All-or-none neural mechanisms underlying face categorisation: evidence from the N170

Running title: All-or-none generation of the N170

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Abstract

Categorisation of visual stimuli is an intrinsic aspect of human perception. Whether the cortical mechanisms underlying categorisation operate in an all-or-none or graded fashion remains unclear. In this study, we addressed this issue in the context of the face-specific N170. Specifically, we investigated whether N170 amplitudes grade with the amount of face information available in an image, or a full response is generated whenever a face is perceived. We employed linear mixed-effects modelling to inspect the dependency of N170 amplitudes on stimulus properties and duration, and their relationships to participants' subjective perception. Consistent with previous studies, we found a stronger N170 evoked by faces presented for longer durations regardless of subjective confidence in perceptual categorisation. However, further analysis with equivalence tests revealed that this duration effect was eliminated when only faces perceived with high confidence were considered. Therefore, previous evidence supporting the graded hypothesis is more likely to be an artefact of mixing heterogeneous "all" and "none" trial types in signal averaging. These results support the hypothesis that the N170 is generated in an all-or-none manner, and, by extension, suggest that categorisation of faces may follow a similar pattern.

Keywords

equivalence tests; event-related potentials; face categorisation; graded responses; subjective perception

1. Introduction

The ability to categorise environmental stimuli is a fundamental function of human perceptual systems. Perceptual categorisation allows us to organize the rich and dynamic inputs from the environment and supports higher-level cognitive processes such as learning and memory (Retter et al., 2020). A critical question is whether the neural mechanisms subserving categorisation function is in a graded or all-or-none fashion. That is, do these system responses grade with the amount of evidence for some particular category, or do they operate in a more binary fashion, generating a full-strength response only when the evidence for that category passes some threshold? Addressing this question will deepen our understanding of the brain basis for categorisation and advance the construction of corresponding theoretical models.

One canonical neural signature of perceptual categorisation in the visual system is the face-specific enhancement of the N1 component of the event-related brain potential (ERP) – typically termed the N170 (e.g., Bentin et al., 1996). The N170 is scalp negativity that is maximal at posterior electrode locations in response to the presentation of a face image. As the nomenclature suggests, the peak amplitude of this component typically occurs around 170 ms poststimulus. It is the earliest reliable ERP correlate of face perception. While the face-specific N170 has been the subject of intense research for nearly three decades (for reviews, see Rossion, 2014; Rossion & Jacques, 2011; Schweinberger & Neumann, 2016), it remains uncertain whether this response is generated in a graded fashion, varying in amplitude as a function of the amount or quality of face information available in an image, or is a full response generated whenever a face is perceived.

The idea that the N170 is graded is supported by the observation that lower N170 (or M170, the equivalent response observed in magnetoencephalography) amplitudes are

recorded when face information is reduced by either reducing the exposure duration (Carbon et al., 2005; Eiserbeck et al., 2021; Tanskanen et al., 2007) or adding noise to the image (Bankó et al., 2011b; Horovitz et al., 2004; Jemel et al., 2003; Navajas et al., 2013; Németh et al., 2014; Philiastides et al., 2006; Philiastides & Sajda, 2006; Rousselet et al., 2008; Schneider et al., 2007; Tarkiainen et al., 2002). While these reports appear to be consistent with the view that N170 amplitudes are graded with the amount of evidence for a face, on critical evaluation this conclusion may not be warranted. A number of studies of face-detection tasks have reported that, in addition to reducing N170 amplitudes, limiting the amount of information available also results in poorer behavioural performance (Bankó et al., 2011a; Eiserbeck et al., 2021; Nasr, 2010; Retter et al., 2020; Rousselet et al., 2008), and that N170 amplitude also varies positively with behavioural performance (Bankó et al., 2011a; Eiserbeck et al., 2021; Nasr, 2010; Philiastides & Sajda, 2006; Rousselet et al., 2008; Tanskanen et al., 2007). There are two possible explanations for the relationships between the quality of face information, the amplitude of the face-specific N170, and behavioural performance on face categorisation tasks. At the single-trial level, reducing the quality of face information in the image may elicit a weaker “face” response – and thus a lower-amplitude N170 compared to trials with higher-quality images (i.e., the N170 is a graded response reflecting the strength of the categorisation response) so the average N170 across trials is commensurately lower in amplitude. Alternatively, the relationship between face information and N170 amplitude could be an artefact of the signal averaging inherent in extracting visual evoked potentials. That is, a full-strength N170 may be generated on every trial on which a face is perceived (i.e., the N170 is an all-or-none response reflecting the perception of a face), but since fewer faces are detected on trials with reduced face information, signal averaging results in an N170 that is lower in amplitude for these trials than it is for trials with more face information. While some studies have tried to resolve these possibilities by only

computing N170 for trials in which a face was correctly perceived (Fisch et al., 2009; Navajas et al., 2013; Rodríguez et al., 2012), it remains possible that the N170 amplitude might still be biased by correct guessing in these studies. To distinguish more completely between these possibilities, it is critical to take both behavioural performance and signal averaging across trials into account.

To disentangle these alternatives, we employed linear-mixed modelling with null-hypothesis significance testing and equivalence tests to examine the dependency of the N170 on face and house images with different durations while participants reported subjective perceptions on each trial. We first inspected this dependence averaged across subjective confidence to replicate previous findings corroborating the graded hypothesis, and then repeated the analysis only for high subjective confidence to exclude contamination from guessing. Moreover, we compared the “full” N170 for different durations in the same blocks to mitigate any effects of experimental context. Overall, our findings support the all-or-none hypothesis for N170 generation.

2. Materials and Methods

2.1. Participants

We recruited 35 participants for this study, but subsequently excluded seven because their performance failed to meet our inclusion criterion. Specifically, we instructed participants to press Key 1 only when they were sure that the stimulus was a face. For these seven participants, accuracy when pressing Key 1 did not meet our criterion of 95% correct ($M = 76\%$, range: 49% - 94%), so they were not included in further analyses.

The remaining twenty-eight participants (20 females, age range: 18-32 years, $M_{\text{age}} = 22.32$) all had normal or corrected-to-normal vision, participated in the experiment in exchange for course credits or supermarket vouchers, and gave written consent before completing the tasks. This study was approved by the University of Auckland Human Participants Ethics Committee (Reference Number 016833).

2.2. Stimuli

The stimuli consisted of 40 photographs of Caucasian (20 female) faces from Ge and colleagues (2009) and 40 house images from Caltech Houses Database (Helle & Perona, 2000). For face images, we removed all external features, such as ears, hair, and necks by masking the image with an oval window (200×256 pixels, $4.94^\circ \times 6.32^\circ$). We applied the same oval window to the house images to ensure that all stimuli shared the same outline. In addition, we converted all the face and house images to greyscale and balanced their luminance using the SHINE toolbox (Willenbockel et al., 2010) in Matlab. We created a scrambled version of each image by randomizing all pixels of each image within the oval window using a custom Matlab script (available: <https://osf.io/nxav8/>). We show example face and house stimuli and their corresponding scrambled images in Figure 1A. In addition to these stimuli, we created a further four face (two female) and four house images to use in practice trials. We displayed all stimuli against a $7^\circ \times 7^\circ$ field of partially overlapping circles, which varied in size, location, and shade of grey (Figure 1B). A mask that was identical in composition to this background appeared before and after stimulus presentation.

2.3. Apparatus

We administered the experiments using E-prime 2.0 (Version 2.0.8.74, Psychology Software Tools, Pittsburgh, PA). Stimuli were displayed on a Samsung Sync Master HDTV

Figure 1. Stimuli and procedures in this experiment. A, Example face and house stimuli, as well as their corresponding scrambled versions, placed on the same masking background. Scrambled stimuli were created by randomizing all pixels within the oval contour. The face example image was not used in the experiment. B, The masking image. C, The trial procedure in this experiment.

monitor (P2270HD) with 1920×1080 resolution and a refresh rate of 60 Hz. The background colour of the screen was grey (RGB values: 128, 128, 128). Participants were seated on a comfortable chair in a dimly lit, electrically shielded room (Belling Lee - Model L3000, Enfield, England). Responses were collected via the keyboard. The viewing distance between participants and the screen was maintained at about 57 cm, so that 1 cm on the screen subtended one degree of visual angle.

Electroencephalography (EEG) was recorded continuously (1000 Hz sample rate; 0.1-400 Hz analog bandpass, 400-M Ω input impedance) throughout each session using 128-channel Ag/AgCl electrode nets (Tucker, 1993) and amplifiers from Electrical Geodesics Inc. (Eugene, Oregon, USA). Electrode impedances were kept below 40 k Ω , an acceptable level for this system (Ferree et al., 2001). Common vertex (Cz) was used as a reference.

2.4. Procedure

Each trial (Figure 1C) in this study started with a fixation cross displayed for 500ms. This was followed by a pre-stimulus mask with variable duration (200ms, 250ms, 300ms, 350ms, or 400ms). Then the experimental stimulus was presented superimposed on the background for either 17ms or 200ms, followed by the post-stimulus mask which remained visible until response. We asked participants to judge whether the stimulus was a face or a house by pressing one of five response keys. They were to press Key 1 if they were sure the stimulus was a face, Key 2 if they were not sure, but thought it was a face, Key 5 if they were sure it was a house, Key 4 if they were not sure, but thought it was a house, and Key 3 if they had no idea what it was. The interval between trials was 1000ms.

We employed a 2 (Type: intact vs. scrambled) $\times$ 2 (Category: faces vs. houses) $\times$ 2 (Duration: 17ms vs. 200ms) within-subject design in this study. There were four blocks in total, and each consisted of 320 trials. In the first two blocks, all stimuli were presented for 17ms. Every intact stimulus was repeated three times, while every scrambled stimulus was displayed once in each of the first two blocks. In the last two blocks, every stimulus was presented once in each condition. It took about one hour to finish all these trials. In addition, prior to the main experiment, participants completed 32 practice trials, in which the practice stimuli were presented for 17ms. No feedback was provided at the single-trial level, and the responses were summarized at the end of the practice.

2.5. EEG data pre-processing

Pre-processing of EEG data was conducted using EEGLAB (Version 14.1.2, Delorme & Makeig, 2004) in Matlab (Version 9.3, MathWorks, Natick, MA). All the steps, except for rejecting the independent components based on the results of independent component

analysis (ICA), were completed using Matlab scripts (available: <https://osf.io/fvyc3/>) in the High-Performance Computing cluster of New Zealand eScience Infrastructure.

The pre-processing pipeline mainly followed “Makoto’s suggestion” from (Miyakoshi, 2019). First, the options of EEGLAB were changed to using double precision. After loading the raw EEG data, the timestamps of all triggers were shifted 50ms earlier to correct for amplifier and display delays. The amplifier delay was due to the amplifier taking time to process signals, which is reported by EGI to be 36ms for a 1000Hz sampling rate. The display delay was caused by the monitor taking time to display the stimuli. This delay time was measured by comparing the differences between the time point at which triggers of a stimulus were sent by E-prime and the time at which a photocell detected the change in luminance on the monitor, which was 14ms on average. In total, the delay time is 50ms. Then the EEG data were downsampled from 1000 Hz to 250 Hz and bandpass filtered (1-50 Hz). Next, the channel location information was loaded, and the line-noise frequencies at 50Hz, 100Hz, 150Hz, 200Hz, and 250Hz were removed with the CleanLine (Version 1.04) plugin. Bad channels were identified and removed with the clean_rawdata (Version 1.00) plugin, and then interpolated. Next, the EEG data were re-referenced to the average of all the channels. ICA was conducted on the continuous EEG data with AMICA (Version 1.5.1), and the results saved for further use. Note that a high-pass filter of 1 Hz was utilized in the initial part of the pre-processing analysis because high-pass filtered data at 1-2Hz works better for ICA (Winkler et al., 2015). However, previous research also found that high-pass filtering (above 0.1 Hz) can distort the early ERP components (Acunzo et al., 2012). Therefore, we repeated all the above pre-processing steps except for the ICA analysis on the original data, but with a high-pass filter frequency of 0.1 Hz instead of 1 Hz. Then the ICA results from the initial pass (filtered with high-pass at 1 Hz) were applied to the data filtered with high-pass at 0.1Hz, as recommended by Makoto (Miyakoshi, 2019). The equivalent-dipole source

localization of independent components was calculated with dipfit (Version 3.0) plugin, which was followed by identifying the components representing bilateral source activities with fitTwoDipoles (Version 0.01) plugin (Piazza et al., 2016). We used the dipole information to reject components that did not appear to have a brain source. Next, the continuous EEG data were segmented into 1500ms epochs, starting 500ms before the stimulus onsets. After completing all the above steps, we transferred the data to a local computer for further processing. Independent components identified as artifacts, such as eye blinks, horizontal eye movements, heartbeats, muscle contractions, and so on, were identified with SASICA (Chaumon et al., 2015), which implemented its own selection algorithms, and other two automated methods: ADJUST (Mognon et al., 2011) and FASTER (Nolan et al., 2010). Manually rejecting artefactual effects was mainly based on the results of SASICA and guided by (Pion-Tonachini et al., 2019). After removing the artifact components, the data were reloaded to the cluster for further pre-processing. Improbable data were identified by joint probability and marked for all the channels. A linear detrend was applied from 200ms prior to 996ms after stimulus onset for each epoch. As the last step of pre-processing, the average voltage during the 200ms prestimulus baseline was subtracted from each data point in each epoch.

2.6. Time windows, peak channels, and mean amplitudes

We used a data-driven method to identify appropriate time-windows for the N170 and P1 components that are unbiased by condition. To identify the N170 time window, we chose P7 (E58) and P8 (E96) as the likely peak channels based on previous literature (Jemel et al., 2003; Nemrodov et al., 2016; Rossion & Jacques, 2008). The cluster channels for P7 (E58) included electrodes E58, E65, E59, E51, E50, E57, and E64. The cluster channels for P8 (E96) included electrodes E96, E101, E97, E91, E96, E95, and E100. A grand-average

waveform for the cluster of channels centred on P7 and P8 was obtained by averaging the data for the entire epoch across participants, conditions, and cluster channels. Then we identified the minimum (i.e., most negative) amplitude of this grand-average waveform between 100ms and 250ms poststimulus. To compute the amplitude of the N170, we initially defined an integration window based on the full-width half-maximum of the component. If the width of this window was outside the range of 36 – 40ms (a reasonable window for N170), the height-width ratio was adjusted iteratively until the integration window was between 36ms and 40ms wide.

After setting the N170 integration window, we created a grand mean scalp distribution for this period across all participants and conditions to allow visual confirmation of the peak channels. We observed that the centres of the negative peak activity were around PO7 (E65) and PO8 (E90), rather than our initial assumption of P7 and P8. Therefore, we updated the channel clusters to centre on PO7 (channels E65, E70, E66, E59, E58, E64, and E69), and PO8 (E90, E96, E91, E84, E83, E89, and E95). We then re-checked the N170 integration window using the same procedure outlined above using the updated peak channels. As a result, the integration window for the N170 was defined as 152-192ms (time window size: 40ms) poststimulus.

We used an analogous procedure to define the integration window for the P1 component, which we include in the analysis as a control, since we do not expect P1 to be modulated by perceptual categorisation. We initially chose PO7 (E65) and PO8 (E90) as the likely scalp maxima of P1 based on previous literature (Bankó et al., 2011a; Kuefner et al., 2010; Rossion & Caharel, 2011; Smith, 2012) and the maximum amplitude value of the grand averaged epoch was identified between 70ms and 140ms after stimulus onsets. As a result, we set the integration window for P1 as 96ms – 136ms (time window size: 40ms) poststimulus. The grand-average scalp distribution for this window confirmed that the peaks

of P1 activity were at the PO7 and PO8 electrodes. Accordingly, the channel clusters for the P1 were identical to those identified for N170.

We defined the amplitudes for the two ERP components (P1 and N170) as the mean amplitudes within their respective integration windows. We measured the amplitudes in each window for every trial, and then submitted the single-trial mean amplitudes to linear mixed modelling (LMM) for further analysis.

2.7. Statistical analyses

2.7.1. Linear mixed modelling

We conducted linear mixed modelling (LMM), instead of repeated-measure analyses of variance (rm-ANOVA), to assess single-trial mean amplitudes. There are several advantages of LMM which make this technique popular as an alternative to rm-ANOVA (Aarts et al., 2014; Baayen et al., 2002; Boisgontier & Cheval, 2016; Jaeger, 2008; Kristensen & Hansen, 2004; Quené & van den Bergh, 2004). The specific benefit of applying LMM in this study is that, compared with rm-ANOVA, LMM can yield unbiased results in the presence of missing data without the need to remove participants (Brauer & Curtin, 2018; Kliegl et al., 2011; Linck & Cunnings, 2015; Magezi, 2015; Matuschek et al., 2017). In this study, we expected that when intact face stimuli were presented for 17ms, some participants may never perceive the stimuli with high subjective confidence, and thus not use the Key 1 or Key 5 responses at all. We also thought it possible that some ratings may not be used by all participants. Another advantage of using LMM is that they can model amplitudes at the level of single observations and estimate multiple random effects. Estimating both participant and stimulus random effects maximizes data use and allows generalization of fixed effects to other similar participants and stimuli.

The general procedures to obtain an optimal model for each dependent variable follow the recommendations of Bates, Kliegl, and colleagues (2015) and Matuschek and colleagues (2017). First, the maximal model is created, in which the random effect structure includes all by-participant and by-item random intercepts and random slopes. If the maximal model fails to converge, the corresponding zero-correlation-parameter (ZCP) model, in which the correlations between random effects are forced to be zero, is fitted. Then the random effects that do not significantly explain the data are removed from the ZCP model, resulting in the reduced model. The extended model is then built by adding back the correlations between the remaining random effects in the reduced model. If the extended model still cannot converge, the random effects with the smallest amount of variance are removed one-by-one until a converged model is achieved, resulting in the final extended model. Next, the reduced and extended models are compared, and the one that explains data better (with smaller Akaike's Information Criterion; Akaike, 1998) is defined as the optimal model. Follow-up comparisons are conducted based on this optimal model.

In this study, we are interested in both the overall ERPs and in the ERP differences between faces and nonface objects. First, to inspect how P1 and N170 amplitudes varied when intact faces were presented for different durations and distinct subjective confidence, we performed pairwise contrasts for all Duration and Confidence levels separately on the results of the optimal LMM for intact faces. Second, to test the dependency of the aspect of the ERP that could be specifically attributed to face processing (here defined as the difference between the face-related and house-related P1 and N170 amplitudes) for intact stimuli on durations and subjective confidence, we computed "pairwise interaction contrasts" between Category and Duration (or Confidence) for intact faces (i.e., simple interaction analysis; Jin, 2021). For instance, the pairwise interaction contrast between Category and Duration in this

study is equivalent to (17ms faces – 17ms houses) – (200ms faces – 200ms houses), i.e., the differences of face-minus-house ERP component between durations.

2.7.2. Null-hypothesis significance tests and equivalence tests

Null hypothesis significance testing (NHST) remains one of the most popular inferential statistical methods used by researchers. When the probability (i.e., p -value) of observing the data and more extreme under the null hypothesis is small (less than some pre-defined α level), we reject the null hypothesis and infer that the alternative hypothesis is true. However, when that probability is not small enough, we cannot conclude whether the null hypothesis is true or whether there is insufficient evidence to make any decision (Cohen, 1994).

In this study, we do expect that some null effects. For example, comparable N170 amplitudes may be generated for faces presented for different durations when they are perceived with high subjective confidence. Such effects can never be positively supported by conventional NHST. Therefore, in addition to conventional NHST, we employ equivalence tests (ET) in this study to test whether the effect is equivalent to a region of null effects (Lakens, 2017; Lakens et al., 2018; Mara & Cribbie, 2012; Meyners, 2012; Rogers et al., 1993; Seaman & Serlin, 1998; Weber & Popova, 2012). ET essentially performs two one-sided tests to determine whether the observed effects are outside a region that is believed to be equivalent to a null effect. In other words, the null hypothesis being tested in ET is that the observed effect is smaller than the lower boundary of the equivalence region or larger than its upper boundary. In this study, we define this region of practical equivalence to zero as $[-0.5\mu\text{V}, 0.5\mu\text{V}]$, which, we think, is reasonably small considering that ERP data are usually noisy. If the probability that the observed effects being outside the region is low (i.e., p -values for the two one-sided tests are both smaller than the conventional α level of 0.05), we

Figure 2. Scenarios of results obtained from conventional null hypothesis significance testing (NHST) and equivalence tests (ET). The black long-dashed vertical line denotes the effect of zero, which represents the null hypothesis in NHST. The grey dashed vertical lines denote the lower and upper boundaries $[-0.5, 0.5]$ of the region equivalent to the null effect in equivalence tests. The horizontal error bars denote the confidence intervals of different effects. Scenario 1 and 2 denote that the NHST is significant but the ET is not, which provides the evidence that the effect of interest is different from 0. Scenario 3 denotes that the ET is significant but the NHST is not, which provides the evidence that the effect of interest is equivalent to the null effect. Scenario 4-6 denote that the effects are inconclusive with the evidence from NHST and ET.

will reject that hypothesis and infer that the observed effect is statistically equivalent to the null effect. If the probability of any direction is not small enough, we cannot infer the effect is equivalent to the null effect.

In summary, we employ both conventional NHST and ET in this study to examine whether an effect is significantly different from zero and whether it is practically equivalent to the region of null effects, respectively. There are (at least) six possible scenarios that can be obtained by combining conventional NHST and ET (see Figure 2 for a schematic

representation of these possibilities). Scenarios 1 and 2 reflect instances in which the null hypothesis is rejected. In these instances, we only report the results of NHST. Scenario 3 reflects cases in which there is evidence in favour of the null effects. Here, we only report the results of ET. Since two one-sided tests are performed in ET, we only report the results of the one-sided test whose absolute t -value is smaller and thus p -value is larger (Lakens et al., 2018). For the other scenarios, in which the null hypothesis can neither be rejected nor supported, and, therefore, the effects are inconclusive, we report results of both NHST and ET.

2.7.3. Software

We performed all statistical analyses using R (R Core Team, 2018) and RStudio (RStudio Team, 2019). Data were tidied up with the Tidyverse package (Wickham, 2017). We performed LMM using the lme4 package (Bates, Mächler, et al., 2015) and follow-up comparisons and ET with the emmeans package (Lenth, 2019). The R Markdown output file is available at <https://osf.io/zv6kg/>.

3. Results

3.1. Allocation of keypress responses

The allocation of responses in each condition is summarized in Figure 3A. Inspection of this figure reveals that, for brief (17ms) presentations, faces were perceived more frequently and with higher confidence than houses. Specifically, when intact faces were presented, participants reported being sure that they had seen a face (Key 1) on about half of trials ($M = 0.469$, 95% confidence interval (CI): [0.346, 0.591]), and unsure, but thought the

Figure 3. Allocation of keypress responses. Response 1 denotes participants were sure the stimulus was a face, response 2 denotes participants were not sure but thought it was a face, response 3 denotes participants had no idea what it was, response 4 denotes participants were not sure but thought it was a house, and response 5 denotes participants were sure it was a house. Error bars represent 95% confidence intervals. Panel A displays the averaged responses within each condition. Panel B depicts the percentage for each response and condition of trials in which the stimulus was a face. For instance, the leftmost column in the first row of Panel B shows that almost all intact stimuli were faces when participants responded with Key 1.

stimulus was a face (key 2) on a further third of the trials ($M = 0.321$, 95% CI : [0.236, 0.405]). When intact houses were presented, participants were less confident. The most common responses were that they were unsure, but thought the stimulus was a house (Key 4; $M = 0.399$, 95% CI : [0.317, 0.481]) or had no idea what were presented (Key 3; $M = 0.387$, 95% CI : [0.292, 0.483]). When the corresponding scrambled images were presented for 17ms, participants most commonly responded that they had no idea what stimulus was presented (Key 3; scrambled faces: $M = 0.714$, 95% CI : [0.635, 0.793]; scrambled houses: $M = 0.700$, 95% CI : [0.618, 0.782]). As expected, when the stimuli were presented for 200ms, participants were essentially perfect in discriminating intact faces from intact houses, and had high confidence in their responses (Key 1; faces: $M = 0.977$, 95% CI : [0.965, 0.989]; houses:

$M = 0.967$, 95% CI : [0.957, 0.977]). When the images were scrambled, the participants once again consistently reported having no idea whether they depicted faces or houses (Key 3; faces: $M = 0.975$, 95% CI : [0.963, 0.988]; houses: $M = 0.973$, 95% CI : [0.960, 0.986]).

Figure 3B depicts the percentage of stimuli that were faces for each response in the intact and scrambled conditions. For instance, the leftmost column in the first row depicts the percentage of stimuli being intact faces when participants responded with Key 1. If participants were following instructions appropriately, they should have pressed Keys 1 and 5 only when they were completely sure of the stimulus. Note that we removed participants who failed to reach 95% accuracy for these responses before conducting any further analysis (see Participants above). Indeed, regardless of stimulus duration, when participants responded with Key 1, almost all the stimuli were intact faces (17ms: $M = 0.988$, 95% $CI = [0.983, 0.994]$; 200ms: $M = 0.996$, 95% $CI = [0.993, 0.999]$), while only very few stimuli were faces when participants responded with Key 5 (17ms: $M = 0.074$, 95% $CI = [0.020, 0.128]$; 200ms: $M = 0.002$, 95% $CI = [0.000, 0.004]$). In addition, we also instructed participants to select Key 3 when they were unable to categorize the stimuli. For scrambled stimuli, this resulted in chance performance for Key 3 responses (17ms: $M = 0.508$, 95% $CI = [0.500, 0.515]$; 200ms: $M = 0.501$, 95% $CI = [0.499, 0.502]$).

These data confirm that participants were using the subjective-confidence scale appropriately and distributing their responses across the five response options. Critically, the variability in subjective confidence when the stimuli were presented for 17ms enables us to explore further the associations between subjective confidence and ERP amplitudes.

3.2. ERP amplitudes averaged across responses

We used LMM to analyse the amplitudes of the P1 and N170 components of the ERP in three different ways. First, we collapsed across response options to replicate the effects of stimulus duration reported in previous literature (Carbon et al., 2005; Mitsudo et al., 2011; Tanskanen et al., 2007), in which N170 amplitudes were larger for longer durations compared with shorter durations. While our main focus was on modulation of N170, we also analysed P1 amplitudes (which we do not expect to be modulated by face stimuli; Rossion & Caharel, 2011) to account for any effects that result from general amplification of the ERP as a function of stimulus duration. The grand average ERP waveforms and topographic maps corresponding to the P1 and N170 time-windows are shown in Figure 4D and 4C, respectively. We fitted amplitudes for each component using LMM and the results were submitted to pairwise contrasts and pairwise interaction contrasts to test the influence of stimulus properties on P1 and N170 amplitudes, as well as on face-minus-house ERP component.

3.2.1. P1 amplitudes

The estimated marginal means of P1 amplitude for each condition are depicted in Figure 4A. To examine the dependency of P1 amplitudes on stimulus properties, we performed pairwise contrasts corrected by the Bonferroni methods for two tests. Results revealed that the differences in P1 amplitudes evoked by intact faces between 17ms and 200ms conditions were statistically equivalent to the null effect for the left-hemisphere electrodes ($t(123.0) = 2.61, p = .01, b = -0.07, 90\% CI = [-0.40, 0.25]$), but remained inconclusive for the right-hemisphere electrodes (NHST: $t(123.0) = -1.24, p = 0.44$; ET: $t(123.0) = 1.80, p = .07, b = -0.20, 90\% CI = [-0.53, 0.12]$). Moreover, to examine the dependency of P1 amplitude differences between faces and houses on stimulus properties, we

Figure 4. ERP results as a function of Hemisphere (left vs. right), Type (intact vs. scrambled), Category (faces vs. houses), and Duration (17ms vs. 200ms) across behaviour responses. *A* and *B* depict the estimated marginal means of P1 and N170 amplitudes, respectively; error bars represent 95% confidence intervals. *C*, Topographic maps corresponding to the P1 (left panel) and N170 (right panel) components. The grey dots in the schematic brain denote the channel locations for both P1 and N170 on both hemispheres. *D*, The grand average ERP waveforms. The grey dashed rectangular denotes the time-window for the P1 (96ms-136ms), while the grey solid rectangular denotes the time windows for the N170 (152-192ms). Please see Figure S1 in supplementary materials for colour topographic maps.

performed pairwise interaction contrasts between Category and Duration for intact stimuli, also corrected by the Bonferroni method for two tests. No significant face-related modulation of the P1 component by stimulus duration was found for the right-hemisphere electrodes ($t(266.2) = -3.12, p = .002, b = 0.01, 90\% CI = [-0.29, 0.32]$), whereas this modulation was inconclusive for the left-hemisphere electrodes (NHST: $t(266.2) = 1.44, p = 0.30$; ET: $t(266.2) = -1.76, p = .08, b = 0.22, 90\% CI = [-0.08, 0.53]$). Both analyses suggest that, neither the overall P1 nor the face-minus-house P1 components were affected by durations, implying that any differences found for N170 amplitudes later could not be attributed to generalised amplification of the ERP for longer stimulus duration.

3.2.2. N170 amplitudes

The estimated marginal means of N170 amplitudes in each condition are displayed in Figure 4B. In general, longer stimulus duration was associated with a weaker (lower amplitude) N170, except when the stimuli were intact faces. Pairwise contrasts, corrected using the Bonferroni method for two tests, confirm that the N170 amplitudes evoked by intact faces were weaker for 17ms relative to 200ms presentations for both hemisphere electrodes (left: $t(100.1) = 2.62, p = .02, b = 0.68, 95\% CI = [0.09, 1.26]$; right: $t(100.1) = 5.02, p < .001, b = 1.30, 95\% CI = [0.71, 1.88]$). This dependence of N170 amplitude on Duration seems to support the graded hypothesis for N170 generation: longer exposure to faces results in larger N170 amplitude, whereas in all other conditions, longer exposure results in lower amplitude.

Next, we compared the face-minus-house N170 components for different durations via pairwise interaction contrasts between Category and Duration for intact stimuli. These contrasts revealed significant interactions between Category and Duration for both hemisphere electrodes (left: $t(104.1) = 8.93, p < .001, b = 1.92, 95\% CI = [1.43, 2.41]$; right:

$t(104.1) = 10.40, p < .001, b = 2.24, 95\% CI = [1.75, 2.73]$), suggesting that N170 amplitudes differences between faces and houses were stronger for 200ms than 17ms conditions. This result also seems to confirm that the face-minus-house N170 component is graded.

3.3. The influence of subjective confidence on ERP amplitudes

The previous analyses compared P1 and N170 amplitudes for face and house images – as well as scrambled versions of both – regardless of the participants' responses. While the results are consistent with the idea that the N170 (but not the P1) is graded in amplitude as a function of the amount of face information, it is possible that the N170 is contaminated by including trials in which no face was perceived. This would be expected to reduce the N170 for the short-duration (17ms) condition more than the long-duration (200ms) condition, perhaps creating an illusion of a graded response. Accordingly, we repeated the analysis taking subjective confidence into account. As shown in Figure 3A, we mostly observed variability in response when intact stimuli were presented for 17ms. In particular, most responses for 17ms intact faces were Key 1, Key 2, and Key 3, whereas most responses for 17ms intact houses were Key 5, Key 4, and Key 3. These keys corresponded to high confidence, low confidence, and guessing for face and house stimuli, respectively. Thus, we converted these responses into a new fixed factor, Confidence, which had three levels: high (Key 1 for faces or Key 5 for houses), low (Key 2 for faces or Key 4 for houses), and guess (Key 3 for both stimuli). Since we also wished to include the 200ms intact stimuli conditions as the baseline level, and most responses in these conditions were Key 1 and Key 5 (i.e., high confidence for faces and houses respectively), we further integrated Confidence with Duration to create a new factor, Duration Confidence, with four levels: 17ms_guess, 17ms_low, 17ms_high, and 200ms_high. We did not include scrambled trials in the analyses.

Figure 5. ERP results for intact stimuli as a function of Hemisphere (left vs. right), Category (faces vs. houses), and Duration Confidence (17ms_guess, 17ms_low, 17ms_high, vs. 200ms_high). *A* and *B* depict the estimated marginal means of P1 and N170 amplitudes, respectively; error bars represent 95% confidence intervals. *C*, Topographic maps corresponding to the P1 and N170 components. The grey dots in the schematic brain denote the channel locations for both P1 and N170 on both hemispheres. *D*, The grand average ERP waveforms. The grey dashed rectangular denotes the time-window for the P1 (96ms – 136ms), while the grey solid rectangular denotes the time windows for the N170 (152-192ms). Please see Figure S2 in supplementary materials for colour topographic maps.

The grand average ERP waveforms and topographic maps corresponding to the P1 and N170 time-windows are shown in Figure 5C (topographies) and 5D (waveforms). We analysed the LMM results using pairwise contrasts and pairwise interaction contrasts to test the influence of Duration Confidence on overall ERP amplitudes and the face-minus-house ERP component.

3.3.1. P1 amplitudes

The estimated marginal means of P1 amplitude for each condition are depicted in Figure 5A. Similar to the earlier analyses, we performed pairwise contrasts to test the dependency of P1 amplitudes on Duration Confidence, corrected with Bonferroni methods for six tests, and the detailed statistical results are available in Table S1. For the left-hemisphere electrodes, P1 amplitudes in 17ms_guess conditions were weaker than those in 17ms_high conditions ($t(20687.5) = -3.14, p = .01, b = -0.43, 95\% CI = [-0.80, -0.07]$). Differences between 17_low, 17_high and 200_high were statistically equivalent to the null effect ($|t| > 2.86, p < .02$) while the comparisons between 17ms_guess and 17ms_low, as well as between 17ms_guess and 200ms_high, were not conclusive (NHST: $|t| < 2.57, p > .06$; ET: $|t| < 1.89, p > .18$). For the right-hemisphere electrodes, P1 differences between 17ms_high and 200_high were statistically equivalent to the null effect ($t(34348.2) = 3.76, p < .001, b = -0.09, 90\% CI = [-0.35, 0.17]$). Moreover, P1 amplitudes for 17ms_guess and 17ms_low were weaker than those for 17ms_high and 200ms_high ($|t| > 2.79, p < .04$). And P1 differences between 17ms_guess and 17ms_low were not conclusive (NHST: $t(35346.6) = -1.51, p = .79$; ET: $t(35346.6) = 2.19, p = .09$). These results indicate that, in general, weaker P1 amplitudes were associated with lower subjective confidence but the effects were quite small, usually smaller than 1 μ V.

We also assessed face-minus-house P1 amplitudes with pairwise interaction contrasts between Category and Duration Confidence, which were corrected with Bonferroni methods for six tests and the detailed statistical results are available in Table S1. For the left-hemisphere electrodes, we found equivalence to null effects only for the comparisons between 17ms_guess and 200ms_high ($t(31977.1) = 2.42, p = .05, b = -0.06, 90\% CI = [-0.50, 0.37]$) and between 17ms_low and 17ms_high ($t(7492.4) = -2.43, p = .05, b = 0.08, 90\% CI = [-0.33, 0.49]$); the other comparisons remained inconclusive (NHST: $|t| < 1.79, p > .44$; ET: $|t| < 1.92, p > .16$). For the right-hemisphere electrodes, we found that the differences in face-minus-house P1 amplitudes between the 17ms_low, 17ms_high, and 200ms_high were statistically comparable ($|t| > 2.58, p < .03$), while other comparisons were inconclusive (NHST: $|t| < 1.23, p > .99$; ET: $|t| < 1.94, p > .15$). In comparison to the overall P1 amplitude results, the face-minus-house P1 component was less likely to be influenced by subjective confidence. That is, variations in P1 amplitude as a function of subjective confidence cannot be attributed to modulation of a face-specific response, but are instead likely to reflect general visual processing.

3.3.2. N170 amplitudes

The estimated marginal means of N170 amplitudes in each condition are displayed in Figure 5B. We conducted pairwise contrasts to compare the differences in N170 amplitudes evoked by intact faces between levels of Duration Confidence, with Bonferroni corrections for six tests, and the statistical results are available in Table S1. For the left-hemisphere electrodes, N170 amplitudes for 17ms_guess were weaker than all other levels of Duration Confidence ($|t| > 4.84, p < .001$). Differences of N170 amplitudes between 17ms_low and 17ms_high conditions were not conclusive (NHST: $t(27206.8) = 2.15, p = 0.19$; ET: $t(27206.8) = -2.12, p = 0.10$) and the amplitudes elicited in both of these conditions were

weaker than those in the 200ms_high condition ($|t| > 3.20, p < .009$). A similar pattern occurred for the right-hemisphere electrodes, with all differences reaching significance. Specifically, N170 amplitudes for 17ms_guess were weaker than all other three levels ($|t| > 5.85, p < .001$). N170 amplitudes for 17ms_low were weaker than 17ms_high and 200ms_high ($|t| > 3.95, p < .001$). Critically, when the subjective confidence was high, N170 amplitudes for the 17ms conditions were still weaker than for 200ms ($t(36540.1) = 5.88, p < .001, b = 0.66, 95\% CI = [0.37, 0.96]$). These results revealed that stronger (absolute) N170 amplitudes were associated with higher subjective confidence. Notably, even when perceived with similarly high subjective confidence, faces presented for 200ms still evoked stronger N170 amplitude compared to 17ms. This result, too, appears to support the graded hypothesis.

We examined the face-minus-house N170 component using pairwise interaction contrasts between levels of Category for each level of Duration Confidence, corrected using the Bonferroni method for six tests, and the statistical results are available in Table S1. For the left-hemisphere electrodes, face-minus-house component in the 200ms_high condition was stronger than all other three levels ($|t| > 8.52, p < .001$). N170 amplitude in the 17ms_high condition was also stronger than in 17ms_guess condition ($t(8673.1) = -3.52, p = .003, b = -0.75, 95\% CI = [-1.31, -0.19]$). Differences between other levels were inconclusive (NHST: $|t| < 2.10, p > .21$; ET: $|t| < 0.76, p > .99$). For right-hemisphere electrodes, the face-minus-house components differed between all levels except for the comparison between 17ms_low and 17ms_high, which remained inconclusive (NHST: $t(5675.1) = -1.75, p = .49$; ET: $t(5675.1) = -0.96, p > .99$). Specifically, the N170 was stronger in the 200ms_high condition than the other three levels ($|t| > 10.01, p < .001$). The N170 amplitudes in the 17ms_high and 17ms_low conditions were stronger than those in the 17ms_guess condition ($|t| > 3.66, p < .002$). Similar to the results of N170 amplitudes, stronger face-minus-house

N170 component was also associated with higher subjective confidence, supporting the notion that N170 is a graded response.

The analyses conducted so far confirm that both the overall N170 and the face-minus-house N170 component grade with stimulus duration and subjective confidence that the stimulus was a face. However, a conclusion that the N170 is generated in a graded fashion would be premature. In the first half of the experiment, we presented all stimuli for 17ms, while in the second half the stimulus duration was either 17ms or 200ms. It remains possible that, although the N170 is generated all-or-none, this discrepancy in parameters may result in distinct amplitudes of the “full” N170 in the two halves, which further led to the observed differences of N170 between 17ms and 200ms conditions in the above results. In other words, if the “full” N170 differed between the two halves, the conclusion that the N170 is generated in a graded manner would still be premature. In this case, the generation of the N170 needs to be tested with faces presented for different durations in the same blocks where the “full” N170 remains constant. On the contrary, if the “full” N170 is similar for the two halves, it would be safer to draw the conclusion that the N170 is graded. Therefore, it is critical to examine whether the “full” N170 was different between the first and second halves before drawing concrete conclusions on the N170 generation. To do so, we compared N170 amplitudes for faces that were presented for 17ms and perceived with high subjective confidence in the two halves to explore whether their “full” N170 is comparable. We additionally inspected the amplitudes for faces presented for 17ms and 200ms with high subjective confidence in the same half to examine whether the N170 is generated in graded fashion or is all-or-none in nature.

3.4. Potentials from trials with high confidence

The main point of interest in this study was to test the amplitude differences between durations when participants had similarly high subjective confidence about the nature of the stimulus. In the following analyses we only include trials in which intact stimuli were presented and high confidence was reported. Because we only included the 200ms duration in the second half of the experiment, we created a new factor for the LMM analysis, Duration Half, which had three levels: 17ms_half1, 17ms_half2, and 200ms_half2.

The grand average ERP waveforms and topographic maps corresponding to the P1 and N170 time-windows are shown in Figure 6D and 6C, respectively. We submitted the LMM results to pairwise contrasts and pairwise interaction contrasts to test the influence of Duration Half on overall ERP amplitudes and the face-minus-house components of both P1 and N170.

3.4.1. P1 amplitudes

The estimated marginal means of P1 amplitudes in each condition are displayed in Figure 6A. Pairwise contrasts, corrected with Bonferroni methods for three tests, explored the influence of Duration Half on P1 amplitude. These contrasts reveal that all comparisons were equivalent to the null effect for both hemisphere electrodes ($|t| > 2.49, p < .007$). Pairwise interaction contrasts for the face-minus-house P1 component, again corrected with Bonferroni tests for three tests, revealed inconclusive results (NHST: $|t| < 0.76, p > .99$; ET: $|t| < 1.71, p > .13$) with the exception that the comparison between 17ms_half1 and 200ms_half2 was equivalent to the null effect ($t(4863.0) = 2.30, p = .03, b = -0.00, 90\% CI = [-0.46, 0.46]$). Overall, these results revealed no systematic influence of Half or Duration on P1 amplitudes for intact stimuli perceived with high confidence.

Figure 6. ERP results for intact stimuli with high subjective confidence as a function of Hemisphere (left vs. right), Category (faces vs. houses), and Duration Half (17ms_half1, 17ms_half2, vs. 200ms_half2. A and B depict the estimated marginal means of P1 and N170 amplitudes, respectively; error bars represent 95% confidence intervals. C, Topographic maps corresponding to the P1 and N170 components. The grey dots in the schematic brain denote the channel locations for both P1 and N170 on both hemispheres. D, The grand average ERP waveforms. The grey dashed rectangular denotes the time-window for the P1 (96ms – 136ms), while the grey solid rectangular denotes the time windows for the N170 (152-192ms). Please see Figure S3 in supplementary materials for colour topographic maps.

3.4.2. N170 amplitudes

The estimated marginal means of N170 amplitudes in each condition are displayed in Figure 6B. Differences of N170 amplitudes between levels of Duration Half were compared with pairwise contrasts, corrected using Bonferroni corrections for three tests. These contrasts revealed two important results, which were similar for both hemispheres. First, N170 amplitudes were weaker for the 17ms_half1 condition compared to those for both the 17ms_half2 (left: $t(18306.7) = 3.97, p < .001, b = 0.60, 95\% CI = [0.24, 0.96]$; right: $t(18304.0) = 6.59, p < .001, b = 1.00, 95\% CI = [0.64, 1.36]$) and 200ms_half2 (left: $t(17686.7) = 4.38, p < .001, b = 0.56, 95\% CI = [0.25, 0.86]$; right: $t(17334.1) = 7.17, p < .001, b = 0.91, 95\% CI = [0.61, 1.22]$) conditions. These results, especially the differences between 17ms_half1 and 17ms_half2, suggest that the “full” N170 differs between the two halves of the experiment. Thus, it is critical to inspect the N170 generation with amplitudes in the same blocks, as shown following. In the second half of the experiment (i.e., the same blocks), the differences in N170 amplitudes between 17ms and 200ms conditions were statistically equivalent to the null effect (left: $t(18181.2) = 2.79, p = .008, b = -0.04, 90\% CI = [-0.39, 0.30]$; right: $t(18079.2) = 2.53, p = .02, b = -0.09, 90\% CI = [-0.43, 0.26]$). This result suggests that a “full” N170 is generated once a face is perceived with high subjective confidence regardless of stimulus duration.

We also analysed the influence of Duration Half on the face-minus-house N170 component, again using pairwise interaction contrasts corrected with Bonferroni methods for three tests. We again found similar effects for both hemispheres. The differences in face-minus-house N170 component between 17ms_half1 and 17ms_half2 conditions were inconclusive for both hemispheres (NHST: $|t| < 1.3, p > .68$; ET: $|t| < 1.56, p > .17$). Nevertheless, the amplitudes in both conditions were weaker than those for the 200ms_half2

condition (17ms_half1 left hemisphere: $t(7112.0) = 6.58, p < .001, b = 1.56, 95\% CI = [0.99, 2.12]$; 17ms_half1 right hemisphere: $t(2326.2) = 8.58, p < .001, b = 1.97, 95\% CI = [1.42, 2.52]$; 17ms_half2 left: $t(13731.6) = 6.68, p < .001, b = 1.90, 95\% CI = [1.22, 2.58]$; 17ms_half2 right: $t(7615.6) = 6.82, p < .001, b = 1.92, 95\% CI = [1.24, 2.59]$). The face-minus-house N170 component was stronger when faces were presented for 200ms relative to 17ms, although stimuli were perceived with high subjective confidence in each case.

4. Discussion

We sought a resolution to the question of whether visual categorization is supported by graded or all-or-none neural mechanisms by inspecting the generation of the N170. To achieve this, we explored the influence of stimulus category (face vs. house; intact vs. scrambled) and duration (17ms vs. 200ms) on the N170 amplitudes, as well as their associations with subjective confidence. We analysed these components in three different ways. In our first analysis, in which we averaged across subjective confidence, we replicated previous observations (Carbon et al., 2005; Tanskanen et al., 2007) that N170 amplitude evoked by intact faces is greater for longer compared to shorter stimulus durations. This finding also concurs with earlier observations of the effects of stimulus onset asynchrony (Eiserbeck et al., 2021; Nasr, 2010) and visual noise (Bankó et al., 2011a; Jemel et al., 2003; Navajas et al., 2013; Philiastides et al., 2006; Philiastides & Sajda, 2006; Schneider et al., 2007) on N170 amplitudes. These studies, and the results of our first analysis, suggest that stimuli with more facial information (temporal or spatial) elicit stronger N170 (or M170) responses. In other words, without considering subjective confidence, our first analysis appears to support the hypothesis that the N170 is a graded response. However, neither our first analysis nor those presented in the earlier studies can rule out the possibility that the

N170 amplitudes observed for brief stimuli are lower because the response is diluted by including trials in which the face stimulus was not detected.

Since detected faces usually evoke greater N170 responses than undetected faces (Fisch et al., 2009; Navajas et al., 2013; Rodríguez et al., 2012), our second analysis explored N170 amplitudes further by considering subjective confidence. In the critical conditions, in which stimuli were correctly categorized with equally high subjective confidence, faces presented for longer durations still evoked greater N170 amplitudes. This finding also appears to support the hypothesis that N170 is a graded response that reflects the subjective strength of the percept of a face. However, this conclusion, too, was undermined because the discrepancy in parameters may lead to differences in the “full” N170 between the first and second halves of the experiment, which in turn could explain the different N170 amplitudes for varying durations. Accordingly, we further examined differences between the N170 evoked by briefly presented faces in the two halves, as well as between faces presented for 17ms or 200ms in the second half of the recording session.

Our final analysis first revealed that N170 amplitudes evoked by faces presented for 17ms and perceived with high subjective confidence were stronger in the second half of the experiment than the first. This might stem from lack of previous knowledge of the faces during the first half where all stimuli were presented for 17ms. Participants may not have had a clear idea of what the face images looked like until they saw the longer-duration stimuli in the second half. In spite of the fact that N170 amplitudes evoked by intact faces for 17ms were stronger in the second half of the experiment, the face-minus-house component was more likely to remain comparable between the two halves. Hence, the differences of the N170 between halves should be attributable to the non-face contribution to the N1/N170 complex. This implies that no matter what causes the stronger N170 in the second halves, the influence on the N170 is not specific to faces.

Since the “full” N170 differs between the first and second halves of the experiment, the N170 generation should be tested within the same blocks. In comparing N170 amplitudes from the same half, the conclusion that the N170 is a graded response is undermined. Specifically, ET revealed that N170 amplitudes in the second half were comparable between 17ms and 200ms conditions when faces were perceived with high subjective confidence. This analysis suggests that rather than being a graded response, the N170 is generated in an all-or-none manner once a face is perceived. All stimuli that were correctly perceived as faces with high subjective confidence appear to have evoked similar N170 amplitudes, regardless of stimulus duration. This conclusion implies that the appearance that N170 grades in strength with stimulus information or subjective confidence is an artefact of mixing heterogeneous trial types in signal averaging.

Distinct from the comparable N170 amplitudes in the 17ms and 200ms conditions with high subjective confidence, the face-minus-house N170 component was higher in amplitude in the 200ms condition than in the 17ms condition when similar high subjective confidence was reported. This result does not seem to be consistent with a recent study which employed rapid serial visual presentation and did not observe the differences in face-minus-nonface signals evoked by stimuli presented for different durations (Retter et al., 2020). This inconsistency may result from the different methods used in the two studies and, therefore, the signals measured may reflect different aspects of ERPs. More specifically, Retter and colleagues (2020) analysed the implicit frequency-tagged face-minus-nonface EEG responses, which are likely to reflect the combined contributions of both early and late ERP components. In other words, their results may suggest that the mixed combinations of face-minus-nonface P1, N170, N250 and other later components were comparable when faces were perceived regardless of stimulus duration. By contrast, our study estimated the ERPs for each component directly. These results suggest that the face-minus-house N170 component

was stronger for stimuli presented for longer durations. This finding, in addition to the observation of comparable N170 for faces with varying duration, indicates that although stimulus duration impacted the general component, potentially also the face-minus-house N1/N170 component, a “full” N170 is always achieved whenever a face is perceived, corroborating that the N170 is generated in all-or-none.

In addition to the N170, we also examined P1 amplitudes in each condition. We found similar P1 amplitudes evoked by intact stimuli in 17ms and 200ms conditions. However, some previous studies have reported that faces embedded in noise evoked stronger P1 amplitudes (Bankó et al., 2011; Rousselet et al., 2008; Schneider et al., 2007; Tanskanen et al., 2005; Tarkiainen et al., 2002; but see Jemel et al., 2003). The discrepancy might result from the fact that embedding faces in noise alters the low-level properties of stimuli, as well as the facial information. In contrast, the low-level information of stimuli remains the same when stimuli were presented for various durations, further leading to comparable P1 amplitudes.

The only factor affecting the P1 amplitudes observed in this study was subjective confidence. Stronger P1 amplitudes were associated with higher confidence for categorization, and the strongest P1 amplitudes were observed when participants were sure what the stimuli were. Interestingly, the N170 for faces was also affected by the subjective confidence in the similar way, i.e., stronger N170 amplitudes being linked with higher confidence. These connections may indicate that the perception of low-level information (indexed by the stronger P1) is a prerequisite for the possible higher-level processing, e.g., categorization with high confidence (indexed by the stronger N170). Specifically, stronger P1 may reflect more attention was allocated on the stimuli, which renders it possible to perceive the stimuli with high subjective confidence.

In this study, we grouped N170 amplitudes by participants' subjective confidence, which should reflect their subjective perception, and observed that the effects of durations on the N170 disappeared, suggesting that weaker N170 reflects the uncertainty of face perception but not the direct impact of limited stimulus durations. Since faces with shorter durations or more noise are both associated with lower stimulus visibility, it may be that similar differences in subjective perception, rather than the direct effect of noise, are linked with N170 differences in previous studies (Bestelmeyer et al., 2008; Horovitz et al., 2004; Németh et al., 2014; Tarkiainen et al., 2002). It is not a coincidence that subjective perception can dissociate trials generating full N170 from others, as the N170 is believed to be the index of subjective face perception/awareness (Rossion, 2014; Rossion & Jacques, 2011). These results provide further support to categorisation of faces occurring in all-or-none fashion.

Given the relationships between subjective perception and the N170(P1), we may need to re-consider the conclusions of other neural indicators drawn from previous studies where subjective perception might vary in different experimental conditions. For example, apart from the N170, stimulus visibility, which was controlled by shortening stimulus durations or adding noise, was also found to modulate the N1 (Bacon-Macé et al., 2005; Haider et al., 1964), N250 (Carbon et al., 2005; Jemel et al., 2010), P300/M300 (Carbon et al., 2005; Philiastides & Sajda, 2006; Tanskanen et al., 2007), other ERP components (Jemel et al., 2010; Nasr, 2010), and even neuro-imaging responses (Bar et al., 2001; Natu et al., 2016). For these studies, caution is needed in drawing conclusions of a graded response before taking into account subjective perception of the stimuli.

We applied some relatively new statistical methods in this study. First, LMM incorporating both by-subject and by-stimulus random effects enables us to generalize our results not only to similar participants, but also to similar stimuli. Moreover, in addition to the conventional NHST, which can test whether there are significant differences but provides no

mechanism for endorsing the null hypothesis (Cohen, 1994), we employed ET to test whether the effects of interest are compatible with the null hypothesis. ET is of great importance in providing evidence for accepting amplitude differences between durations being equivalent to null effects, which corroborates the all-or-none hypothesis.

In summary, our study showed that the “full” N170 is generated once a face is perceived with high subjective confidence, supporting the all-or-none hypothesis for the N170 generation. These results further suggest that categorisation of faces also occurs in a similar all-or-none fashion.

Contributions:

Haiyang Jin: conceptualization, data curation, formal analysis, validation, investigation, methodology, project administration, resources, visualization, writing – original draft, writing – review & editing

William G. Hayward: conceptualization, funding acquisition, supervision, writing – review & editing

Paul M. Corballis: conceptualization, funding acquisition, supervision, writing – review & editing

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