd/m²). The images were projected onto a screen placed 90 cm in front of participants' eyes while they sat under the MEG helmet. Three different types of stimuli were recruited in the present study, including the human face, monkey face, and motorbike. We presented two images of the same type in sequential order during each trial. The beginning time of the presentation for the second image was after a delay of 1.2 ± 0.3 s, pursuing the first displayed image. Subjects had to decide about the equality of the second image with the first one in a response window of 1 second. In other words, our task contained a perception level in the first presented stimulus and a recognition level in the second presented stimulus per trial. The two presented images in each trial were always from the same type and were displayed in random. We included 48 trials per category in half of which the first image was repeated as the second image and in the other half not.

While the subjects were doing the task, the neuromagnetic responses were recorded with the VectorViewTM MEG system of the Brain Research Group at the Oxford Centre for Human Brain Activity. During the recording, the sampling frequency was set to 1000 Hz (0.03 – 330 Hz bandwidth).

Data Preprocessing

The initial preprocessing was performed using the Signal-space separation (SSS) noise reduction method implemented in MEGIN/ Elekta Neuromag Maxfilter (Maxfilter Version 2.2.15, MEGIN, Helsinki) and we used the FieldTrip toolbox for EEG/MEG-analysis (Oostenveld, Fries et al. 2011) for our later analyses. We segmented the data such that each epoch started from 300 ms before stimulus onset and continued to 1000 ms after stimulus onset. To filter the data, we first padded the trials by setting the padding length to 10 seconds. Later, low-pass and then high-pass filters were applied with cutoffs at 0.5 and 150 Hz b-y

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applying a single-pass, zero-phase windowed sinc FIR filter, and Kaiser window setting max passband deviation to 0.001. The number of coefficients were 93 and 3625 for low-pass and high-pass filters respectively. To reduce the heartbeat (ECG) and eye movement (EOG) artifacts, we used independent component analysis (ICA) and removed the contaminated components.

Data processing and Statistical Analyses

Data were processed based on the data in magnetometer channels. This is due to the fact that after applying the SSS correction, information in magnetometer and gradiometer channels is about the same (Garcés, López-Sanz et al. 2017).

We considered various pairs of stimuli to compare face and object processing in perception and recognition. We considered three different categories for faces, i.e. human face, monkey face, and general face (the combination of human and monkey faces) and compared any of these types with motorbike stimuli. We also compared human and monkey face processing. Additionally, we compared the perception and recognition per stimulus type. To compare any pair of conditions, we first normalized the data between that pair per subject and then ran cluster-based permutation on the evoked responses of the two conditions using a dependent-sample permutation two-tail t-test (Maris and Oostenveld 2007) separately for M100 and M170 components. This was done to test whether there is a significant difference between the two conditions in any of these components. We applied the Monte Carlo method for cluster-based permutation and considered the time interval from 80ms to 130ms after stimulus onset for the M100 component and the period from 130ms to 200ms after stimulus onset for the M170 component. Temporal and spatial adjacent samples whose t-values exceeded a critical threshold for an uncorrected p-level of 0.05 were clustered in connected sets. Cluster level statistics were calculated by taking the sum of the t-values within every cluster and then considering the maximum of the cluster-level statistic. The statistical test was corrected for the false alarm rate using a threshold value of 0.05 for the two-tail test.

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We set the number of draws from the permutation distribution to 1000. As we performed the analysis separately for M100 and M170 components, we performed a Bonferroni correction for them, i.e. we accepted the cluster level statistic only if the related p-value was less than 0.025.

To have a more exact approximation for the onset and the peak effect of the effects we found by cluster-based permutation, we used the bootstrapping approach. This was carried out by bootstrapping the participants' samples to determine the 95% confidence interval for the onset and peak latencies of the significant effects revealed by the cluster-based permutation analyses. The overall procedure was based on the approach explained in (Cichy, Pantazis et al. 2014) by creating 100 bootstrapped samples by sampling from the participant with replacement and each time repeating the cluster-based permutation test with the same configurations as the initial level of permutation analyses.

Results

Examining the M100 component in general face perception and comparing it to motorbike perception, we found a significant effect manifested from 81ms to 130ms after stimulus onset (p=0.004). The 95% confidence interval for the beginning time of this effect started from 81ms and ended at 114ms. For the peak of this effect, the 95% confidence interval was from 81ms to 124ms after stimulus onset. There was also a significant effect between faces and motorbikes when considering the M170 component (p=0.002) that emerged from 153ms to 200ms after stimulus presentation. For this effect, 95% confidence intervals for starting and peak time were 149ms to 193ms and from 162.5ms to 198ms, respectively.

Going into more detail by separately comparing human face perception and monkey face perception with motorbike perception, the results were as follows. Focusing on the M100 component when comparing human face vs. motorbike perception, we could not find any significant effect after Bonferroni correction (p=0.026). There was however a significant effect between monkey face and motorbike perception in the M100 component, manifested from 90ms to 125ms after stimulus onset (p=0.018) with the 95%

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confidence interval for the beginning time from 89ms to 130ms and from 89.6ms to 120ms for the peak time. Considering the N170 component, cluster-based permutation revealed a significant difference (p=0.002) between the human face and motorbike perception. This effect was found from 149ms to 181ms after stimulus onset. Bootstrapping showed that 95% confidence interval for the onset time of this effect started from 141ms and continued to 171ms after stimulus onset. These values were from 159ms to 178ms for the peak time of the effect. About monkey face vs. motorbike perception, the significant difference in M170 component appeared from 158ms to 200ms after stimulus onset (p=0.002) with 95% confidence intervals from 156ms to 192ms for the onset and from 176ms to 200ms for the peak time.

There were no significant results in the comparison of M100 between the human face and monkey face perception (p=0.34). However, the difference between the two stimuli was significant in M170 (p=0.002) with the 95% confidence interval from 134ms to 192ms for the beginning time and from 147ms to 200ms for the peak time.

The topoplot for the grand averages difference between the mentioned comparisons in perception is shown in Fig.1 which shows the activation mainly in occipitotemporal channels.

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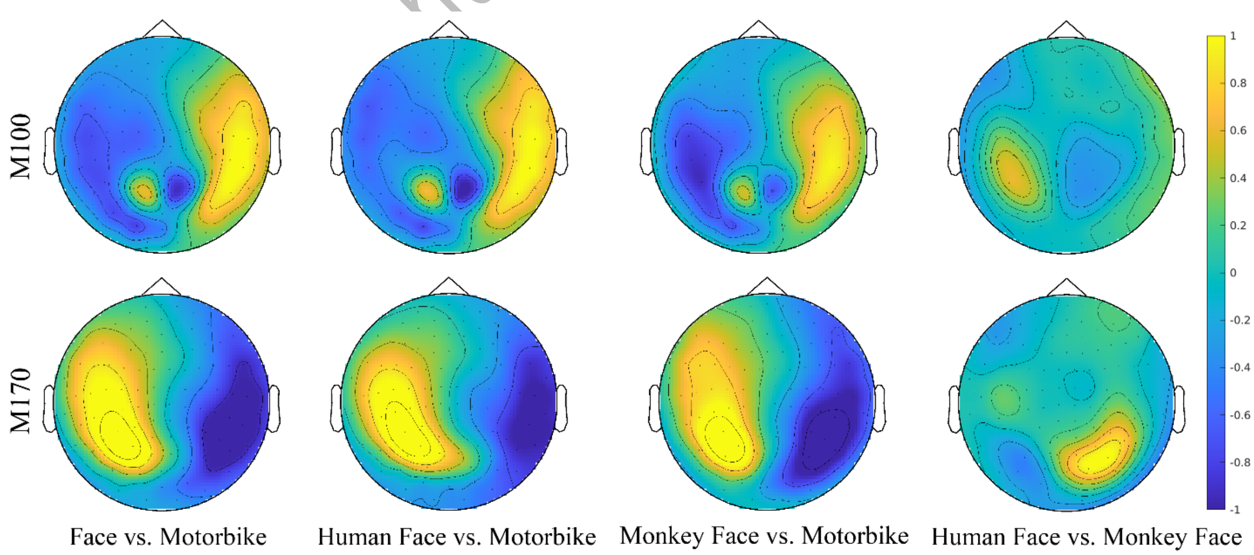

Figure 1. Grand averages difference of stimuli pair in perception for M100 and M170 components

The time-courses for the grand average of the stimuli perception over the occipitotemporal channels are shown in Fig. 2.

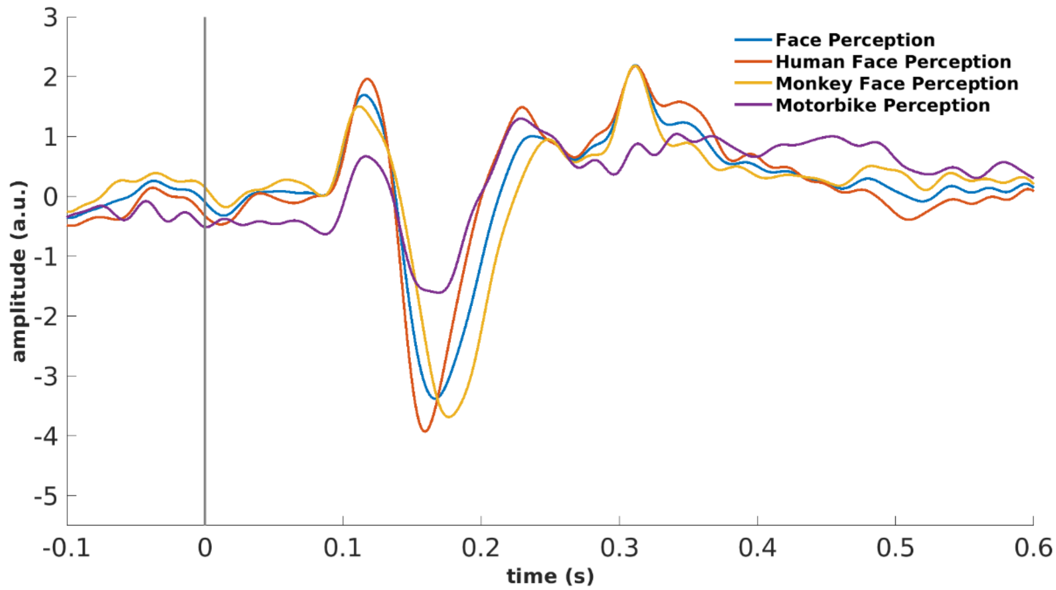

Figure 2. Time courses of various stimuli in perception

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The difference between the stimuli in recognition was significant in most of the cases. Considering general faces and motorbike stimuli, there was a significant difference in M100 (p=0.006) emerging from 93ms to 114ms after stimulus onset with the 95% confidence interval for the onset from 81ms to 109ms and for the peak time from 82ms to 115ms after stimulus onset. The comparison between the two kinds of stimuli was also significant in M170 (p=0.002) and was emerged from 149ms to 200ms after stimulus onset. For the beginning time of this effect, the 95% confidence interval was from 146ms to 192ms, while it was from 155.5ms to 198ms for the peak time.

There was no significant effect when comparing M100 components of human face recognition and motorbike recognition (p= 0.058). However, the difference between the two kinds of stimuli was significant in M170 emerging from 142ms to 180ms after stimulus onset. For this effect, the 95%

confidence interval was from 136ms to 178ms for the beginning time and from 153ms to 178.65ms for the peak time.

The comparison between monkey face vs. motorbike recognition was significant for both M100 (p=0.004) and M170 (p=0.002) components. Regarding the M100, the significant effect was found from 81ms to 117ms with the 95% confidence interval from 81ms to 110ms for the onset and for the peak time from 82ms to 116ms after stimulus onset. Concerning M170, the significant effect emerged from 159ms to 200ms after stimulus onset. The 95% confidence intervals were from 159 to 195 for the onset and from 180 to 199 for the peak time.

Subcategories of face recognition also showed a significant difference in M100 and M170 (p=0.002, for both components). The difference between human face recognition and monkey face recognition in M100 was emerged from 95ms to 130ms and in M170 from 131ms to 200ms after stimulus onset. The 95% confidence interval for the onset of the effect was from 81ms to 125ms and for the peak time from 81.4ms to 130ms in M100. Considering the M170 component, the 95% confidence interval was from 131ms to 190ms for the beginning time and from 143ms to 197.5ms for the peak time.

The topoplots for the difference in recognition are shown in Fig. 3.

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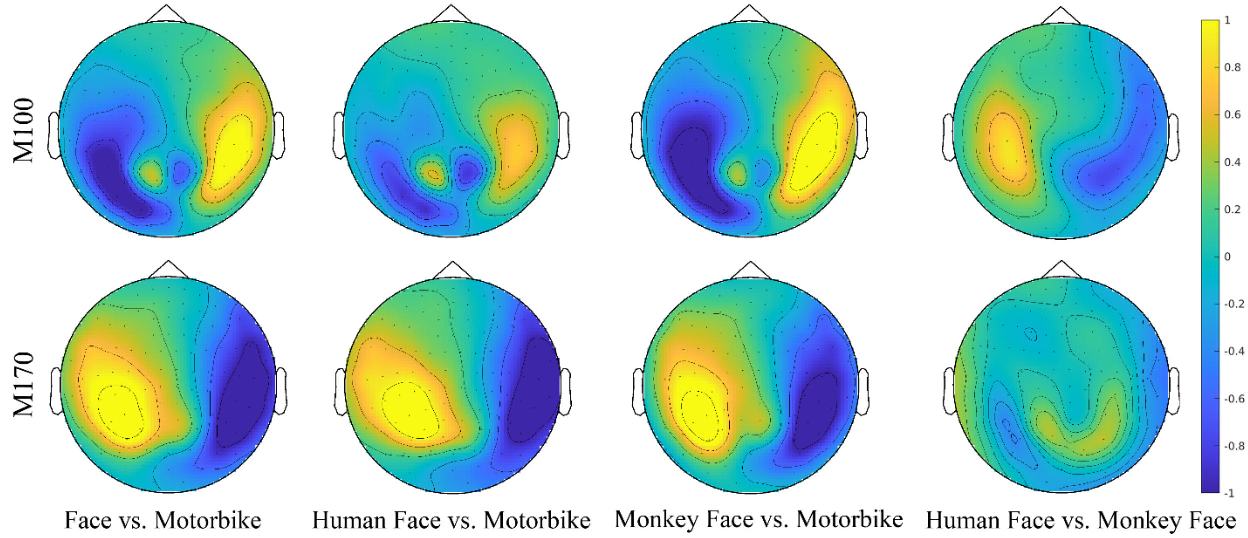

Figure 3. Grand averages difference of stimuli pair in recognition for M100 and M170 components

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Fig. 4 plots the time courses for the grand average of various stimuli types over the occipitotemporal channels in recognition.

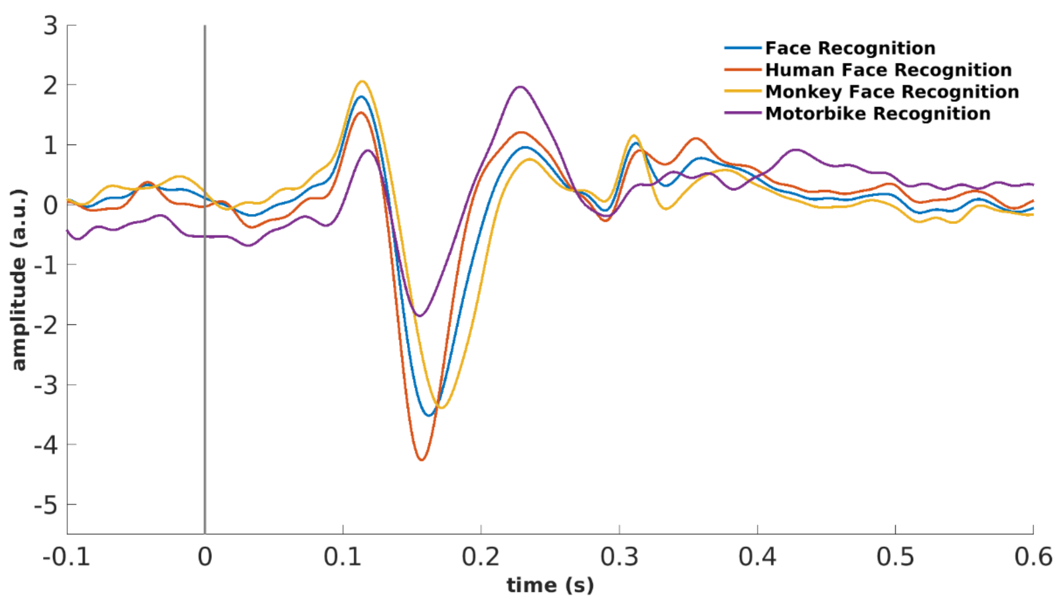

Figure 4. Time courses of various stimuli in recognition

Taking into account the face as a single stimulus type and comparing the perception and recognition, we could not find any significant effect in M100 and M170 components (p= 0.61 and 0.07, respectively).

There was a significant effect in the M100 component (p=0.01) when comparing human face perception with recognition, which appeared from 117ms to 130ms after stimulus onset. The 95% confidence interval for this effect was from 93ms to 129ms for the onset and from 98ms to 130ms for the peak time. There was however no significant effect in M170 between human face perception and recognition after Bonferroni correction (p=0.032).

The comparison between monkey face perception and recognition did not lead to a significant effect in M100 (p=0.31) nor M170 after Bonferroni correction (p=0.026). There was also no significant effect in motorbike perception and recognition in M100 (p=0.47) and M170 (p=0.14) components.

The topoplot in Fig. 5.A shows the difference between grand averages of human face perception and recognition in the M100 component. The time course over occipitotemporal channels for human face perception and recognition is shown in Fig. 5.B.

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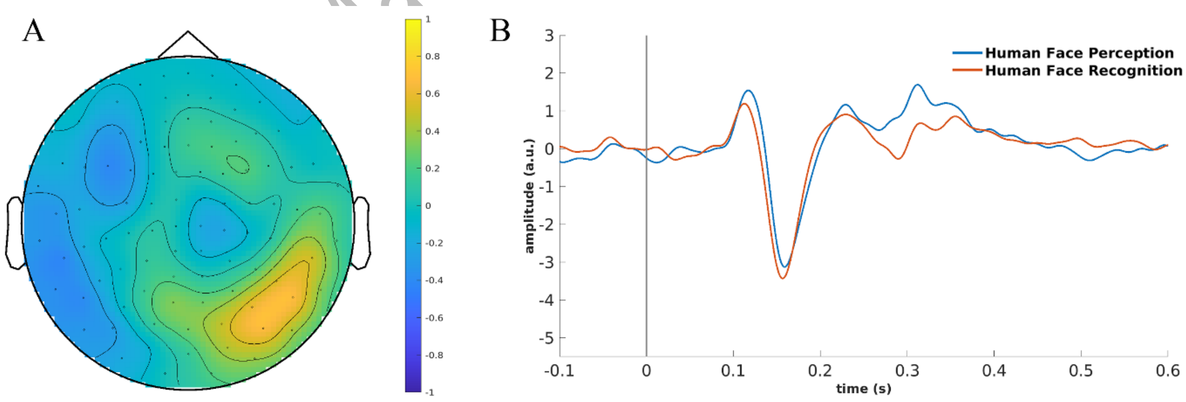

Figure 5. A)Topoplot and B) the time courses for human face perception vs. recognition in M100 component

The onset and the peak time for the significant effects we found when comparing various stimuli pairs in M100 and M170 components in perception and recognition, as well as the onset and the peak time for the effect found in perception vs. recognition contrast, is shown in Table 1. The comparisons which showed no significant effect were highlighted in grey.

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Table 1. The onset and peak time for the significant effects founded in the comparison of various stimuli pairs in M100 and M170 components in perception and recognition together with the onset and the peak time for perception vs. recognition comparison in the single stimulus

	M100		M170	
	Onset	Peak	Onset	Peak
Face Perception vs. Motorbike Perception	81-114	81-124	149-193	162.5-198
Human Face Perception vs. Motorbike Perception			141-171	159-178
Monkey Face Perception vs. Motorbike Perception	81-112	89.6-120	156-192	176-200
Human Face Perception vs. Monkey Face Perception			134-192	147-200
Face Recognition vs. Motorbike Recognition	81-109	82-115	146-192	155.5-198
Human Face Recognition vs. Motorbike Recognition			136-178	153-178.65
Monkey Face Recognition vs. Motorbike Recognition	81-110	82-116	159-195	180-199
Human Face Recognition vs. Monkey Face Recognition	81-125	81.4-130	131-190	143-197.5
Face Perception vs. Face Recognition				

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Human Face Perception vs. Human Face Recognition	93-129	98-130		
Monkey Face Perception vs. Monkey Face Recognition				
Motorbike Perception vs. Motorbike Recognition				

Discussion

The most prominent visual event-related activities happen before 200ms after stimulus onset (Rossion and Caharel 2011). In this study, we assessed two of the most conspicuous event-related components, i.e. M100 and M170, and traced their changes of amplitude in stimulus perception and recognition. To this end, we ran cluster-based permutation separately for each pair of stimulus type in perception and recognition. We also performed cluster-based permutations between perception and recognition of any stimulus type. To determine the onset and peak time for the significant effects found by permutation analyses, we ran separate bootstrap tests for any of those effects.

Considering the M100 component, human face traces had a bigger peak in contrast to the motorbike in the recognition phase, but the comparison was not significant in perception after Bonferroni correction. Nevertheless, we could still see the same pattern between the human face and motorbike perception based on grand average time courses. Consistent with our findings, multiple previous studies reported a larger amplitude of M100 for faces than objects (Herrmann, Ehlis et al. 2005, Okazaki, Abrahamyan et al. 2008, Rossion and Jacques 2008). The comparison between monkey face and motorbike stimuli in M100 was significant both in perception and recognition states, with always the same pattern in which monkey faces had a bigger peak in contrast to motorbike traces. This implies that a more face-selective pattern in

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M100 is present for non-human faces. Examining the difference between human face vs. monkey face activities in the M100 component, we found that monkey face stimulus had a bigger peak in comparison to human faces in recognition. Compatible with our results, (Balas and Koldewyn 2013) found a significant difference between human and non-human face processing in M100 in which a larger peak amplitude for dog faces was observed than human faces. Based on our findings, we were unable to dissociate human face perception from monkey face activities in the M100 component. Our results suggest that while we usually have face selectivity in the M100 component, it is not always the case which is compatible with the debate already present in the literature about the face-selectivity of this component (Boutsen, Humphreys et al. 2006, Rivolta, Palermo et al. 2012). In other words, while M100 is face-selective in recognition for both human and monkey face stimuli, it is not face-selective in perception for human faces (but still selective for monkey faces) if conservative statistical tests like permutation analyses and Bonferroni correction are applied.

Based on our results, in most cases, there is a clear pattern between the stimuli amplitudes in M170 in perception and recognition phases. In more detail, the amplitude of M170 always had a bigger peak in human face traces in comparison to motorbike time courses. The fact that faces generate a bigger peak in contrast to object in M170 has been prevalently reported in the literature (Rousselet, Husk et al. 2008, Rossion and Caharel 2011, Daniel and Bentin 2012). On the other hand, the comparison between subcategories of faces (in our study, human face vs. monkey face) was more challenging. Previous studies mainly compared the human and non-human faces in perception level. In this issue, some studies reported no difference between human and non-human face perception in M170 (Carmel and Bentin 2002, Rousselet, Macé et al. 2004, Balas and Koldewyn 2013), while there are some studies which reported a bigger peak of M170 for non-human face in comparison to human face stimuli (Haan, Pascalis et al. 2002). Based on our results, when examining the differences between human face perception and monkey face perception, multiple occipitotemporal channels emerged during the permutation analyses.

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While in some of these channels we observed a bigger peak of M170 for monkey faces in contrast to human face stimuli, there were also some temporal as well as some occipital channels in which the reverse was detected, i.e. the amplitude of M170 in human face perception traces was larger than the monkey face perception time courses. Inspecting the difference between human faces and monkey faces at the recognition level, we observed a bigger peak of M170 for human faces than monkey faces in the recognition stage. This may be due to human expertise in their own face processing, but not in other species' facial processing (Pascalis and Bachevalier 1998).

The monkey face traces had a bigger peak in M170 in comparison to motorbike traces in the same component. This pattern was the same in perception and recognition states. Moreover, when merging human face and monkey face stimuli and considering them as the general face, again the amplitude in M170 had a bigger peak in contrast to motorbike time course. This implies that in the comparison between faces and objects, rarely the race of the face matters, and the brain always generates a larger M170 for faces than objects.

About the differentiation between perception and recognition per stimulus type in the M100 component, the only significant comparison was for the human face stimulus. This indicates that human face stimuli require different levels of attentional resources, while the amount of attention used in perception and recognition by other stimuli are not too different.

The difference between perception and recognition in the M170 component was not significant in any of the stimulus types which is in contrast to what was found by (Daniel and Bentin 2012) indicating a significant difference between face perception and recognition in M170. However, the criterion for recognition in Daniel and Bentin's study was different from ours. In other words, while in their study participants should decide about the gender or familiarity of the second presented stimulus, in our

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research, the equality of the second presented stimulus with the first one matters. This discrepancy in the results shows the high sensitivity of the result to the task design as well as analysis methods.

Considering onset time for the significant effects, the 95% confidence interval helps us understanding the speed at which the distinction between various stimulus types happens in the human brain. On the other hand, the 95% confidence interval of the peak time for the significant effects, shed lights on the time point at which the maximum separability between two kinds of stimuli has occurred. Our results indicate that there was a unique pattern for the speed at which various comparisons happened in the N170 component, both for the onset and the peak times and in perception and recognition. In more detail, the distinction between human face vs. monkey face happened earlier than the discrimination between human face vs. motorbike which itself has occurred earlier than the differentiation between monkey face vs. motorbike, both in terms of the onset and the peak time in N170 component. This pattern has been repeated in perception and recognition. Previous studies have prevalently reported that face processing happens faster than object processing and this speed is mostly exposed in the N170 component (Hsiao and Cottrell 2008, Crouzet, Kirchner et al. 2010, Rossion 2014). Our results extend these findings by revealing that this speed is also present in discerning between the sub-categories of faces, i.e. in human vs. monkey facial processing. Moreover, our results signify that the distinguishment between human face vs. motorbike happens earlier than monkey face vs. motorbike which is likely because of human expertise in own species face processing, but not in other species (Pascalis and Bachevalier 1998). Although when searching for the distinction between perception and recognition per stimulus type in N170, we were unable to find any significant results, in the comparisons between any pair of stimuli, we usually inspected earlier onset and peak time in recognition than perception. This is probably due to the facilitation that happens in recognition in comparison to perception due to our task design. In other words, because participants knew the second presented stimulus in each trial is always from the same category as the first one, it is rational that the N170 onset and peak happens earlier in recognition than for perception.

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Regarding the M100 component, there was rarely any difference between the onset and peak time of various kinds of comparisons, meaning that we could barely discriminate between the speed and maximum separability time of any pair of stimuli at about 100ms after stimulus onset.

Conclusion

In the current study, we examined the differences between face and object processing in perception and recognition in M100 and M170 components.. Based on our findings, M100 is a face-selective component in recognition, but not always in perception. The comparison between face and object in M170 always revealed a bigger peak for faces than objects. Considering the onset and the peak time, our results suggest that while there was rarely any distinction between various comparisons in M100, a unique pattern was present in the M170 component. The major limitation of this study was confining the results to sensor space activities. This was due to the absence of individual MRI scans. In future studies, it would be helpful to find out about the brain regions involved in the effects we have found and the possible latencies in those regions. Additionally, ERF components later than 200ms also deserve to be assessed in later studies, especially in terms of the onset and the peak time of them.

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