# Electrophysiological evidence for differences between fusion and combination illusions in audiovisual speech perception

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**Title: Electrophysiological evidence for differences between fusion and combination illusions in audiovisual speech perception.**

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**Abstract**

**Incongruent audiovisual speech stimuli can lead to perceptual illusions such as fusions or combinations. Here, we investigated the underlying** audiovisual integration process by measuring ERPs. We observed that **visual speech-induced** suppression of P2 amplitude (which is generally taken as a measure of audiovisual integration) for fusions was **comparable** to suppression obtained with **fully** congruent stimuli, whereas P2 suppression for combinations was larger. **We argue that these effects arise because the phonetic incongruency is solved differently for both types of stimuli.**

## Introduction

When a speech sound (A, for auditory speech) is accompanied by the speaker's articulatory gestures (V, for visual speech), the listener's brain integrates the unimodal signals. Audiovisual (AV) speech integration can lead to percepts that correspond to the phonetic identity of the visual (or auditory) component (e.g., Alsius et al., 2014; Saint-Amour et al., 2007; Tuomainen et al., 2005), but can also lead to percepts that are different from either A or V. This is evident from a highly influential paper by McGurk and MacDonald (1976) who showed that seeing "g" while the actual speech sound is a "b" (i.e., $A_bV_g$), may yield illusory "d" percepts. This effect is usually referred to as a McGurk fusion (e.g., Green et al. 1991; Schwartz, 2010; Sekiyama & Tohkura, 1991; Tiippana, 2014; van Wassenhove, 2013; van Wassenhove et al., 2005), as the brain solves the phonetic AV conflict by fusing the place of articulation cues. Such fusions do not always occur; changing the modality of the conflicting consonants can produce a combination percept in which both A and

V are represented (i.e., $A_gV_b$, is perceived as "bg" or "gb", e.g., MacDonald & McGurk, 1978).

Colin et al. (2002) showed that fusions tend to occur more often with voiced consonants (e.g., "b", "g") whereas combinations are more prominent with voiceless ones (e.g., "p", "k"). Moreover, fusions show a left hemifield advantage (when V is presented in the left hemifield), and combinations a right hemifield one (Diesch, 1995). It thus appears that fusion and combination percepts may not necessarily be driven by the exact same processes. Here, we explored whether the electrophysiological correlates of AV integration are different for McGurk fusion and combination stimuli.

Past work has demonstrated that effects of AV speech integration are characterized by V-induced speeding-up and suppression of the auditory evoked N1 and P2 peaks (e.g., Klucharev et al., 2003; van Wassenhove et al., 2005, see Baart, 2016, for a meta-analysis). Although phonetic AV integration is reflected at the P2 (Baart et al., 2014), the complete process requires a subsequent feedback loop that involves STS (Arnal et al., 2009). Therefore, we hypothesized that differences in AV integration patterns between McGurk fusions and combinations at/after the P2, could hint at differences related to congruency processing. To investigate this, we compared V-induced electrophysiological effects for McGurk fusions and combinations with the effects obtained with AV congruent stimuli.

## Materials and Methods

### Participants

38 right-handed native speakers of Spanish with (corrected-to) normal vision and no known hearing or neurological impairments participated in return for a 10€/hour payment. All participants provided written informed consent prior to testing. The experiment was conducted in accordance with the Declaration of Helsinki. Six participants were excluded from analyses (four had substantial artifacts in the EEG, one mixed-up response categories, and one was removed due to software failure). Mean age in the final sample of 32 participants (19 females) was 23.5 years (SD = .51).

### Stimuli

A male speaker (MB) was recorded with a digital video camera (videos were framed as headshots) and its internal microphone (Canon Legria HF G10, 25 frames/s) while pronouncing /bi/ and /gi/. With FFmpeg, AV /bi/ and /gi/ video segments were extracted from the recordings, and sounds were extracted from the segments (and equated in maximum intensity). The first three and final two frames of the videos were faded in/out, and the videos were saved as bitmaps strings (30 bitmaps per video). AV stimulus presentations consisted of auditory /bi/ and /gi/ and a simultaneously presented /bi/ or /gi/ bitmap string (40 ms/bitmap, 520 ms of anticipatory motion before sound onset), resulting in two AV congruent stimuli ($A_bV_b$, $A_gV_g$) one fusion stimulus ($A_bV_g$), and one combination stimulus ($A_gV_b$). For V-only presentations ($V_b$, $V_g$), the /bi/ and /gi/ bitmaps were delivered in silence, and for auditory only presentations ($A_b$, $A_g$), the bitmap string consisted of black images.

**Procedure**

Participants sat in front of a 17-in. CRT monitor (100 Hz vertical refresh) in a dimly lit booth. Speech sounds were delivered via two regular computer speakers (placed on both sides of the monitor) at an intensity of ~67 dB(A). Videos were 20.6 (W) × 22.5 (H) cm in size. In total, 640 trials were presented in random order. Half of the trials were unimodal ($A_b$, $A_g$, $V_b$, $V_g$), and half were **bimodal** ($A_bV_b$, $A_gV_g$, $A_bV_g$, $A_gV_b$). Each stimulus was presented 80 times. During a trial, a 1200 ms black screen was followed by a white fixation cross (400 ms) and a period of silence that jittered between 1000 and 1400 ms. Next, the stimulus was presented, which was followed by a response screen that appeared 1000 ms after the last video frame had disappeared. On the response screen, four response categories were presented horizontally in print ("b", "g", "d", "bg/gb"), and participants indicated which alternative corresponded to their percept. Responses were collected with four fingers of the right hand via the F5 through F8 keys on a regular keyboard (inverted by 180°), and each response category was randomly assigned to a finger for each participant. As soon as a response was collected, the next trial began. There were five ~12 min. blocks with self-paced breaks in between. The experiment was preceded by a six trial practice block that contained two A, two V and two congruent AV trials.

**EEG recording**

The Electroencephalogram (EEG) was recorded at a 500 Hz sampling rate using a 32-channel BrainAmp system (Brain Products GmbH) and 28 Ag/AgCl electrodes that were placed in an EasyCap recording cap. Electrode locations corresponded to a subset of the international 10-10 placement system and included Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, CP5, CP1,

CP2, CP6, P7, P3, Pz, P4, P8, O1, O2, and FCz (ground). Four electrodes (2 on the orbital ridge above and below the right eye, and 2 next to the lateral canthi of both eyes) recorded the vertical- and horizontal Electro-oculogram (EOG). Two additional electrodes were placed on the mastoids, of which the left was used to reference the signal on-line. After placement of the cap, electrode impedance was adjusted to < 5 kΩ (scalp electrodes) and < 10 kΩ (EOG electrodes).

**Preprocessing of Event-related potentials (ERPs)**

Using Brain Vision Analyzer 2.0, the signal was re-referenced off-line to an average of the two mastoid electrodes and high-pass filtered (0.1 Hz 24 dB/ octave). Next, coarse non-ocular artifacts (EMG bursts or glitches, defined as amplitude changes > 70 µV/ms), were identified, and the data were decomposed into 32 independent components (restricted infomax). Components that captured EOG activity (2.6 on average, identified through visual inspection) and ECG activity (present in 10 participants, identified at the right mastoid) were removed. The data was low-pass filtered (30 Hz 24 dB/ octave) and segmented into 1720 ms epochs. **The V as well as the AV epochs contained 200 ms before onset of the video. Auditory onset lagged video onset by 520ms. Accordingly, the A (and AV) epochs contained 720 ms before sound onset.**

Epochs that contained additional artifacts (amplitude changes > 30 µV/ms, and amplitudes </> -100/100 µV, or < .5 µV/200 ms) were removed. Four participants with high artifact rates (> 47% per condition) were excluded from analyses. For the remaining participants (N = 32) mean artifact rate was < 11% per condition. The data was base-line corrected using the 200 ms pre-video time-window, averaged per condition, and exported for statistical analyses.

## Results and Statistical Analyses

**Behavioral responses**

We computed the averaged proportions of "b", "g", "d", and "bg/gb" responses per stimulus and submitted these data to an 8 (Stimulus; Ab, Ag, Vb, Vg, AbVb, AgVg, AbVg, AgVb) × 4 (Response category; "b", "g", "d", "bg/gb") repeated measures ANOVA. The ANOVA revealed an interaction effect, $F(21,651) = 156.33$, $p < .001$, $\eta_p^2 = .835$, indicating that the stimuli were perceived differently, and as intended (see Figure 1). This was confirmed in eight FDR-corrected pair-wise comparisons that tested the proportion of 'correct' responses (i.e., "b" for $A_b$, $V_b$, $A_bV_b$, "g" for $A_g$, $V_g$, $A_gV_g$, "d" for $A_bV_g$, and "bg/gb" for $A_gV_b$) against the sum of all other proportions for each stimulus, $ts(31) > 2.53$, $ps < .017$, $ds$ in between .447 and 3.06. Figure 1 additionally displays the 24 comparisons between 'correct' responses and all individual response categories.

To compare the strength of the fusion and combination illusions, we also tested the proportions of "d" responses on fusion stimuli against the proportion of "bg/gb" responses on combination stimuli, but this difference was not significant, $t < 1$.

**ERP data**

Following an additive model, AV integration effects can be captured by comparing A-only ERPs with AV – V difference waves (e.g., Alsius et al., 2014; Baart et al., 2014; Besle et al., 2004; Giard & Besle, 2010; Stekelenburg & Vroomen, 2007). Figure 2a displays the A-only grand averages and the AV – V difference waves at electrode Cz for the conditions with auditory "b" ($A_b$, $A_bV_b$ – $V_b$ and $A_bV_g$ – $V_g$; left panel) and auditory "g" ($A_g$, $A_gV_g$ – $V_g$ and $A_gV_b$ – $V_b$; right panel).

As indicated in Figure 2a, the averaged P2 peaks for $A_g$, $A_gV_g$, and $A_gV_b - V_b$ are not as well-defined as for $A_b$, $A_bV_b$, and $A_bV_g - V_g$. Because individual peaks in those conditions could not always be determined, our analyses contained two steps. First, we cast a wide temporal net around the effects of interest by computing the average amplitude at electrode Cz in relatively large time-windows around the N1 (100-200 ms) and P2 (200-300 ms), and we analyzed those amplitudes in repeated measures ANOVAs. The second step comprised of a more detailed analyses between conditions using FDR corrected pair-wise t-tests that included all electrodes (see Figure 2b).

For the N1, a 3 (Stimulus type; A, AV congruent [i.e., $A_bV_b - V_b$ and $A_gV_g - V_g$], AV incongruent [i.e., $A_bV_g - V_g$ and $A_gV_b - V_b$]) × 2 (Auditory component, /b/ or /g/) repeated measures ANOVA showed a main effect of Stimulus type, $F(2,62) = 6.15$, $p = .004$, $\eta_p^2 = .166$, because V had suppressed the N1 for both congruent and incongruent stimuli, $ts(31) > 2.39$, $ps < .024$, $ds > .428$. There was also a main effect of Auditory component, $F(1,31) = 16.05$, $p < .001$, $\eta_p^2 = .341$, as overall N1 amplitude was larger for auditory "g" than "b" stimuli. There was no interaction between the two factors, $F < 1$. This was confirmed in a 2 (Stimulus type; AV congruent, AV incongruent) × 2 (Auditory component, /b/ or /g/) ANOVA without the A-only data, which also revealed no interaction, $F < 1$.

For the P2, the 3 × 2 ANOVA also yielded a main effect of Stimulus type, $F(2,62) = 6.39$, $p = .003$, $\eta_p^2 = .171$, as V had suppressed the P2 for congruent and incongruent stimuli, $ts(31) > 2.63$, $ps < .012$, $ds > .465$. There was a main effect of Auditory component, $F(1,31) = 30.90$, $p < .001$, $\eta_p^2 = .499$, as the overall P2

amplitude was larger for auditory "b" stimuli than for auditory "g" stimuli. The interaction was significant, $F(2,62) = 5.57$, $p = .006$, $\eta_p^2 = .152$, and was also observed when the auditory-only stimuli were omitted from the ANOVA, $F(1,31) = 6.45$, $p = .016$, $\eta_p^2 = .172$, because for $A_b$, P2 amplitude was alike for congruent stimuli and fusion stimuli, $t(31) = 1.63$, $p = .113$, $d = .289$, whereas for $A_g$, P2 suppression was larger for combinations than for congruent stimuli, $t(31) = 2.71$, $p = .011$, $d = .490$.

The results of the FDR corrected pair-wise t-tests are displayed in Figure 2b, and confirm that V had indeed suppressed (and possibly sped-up the N1 and) P2. Most importantly, P2 suppression was larger for McGurk combinations ($A_gV_b - V_b$) than for congruent $A_gV_g - V_g$, whereas there were no significant differences between fusions ($A_bV_g - V_g$) and congruent $A_bV_b - V_b$. When averaging amplitude at Cz in a 190-200 ms and 360-440 ms window however, the differences between $A_bV_b - V_b$ and fusions were significant, $ts(31) > 2.21$, $ps < .035$, $ds > .391$, but these differences did not correspond to the ERP peaks under investigation, and lost significance in the FDR correction.

## Discussion

We sought to determine whether the electrophysiological correlates of AV integration at the N1/P2 are different for McGurk fusions and combinations. V-induced suppression of the N1/P2 is generally interpreted as an effect of AV integration, and from that perspective, it is evident that A and V are integrated in both types of McGurk stimuli. There was however, one important difference between fusions and combinations.

For fusions, P2 suppression was equal to the suppression effect for congruent $A_bV_b$. This is in line with Figure 2 in van Wassenhove et al. (2005) where the fusion AV P2 amplitude ($A_pV_k$, fusion percept = "t") is more similar to the amplitude of congruent stimuli with the same auditory component ($A_pV_p$), than to the amplitude of the AV congruent stimulus with same auditory component as the fusion ($A_tV_t$). For combinations however, we observed that P2 suppression was significantly larger than the effect observed with congruent $A_gV_g$.

Interestingly, V-induced suppression of the auditory P2 is larger for AV incongruent than congruent speech (such as when auditory "fu" is combined with lip-read "bi", see Stekelenburg & Vroomen, 2007). The current findings therefore suggest that the AV incongruency in combination stimuli has a different impact than the incongruency in fusion stimuli: relatively early processing (measured at the P2) of combination stimuli resembles the pattern observed with fully phonetically AV incongruent material (Stekelenburg & Vroomen, 2007), whereas the P2 suppression for fusions resembles the pattern of AV congruent speech. It may thus be that the differences between fusions and combinations reflect differences in processing of AV congruency, which is supported by the clear differences between the combination difference wave and all others *after* the P2 (in line with Arnal et al., 2009, who argued that processing of AV congruency requires multiple feedback loops).

However, it is possible that listeners did not notice the AV incongruency in combination stimuli (this was not measured), and the differences between fusions and combinations may therefore be explained by other stimulus features. For example, in consonant-vowel stimuli, the (latency) and amplitude of the N1/P2 can

reflect stimulus differences in voice onset time (e.g., Digeser et al., 2009; Tremblay et al., 2003), amplitude rise time, and rate of formant transition (Carpenter & Shahin, 2013). If such basic acoustic features modulate the P2, it is possible that the difference between the McGurk combinations and fusions is related to the fact that in combinations, *two* consonants instead of one are perceived, despite that physically, all our AV stimuli contained only one auditory consonant. Related to this, fusion likely occurs in AV congruent stimuli as well as in the McGurk fusion stimulus, and the combination stimulus is thus fundamentally different that all other stimuli.

However, the interpretations outlined above are speculative at this point as they require future work to determine how the number of consonants modulates the ERPs (for example, by including genuine "bg" or "gb" AV congruent speech), and the degree to which combination ERPs resemble those obtained with AV incongruent stimuli in which the phonetic incongruency is impossible to overcome (e.g., "bi" vs. "fu").

**To conclude, we observed that the ERP pattern of AV integration for McGurk fusions clearly differs from combinations. It is unlikely that these differences stem from actual differences in the underlying integration process. Instead, the inherent differences between fusion and combination stimuli differentially constrain the perceptual system when it is trying to solve the AV incongruency.**

## Acknowledgements

## Competing Interests

The authors declare no conflict of interests.

## Author contribution

The study was designed by MB, AL and TSA. MB created the stimuli. AL programmed the experiment. MB oversaw data-collection and analyzed the data. MB, AL and TSA wrote the manuscript.

## Data Accessibility

Anonymized data, stimuli, and details about preprocessing/analyses will be made available to colleagues if requested.

## Abbreviations

A = auditory

AV = audiovisual

EEG = electroencephalogram

EMG = electromyogram

EOG = electro-oculogram

ERP = event-related potential

V = visual lip-read information

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**Figure captions**

Figure 1. Proportions of "b", "g", "d", and "bg/gb" responses per stimulus. Panel a depicts individual data (grey), averages (white), and standard errors of the mean (shaded areas). Significance of the pair-wise comparisons for 'correct' versus 'incorrect' responses per stimulus is indicated below the plots. Panel b shows the corresponding test-statistics, *p*-values and effect-sizes (all significant after FDR correction). 'Stim' indicates stimulus type and 'CR' indicates the correct response to a stimulus.

Figure 2. Auditory grand averages, AV – V difference waves and statistical comparisons. Panel a shows the waveforms at Cz for stimuli with auditory "b" (left column) and auditory "g" (right column). In panel b, time zero corresponds to sound onset, and grey horizontal bars represent significant differences between conditions. For each pair-wise comparison, the ERPs from electrode Cz are overlaid.

## a



## b

| Stim | CR | Response category | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | "b" | | | "g" | | | "d" | | | "bg/gb" | | |
| | | t | p | d | t | p | d | t | p | d | t | p | d |
| Ab | "b" | - | - | - | 23.69 | <.001 | 4.91 | 12.74 | <.001 | 2.25 | 15.73 | <.001 | 2.79 |
| Vb | "b" | - | - | - | 23.11 | <.001 | 5.21 | 12.49 | <.001 | 2.62 | 14.13 | <.001 | 4.29 |
| AbVb | "b" | - | - | - | 33.68 | <.001 | 6.52 | 29.82 | <.001 | 5.45 | 19.81 | <.001 | 3.50 |
| AbVg | "d" | 5.37 | <.001 | .95 | 9.97 | <.001 | 2.29 | - | - | - | 5.37 | <.001 | .95 |
| Ag | "g" | 27.58 | <.001 | 6.71 | - | - | - | 27.01 | <.001 | 5.83 | 12.20 | <.001 | 2.16 |
| Vg | "g" | 16.23 | <.001 | 3.31 | - | - | - | 5.00 | <.001 | .88 | 16.11 | <.001 | 3.19 |
| AgVg | "g" | 33.15 | <.001 | 6.96 | - | - | - | 33.49 | <.001 | 7.16 | 16.20 | <.001 | 2.86 |
| AgVb | "bg/gb" | 10.29 | <.001 | 2.37 | 2.68 | .012 | .47 | 10.41 | <.001 | 2.49 | - | - | - |

## a



## b



Significant after FDR correction for 13500 comparisons
(27 electrodes × 500 samples)