Flexing gender perception: Brain potentials reveal the cognitive permeability of grammatical information

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Abstract

A growing body of recent research suggests that verbal categories, particularly labels, impact categorization and perception. These findings are commonly interpreted as demonstrating the involvement of language on cognition, however, whether these assumptions hold true for grammatical structures has yet to be investigated. In the present study, we investigated the extent to which linguistic information, namely, grammatical gender categories structures cognition to subsequently influence categorical judgments and perception. In a non-verbal categorization task, French-English bilinguals and monolingual English speakers made gender-associated judgments about a set of image pairs while event-related potentials were recorded. The image sets were composed of an object paired with either a female or male face, wherein the object was manipulated for their conceptual gender relatedness and grammatical gender congruency to the sex of the following target face. The results showed that grammatical gender modulated the N1 and P2/VPP, as well as the N300 exclusively for the French-English bilinguals, indicating the inclusion of language in the mechanisms associated with attentional bias and categorization. In contrast, conceptual gender information impacted the monolingual English speakers in the later N300 time window given the absence of a comparable grammatical feature. Such effects of grammatical categories in the early perceptual stream have not been found before, and further provide grounds to suggest that language shapes perception.

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1. Introduction

The question of whether low-level perceptual processes are encapsulated and impervious to high-level cognitive functions remains an issue of ongoing debate (e.g., Firestone & Scholl, 2016; Fodor, 1983; Pinker, 1994). Advocates for encapsulated models have been challenged by recent advances in linguistics and psychology which view the cognitive system as being an interactive architecture implicating top-down influences of prior linguistic knowledge (e.g., Lupyan, 2012, 2016). A considerable amount of empirical evidence now supports the notion that language provides predictive means that regulate perceivers' representation of incoming sensory information (e.g., Lupyan, 2012; Lupyan & Clark, 2015; Simanova, Francken, de Lange, & Bekkering, 2016). Labels are considered to render objects more visible by providing top-down feedback that perceptually heightens shared features among its category members. These findings are commonly taken as support for *linguistic relativity*, a tenet assuming that the languages we speak shape thought in predictable ways (Casasanto, 2008; Lucy, 1997; Whorf, 1956).

While these studies reinforce the idea that languages interact with different domains of cognition, little attention has been given to Whorf's original argument that a language's *grammar* may structure these cognitive mechanisms (Lucy, 2016). To date, a majority of studies have investigated the impact of lexical idiosyncrasies focusing on labeling effects, yet only a handful of studies have empirically addressed the impact of more abstract grammatical instances on non-verbal tasks. In contrast to labels which offer concrete means to encode concepts, Lucy (2016) emphasizes the potential impact of morphosyntactic properties based on structural relations. Any cognitive impact deriving from these morphosyntactic properties suggests that perceivers may somehow transfer the features linked to these structural relations which then impact perceptual experiences. However, the question of how these morphosyntactic properties operate and rapidly calibrate our perceptual integration of reality remains an open question. To further address this issue, the present study specifically focuses on grammatical gender, a morphosyntactic feature that has been frequently explored to investigate questions pertaining to the relationship between language and thought.

Grammatical gender can be found in languages such as French that consist of a binary grammatical gender system, in which all nouns are assigned to either a feminine or masculine category. Apart from animate nouns whose membership to the gender category matches their biological sex (i.e., grammatically feminine = female sex, grammatically masculine = male sex), the gender attribution of inanimate nouns is functionally orthogonal to any of its semantic connotations (Corbett, 1991). Employing this grammatical feature is particularly applicable for discussions on linguistic relativity as they offer examples of linguistic phenomena that are unrelated to real-world differences and are thus considered to be purely linguistic in nature (Bassetti, 2007).

Notwithstanding this assumed arbitrary relationship, studies have reported that when asked to make gender-based decisions, perceivers take into account the grammatical gender of an object to allocate associated gendered traits (e.g., Flaherty, 2001; Konishi, 1993; Sera, Berge, & del Castillo Pintado, 1994; Sera, Elieff, Forbes, Burch, Rodríguez, & Dubois, 2002) or to retain its gender-associated information in memory (Boroditsky, Schmidt, & Phillips, 2003). These findings indicate that perceivers may transfer gender features linked to the grammatical gender category to its referent which can subsequently motivate its perceived conceptual femaleness or maleness (e.g., Boroditsky et al., 2003; Sera et al., 1994). While these findings are commonly interpreted as evidence for the impact of language on cognition, it is plausible that this effect could have been prompted by participants capitalizing on the salient grammatical feature available to them in an effort to resolve the experimental task. Consequently, strategic introspection by means of covert verbal encoding would be inevitable, nullifying the results that aim to argue for the case of linguistic relativity as an unconscious, automatic process.

As a way to depart from such potential confounds, more recent studies have devised non-verbal categorization tasks manipulating the object's grammatical gender blind to the participants. For example, Spanish-English bilinguals and English speaking controls in Boutonnet, Athanasopoulos and Thierry (2012) categorized objects based on their semantic category while event-related potentials (ERP) were being recorded. While an N400 reflecting semantic processing was observed for all participants, a left-anterior negativity (LAN) deflection indexing morphosyntactic processing emerged only for the bilinguals when the grammatical gender of the target object in Spanish was inconsistent with the other objects. Their study demonstrated an automatic deployment of grammatical gender in a task that restricted participants from engaging in covert verbal strategies. Similarly, Sato and Athanasopoulos (2018) attempted to investigate the extent of this potential grammatical activation by also taking into consideration an object's associated conceptual gender, such as whether it is stereotypically related with the female or male gender. French-English bilinguals and monolingual English controls were instructed to make decisions relating to the associated conceptual gender link of an object. The authors found that irrespective of the overt task focusing on conceptual gender, the grammatical gender category to which the object belonged consistently and reliably predicted categorization patterns of the French-English bilinguals.

The findings from these studies establish that perceiving an object can unconsciously activate the corresponding grammatical gender and further support the latent impact this activation has on categorization. However, such findings do not yet allow us to disentangle whether or not these observed categorization patterns are based on cognitive structuring by grammatical information, and whether they may extend to early stages of integration in the visual processing stream. We, therefore, aimed to determine whether or not these grammatical properties contribute in biasing perception and categorization by comparing French-English bilinguals for whom this grammatical feature is available in the first language (L1) and monolingual English controls who do not share such a comparable feature. All participants were tested in an English-speaking environment, which allowed the task to be conducted entirely in the French-English bilinguals' second language (L2) without explicitly referencing their L1. Because bilinguals maintain the activation of both languages independent of its active use (e.g., Abutalebi & Green, 2007; Green, 1986; Marian & Spivey, 2003), any evidence of grammar emerging in the French-English bilinguals' data will provide evidence of the impact of the non-deployed language and how it may shape non-verbal perception. Importantly, we examined ERPs that allow the direct observation of brain activity time-locked to the stimulus event, which consequently provide a better understanding of the time course in which the impact of grammatical gender unfolds during visual perception. Assessing ERP components linked to earlier and later attentional processes in the visual processing stream also allowed us to rule out possible effects of covert verbal strategies, the main research confound mentioned previously.

We adapted Sato and Athanasopoulos's (2018) experimental paradigm where French-English bilinguals and monolingual English speakers made judgments on image sets consisting of stereotypically gender-associated objects paired with either a male or female face. The presented image sets could either have a conceptually gender-related or gender-unrelated link between the object and the face gender, and participants simply indicated whether or not the objects made them think of the succeeding face. Critically, a covert grammatical manipulation was also incorporated, whereupon the grammatical gender of the object could either match or mismatch the following face gender. ERP evidence on gender information processing shows that gender face discrimination can occur as early as 45 ms after face onset, independently of whether gender identification is either intentional or incidental (Mouchetant-Rostaing & Giard, 2003; Mouchetant-Rostaing, Giard, Bentin, Aguera, & Pernier, 2000). If grammatical gender permeates and modulates perceptual processes, these effects should emerge exclusively for the bilinguals during early face processing irrespective of their relevance to the task.

We therefore evaluated early ERP components such as the N1, associated with perceptual expectations and evaluation, as well as the P2 or vertex positive potential (VPP), reflecting the categorical perception of faces. The N1 is a negative-going potential peaking around 100 ms post-stimulus onset which has been associated with directing top-down attentional biases originating in the prefrontal cortex (Di Russo, Martínez, & Hillyard, 2003; Hillyard & Anllo-Vento, 1998). Its subcomponent emerging at anterior-central sites has been considered to index attentional facilitation (Marzecová, Schettino, Widmann, SanMiguel, Kotz, & Schröger, 2018; Qiu, Wei, Li, Yu, Wang, & Zhang, 2009) and is thus modulated by the expectations of concurring stimuli (e.g., Federmeier & Kutas, 2001; Lee, Liu, & Tsai, 2012). The P2/VPP is a positive-going potential peaking around 150 ms at anterior-central sites (Jeffreys, 1989; Joyce & Rossion, 2005) and is the classic ERP correlate of face perception. Specifically, the VPP emerges when averaged mastoids are used as the reference as opposed to the average of all electrodes, where an N170 modulation is typically observed (see Joyce & Rossion, 2005). The N170/VPP complex is thought to reflect the structural encoding of faces, and it is thus modulated by the categorical perception of facial expressions, race, and gender (Ito & Urland, 2005; Kecskés-Kovács, Sulykos, & Czigler, 2013). Recently, Yu, Li, Mo and Mo (2017) showed that this index of structural encoding of faces could also be modulated by newly trained lexical categories, suggesting that categorical perception of faces could be the result of acquired categories. Grammatical gender categories elicited by objects was therefore predicted to affect the structural encoding of faces as indexed by greater P2/VPP modulations for faces whose gender match the grammatical gender of the object primes.

Regarding later stages of the visual processing stream, we expected a modulation of the N300, a negative deflection with an anterior to central-parietal distribution peaking at 300 ms post-stimulus onset indexing pictorial semantic categorization (Eddy, Schmid, & Holcomb, 2006; Hamm, Johnson, & Kirk, 2002; McPherson & Holcomb, 1999). Specifically, the N300 component has been linked with mechanisms of perceptual object identification (Federmeier & Kutas, 2001) and has been found to reflect early matching operations of perceived visual information to that of stored structural representations (Mudrik, Lamy, & Deouell, 2010; Schendan & Kutas, 2002). Greater negativity is elicited by pictures that mismatch semantic categorical information than those that match. Consequently, if the conceptual gender links between the object prime and target face dictate categorization, the N300 should indicate greater negativity for conceptually unrelated trials than related trials for all participants (see Zhang, Li, Sun, & Zuo, 2018). Alternatively, if grammatical gender is activated and instigates a stronger influence than conceptual information, a greater N300 for grammatically incongruent than congruent trials should emerge exclusively for the French-English bilinguals.

Our overall approach of investigating trends observed in early and late time windows known to be associated with brain signatures of attentional facilitation (N1) and categorical perception (P2/VPP), as well as conceptual integration (N300), should better allow us to disentangle the extent of the grammatical influence at play. This will establish whether this influence can be traced at early components of visual integration, as well as later ones.

2. Method

2.1. Participants

Data were collected from 20 French-English bilinguals (14 females; M_{age} = 22.7, SD_{age} = 4.53, age-range = 17 – 34 years) and 20 monolingual English speakers (13 females; M_{age} = 22, SD_{age} = 5.16, age-range = 18 – 34 years) recruited at Lancaster University (U.K.). The study was advertised by means of fliers as well as emails which were specifically sent out to the native French speakers in the university community.

The participants' language background was assessed with a self-rated questionnaire conducted prior to the experiment. The French-English bilinguals had acquired English at school as an L2 (M_{AOA} = 7.75, SD_{AOA} = 2.93, range = 0-11), whereas the English speakers reported little to no knowledge of an L2. Details of the bilinguals' language profile are shown in Table 1.

None of the participants reported having any physical impairments, and all had normal or corrected-to-normal vision. All participants gave written informed consent prior to the experiment and participated in return for payment. The study protocol was approved by the research ethics committee at Lancaster University (U.K.).

------------------------------Insert Table 1 about here -------------------------------

2.2. Stimuli

The stimuli consisted of sets of image pairs, each consisting of an image of an object coupled with a male or a female face (a list of all materials can be found on the Open Science Framework [OSF]: https://osf.io/9w3nh/). A pretest prior to the experiment was conducted with different participants in order to obtain object images that were perceived as being conceptually typical for each gender.

A set of 240 images of inanimate entities, preselected from the Bank of Standardized Stimuli (BOSS; Brodeur et al., 2012; Brodeur, Dionne-Dostie, Montreuil, & Lepage, 2010) were initially rated on a 7-point Likert scale for their conceptual gender association (i.e., “very feminine” [1] to “very masculine” [7]) by ten native French and 13 native English speakers. Based on these ratings, objects that matched in their mean conceptual gender association (i.e., gender prototype) in both of the languages were retained. Subsequently, and critical to our study, we selected objects which had the highest gender association as indicated by the mean ratings of the two language groups and that resulted in half of the names of the objects belonging to a grammatically feminine and the other half to a grammatically masculine category for each conceptual gender association. This created a total of 96 objects; 48 that were judged to have a prototypically female (e.g., *collier* [necklace]) and 48 prototypically male (e.g., *cravate* [necktie]) conceptual association in both French (Female: $M = 2.81$, $SD = 0.76$; Male: $M = 5.21$, $SD = 0.66$) and English (Female: $M = 2.86$, $SD = 0.63$; Male: $M = 5.43$, $SD = 0.61$). Conceptually female and male objects differed significantly in their ratings in each language ($t_{French}(94) = -16.52$, $p < .001$; $t_{English}(94) = -20.23$, $p < .001$), as well as on the average ratings of the two languages (Female: $M = 2.84$, $SD = 0.66$; Male: $M = 5.32$, $SD = 0.6$; $t(94) = -19.26$, $p < .001$). Although past research has shown that grammatical gender can affect conceptual representations (Boroditsky et al., 2003; Imai, Schalk, Saalbach, & Okada, 2014; Kurinski & Sera, 2010), in this particular instance we explicitly asked our participants to make a conscious conceptual gender association as to the femininity or masculinity of the objects. Thus, not surprisingly, results showed no differences in the ratings between the grammatically feminine and masculine objects in both the female (French: $M_{\text{grammatically feminine}} = 2.86$, $SD = .72$, $M_{\text{grammatically masculine}} = 2.76$, $SD = .82$, $t(46) = .44$, *ns.;* English: grammatically feminine: $M_{\text{grammatically feminine}} = 2.98$, $SD = .64$, $M_{\text{grammatically masculine}} = 2.75$, $SD = .61$, $t(46) = 1.27$, *ns.*) and male (French: $M_{\text{grammatically feminine}} = 5.24$, $SD = .67$, $M_{\text{grammatically masculine}} = 5.19$, $SD = .66$, $t(46) = .25$, *ns.;* English: grammatically feminine: $M_{\text{grammatically feminine}} = 5.57$, $SD = .52$, $M_{\text{grammatically masculine}} = 5.29$, $SD = .68$, $t(46) = 1.61$, *ns.*) conceptual gender category. As the selected objects all scored high on each gender typicality and participants were explicitly asked to rate their conceptual gender associations, the impact of grammatical gender on their representations in this pretest is likely to have been limited.

Images of 12 Caucasian female faces and 12 Caucasian male faces were taken from the Chicago Face Database (Ma, Correll, & Wittenbrink, 2015) to be paired with the objects. The selected faces had high typicality scores for perceived femaleness and maleness (female faces: $M_{\text{femaleness}}$: 5.41, $SD_{\text{femaleness}}$: .2, M_{maleness}:1.68, SD_{maleness}: .19; male faces: $M_{\text{femaleness}}$: 1.65, $SD_{\text{femaleness}}$: .23, M_{maleness}: 4.93, SD_{maleness}: .19). All raters from Ma et al.'s (2015) original norming study indicated full agreement to the perceived sex of the selected faces.

Each object was then paired once with an image of a male face and once with a female face to construct two separate items. This yielded 192 critical items for a 2 x 2 factorial design with *conceptual gender relatedness* of the object with the target face sex (related vs. unrelated) and *grammatical gender congruency* of the object with the target face sex (congruent vs. incongruent) as within-participant conditions. As each object was presented twice coupled with a different face sex, each trial was allocated to two separate experimental blocks. Thus, an object appeared only once in each block, with block order being counterbalanced across participants. All trials were randomized for each participant.

The conceptual gender association of the object with the face and their grammatical gender congruency with the face were fully counterbalanced across the experimental conditions. This resulted in 96 conceptually gender-related and 96 conceptually gender-unrelated trials or 96 grammatically congruent and 96 grammatically incongruent trials, with 48 trials in each condition. Details of the experimental conditions and sample items are indicated in Table 2.

-----------------------------Insert Table 2 about here ------------------------------

2.3. Procedure

Participants were tested individually in a dimly lit booth, seated approximately 60 cm from a flat CRT monitor. Stimuli were presented in greyscale against a grey backdrop subtending approximately six visual degrees. The experiment session was conducted entirely in English for all participants so as to avoid any possible indication for the bilingual participants that the task was related to their first language. Responses to the target face were recorded with a button box, and EEG activity was monitored while participants completed the main experimental task.

Each trial was initiated with a pre-stimulus fixation point of 1000 ms presented at the center of the screen, followed by the object image which was displayed for 600 ms. A variable interval randomized between 300 to 500 ms in steps of 50 ms was presented before the target face image appeared on the screen (*Fig*. 1). Participants were instructed to judge if the object made them think of the person represented by the face with a *yes* or *no* button press allocated on the outer edges of the button box. The target face remained on the screen until the participants' responses were registered or 5000 ms elapsed. Although participants did not receive any explicit instructions with regard to response promptness, if a response was not registered within the given time, a feedback display prompted them to react more quickly. In order to minimize eye-movements, the trial finished with a green prompt (+++) where participants were encouraged to blink if needed. A self-timed break was provided with every 12 trials, and six practice items preceded the experiment task.

-----------------------------Insert Figure 1 about here ------------------------------

2.4. EEG recording

EEG was acquired with Curry7 software (Compumedics Neuroscan, USA) attached to a 34-channel elastic cap positioned according to the standard 10-20 system (FP1, FP2, Fz, F3, F4, F7, F8, FT9, FT10, FCz, FC1, FC2, FC5, FC6, Cz, C3, C4, T7, T8, CP1, CP2, CP5, CP6, Pz, P3, P4, P7, P8, Iz, O1, O2, PO9, PO10). EEG recordings were amplified and digitized with NuAmps amplifier (Compumedics Neuroscan, USA) at a sampling rate of 1 kHz. Electrodes were referenced to the left mastoid during recording with a 200 Hz filter , and additional electrodes were placed above and below the eye to record vertical eye-movements and on the outer canthus of each eye to record horizontal eye movements. The impedance of the mastoid and scalp electrodes was maintained below 5 kΩ and the EOG electrodes below 10 kΩ throughout the recordings.

2.5. Data analyses

2.5.1. Behavioral data analyses

Participant's responses to the experimental task generally conformed to our anticipated responses, with conceptually gender related trials being responded with the anticipated "yes" response on 74.19% (*SD* = 43.76) of the trials and conceptually gender unrelated trials being responded with the expected "no" response on 73.63% (*SD* = 44.07) of the trials. However, irrespective of the conformity of participants' responses to our anticipated responses, all individual RTs were subject to analyses (Boutonnet et al., 2012; Sato & Athanasopoulos, 2018). This was because the experimental task was designed to elicit participants' subjective judgments about an object's conceptual gender association, and conscious decisions participants made concerning conceptual gender were not informative regarding the unconscious access to grammatical information.

Before further analyses, all RTs below 100 ms and exceeding more than 2 SD from each within-participant condition means were removed as outliers (4.39 % of all data). RTs were subsequently subject to a three-way repeated measures ANOVA, taking Language group (French-English bilinguals vs. monolingual English speakers) as a between-participant factor, and Conceptual gender relatedness (related vs. unrelated) and Grammatical gender congruency (congruent vs. incongruent) as within-participant factors. See Fig. 2 for the mean RTs.

------------------------------Insert Figure 2 about here -------------------------------

2.5.2. EEG data analyses

EEG data were down-sampled offline at 500 Hz and re-referenced to the average of the two mastoids. The signals were then bandpass filtered at 0.01 and 30 Hz, and eye-movements were identified and corrected with Independent Component Analysis (ICA: Makeig, Anllo-Vento, Jung, Bell, Sejnowski, & Hillyard, 1996). Average ERPs time-locked to the target face stimulus onset were computed from epochs ranging from -100 ms to 600 ms post-stimulus onset and baseline corrected in reference to 100 ms pre-stimulus activity. Epochs with deflections exceeding ±75 µV were automatically removed, and any remaining degraded epochs were manually rejected with visual inspection. This resulted in the removal of 5.75% of the data with a minimum of 41 valid trials per individual condition for all participants. Valid epochs were subsequently averaged to calculate grand averages across participants for each condition.

Visual inspection of the grand-averaged ERPs revealed the expected early and late ERP components in an anterior to central region of interest. The amplitude of the anterior N1 was measured at 60-120 ms, the P2/VPP at 120-180 ms, and the N300 at 250-350 ms, which were consistent with previous literature (e.g., N1: Ho, Schröger, & Kotz, 2015; Ito & Urland, 2005; P2/VPP: Ganis, Smith, & Schendan, 2012; Sui, Zhu, & Han, 2006; N300: Mudrik, et al., 2010; Sitnikova, Holcomb, Kiyonaga, & Kuperberg, 2008). Thus, the mean amplitudes for all three ERP components were analyzed with a four-way repeated measures ANOVA, including Language group (French-English bilinguals vs. monolingual English speakers) as a between-participant factor, and Region (Anterior: Fz, F3, F4, FC1, FCZ, FC2 vs. Central-parietal: C3, CZ, C4, CP1, CP2 vs. Parieto-occipital: P3, PZ, P4, O1, IZ, O2), Conceptual gender relatedness (related vs. unrelated), and Grammatical gender congruency (congruent vs. incongruent) as within-participant factors. The Greenhouse-Geisser correction was applied when sphericity assumptions were violated (Greenhouse & Geisser, 1959). See Fig. 3 for the grand averaged ERPs.

------------------------------Insert Figure 3 about here ------------------------------

3. Results

All data and analysis codes can be found on the Open Science Framework (OSF): https://osf.io/9w3nh/.

3.1. Behavioral results

The analyses revealed a significant main effect of Conceptual gender relatedness [$F(1, 38) = 4.40$, $p < .05$, $\eta_p^2 = .1$], such that RTs for conceptually gender related trials were responded to faster than gender unrelated trials for all participants ($M_{\text{Related}} = 843.82$ ms, $SD_{\text{Related}} = 414.09$ vs. $M_{\text{Unrelated}} = 875.51$ ms, $SD_{\text{Unrelated}} = 406.89$). No other main or interaction effects were significant (all $Fs < 1.1$). In sum, RTs for both language groups were influenced by the conceptual gender link between the image pairs. Critically, there were no indications of grammatical gender impacting the categorization task for either language group.

3.2. ERP results

We begin by presenting the results from later components indexing visual semantic categorization (N300) to earlier components indexing categorical perception of faces (P2/VPP), to the first brain signature of visual discrimination (N1), where an effect of language is the least expected.

3.2.1. N300 (250-350 ms) time window

The analyses yielded a significant main effect of Region [$F(1.21, 46.15) = 52.41$, $p < .001$, $\eta_P^2 = .58$)] and Conceptual gender relatedness [$F(1, 38) = 9.06$, $p < .01$, $\eta_P^2 = .19$)]. The effect of Conceptual gender relatedness was further qualified by a significant interaction with Language group [$F(1, 38) = 3.94$, $p = .05$, $\eta_P^2 = .09$]. This interaction indicated a greater negativity for conceptually gender unrelated than related trials for the monolingual English speakers [$t(19) = 3.94$, $p < .001$], although comparable differences were not found among the French-English bilinguals [$t(19) = .59$, *ns.*].

We also observed a significant interaction between Language group x Region, x Grammatical gender [$F(1.20, 45.51) = 4.14$, $p < .05$, $\eta_P^2 = .1$)], revealing that the Grammatical gender congruency effect varied across scalp regions solely for the French-English bilinguals. Specifically, while there were no differences for Grammatical gender congruency for the monolingual English speakers [anterior: $t(19) =-1.01$, *ns.*; central-parietal: $t(19) = -.61$, *ns.*; parieto-occipital: $t(19) = .15$, *ns.*], grammatically incongruent items indicated a greater negativity than congruent items for French-English bilinguals at the anterior region [anterior: $t(19) = 2.25$, p

$< .05$; central-parietal: $t(19) = 1.73$, *ns.*; parieto-occipital: $t(19) = .69$, *ns.*]. No other main or interaction effects were significant (all *Fs* < 2.79, *ns.*).

In sum, the results showed that grammatical gender exclusively modulated the judgments of the French-English bilinguals as reflected in the N300 emerging in the anterior regions. As for the monolingual English speakers, their judgments were modulated by the Conceptual gender relatedness of the image pairs, although this was not the case for the French-English bilinguals.

3.2.2. P2/VPP (120-180 ms) time window

The analyses yielded a significant Language group x Region x Grammatical gender congruency interaction [$F(1.23, 46.65) = 6.15$, $p < .05$, $\eta_P^2 = .14$]. Follow-up contrasts indicated that the effect of Grammatical gender congruency persisted in the P2/VPP exclusively for the French-English bilinguals. Specifically, greater enhancements were observed for the grammatically congruent than incongruent pairs in the anterior region [$t(19) = 2.8$, $p < .01$], although such differences were not evident in the central-parietal [$t(19) = 1.89$, *ns*.] and the parieto-occipital region [$t(19) = 1.39$, *ns*.] for the French-English bilinguals. In contrast, the monolingual English speakers showed no such differences (all *t*s < 1.65, *ns*.). Importantly, the main effect of Conceptual gender relatedness did not emerge [$F(1, 38) = .26$, *ns*.]. No other main or interactions effects were significant (all *F*s < 3.06, *ns*.).

3.2.3. N1 (60-120 ms) time window

The overall ANOVA revealed significant main effects of Region [$F(1.11, 42.31) = 85.83$, $p < .001$, $\eta_P^2 = .69$] and Grammatical gender congruency [$F(1, 38) = 4.2$, $p < .05$, $\eta_P^2 = .1$], which were qualified by a significant Language group x Region x Grammatical gender congruency interaction [$F(1.14, 43.45) = 3.9$, $p < .05$, $\eta_P^2 = .09$]. Subsequent analyses indicated that while this effect of grammatical gender was absent among the monolingual English speakers (all *ts* < 0.8, *ns.*), the effect of grammatical gender was localized in the frontal regions for the French-English bilinguals. Specifically, grammatically incongruent pairs showed a greater negativity than congruent pairs in the anterior [$t(19) = 2.97$, $p < .001$] and the central-parietal [$t(19) = 2.43$, $p < .05$] regions, but not in the parieto-occipital regions [$t(19) = 1.46$, *ns.*]. We also observed a significant Region x Conceptual gender relatedness interaction [$F(1.16, 44.04) = 3.79$, $p = .05$, $\eta_P^2 = .09$]. However, the source of the interaction did not originate from differences arising between conceptually gender-related and unrelated conditions across scalp regions (all *ts* < 1.81, *ns.*). No other main or interaction effects were significant (all *Fs* < 2.57, *ns.*).

Overall, the results indicated that grammatical gender information exclusively influenced the French-English bilinguals' perceptual judgments on the target face at very early stages of processing, as reflected by the greater negativity for grammatically gender incongruent pairs than congruent pairs in the anterior region. On the other hand, no comparable effects for monolingual English speakers were evident. Importantly, Conceptual gender relatedness between the object and face associations did not modify the N1 for either of the language groups, showing no differences between gender related and unrelated trials.

4. Discussion and conclusion

To assess the contribution of grammatical gender information in regulating perception and categorization, we compared brain signatures associated with stages of visual integration between French-English bilinguals and monolingual English speakers on an object categorization task covertly manipulated for grammatical gender congruency. Overall, we found evidence that grammatical gender congruency between image pairs of an object and a face exclusively impacted the French-English bilinguals' early (anterior N1 and P2/VPP) and late (N300) ERP components. Grammatically gender incongruent trials prompted greater amplitude modulations than gender congruent trials for the N1 and N300, and led to reduced amplitudes for the P2/VPP. On the other hand, monolingual English speakers were not impacted by the grammatical gender manipulation, given the absence of this morphosyntactic property in their linguistic inventory.

The differential patterns occurring in the anterior N1 considered to index attentional facilitation (e.g., Marzecová et al., 2018; Qiu et al., 2009) and the P2/VPP reflecting facial encoding (Joyce & Rossion, 2005), strongly indicate that these grammatical cues offered French-English bilinguals with expectations regarding the evaluation and recognition of the target face stimuli. The time course of these emerging effects is consistent with studies reporting rapid categorization of face stimuli observed as early as 45-85 ms which have been interpreted as indicating coarse visual categorization (Mouchetant-Rostaing et al., 2000). Assuming that our participants had specifically anticipated the target stimuli to be either a female or a male face, it appears that grammatical gender supported this anticipated categorization of gender. Additionally, greater modulations observed in the P2/VPP for grammatically gender congruent than incongruent trials appear to be indicative of the recruitment of attention to gender features that were relevant for resolving the task, as P2/VPP modifications have been shown to be greater for attended facial information as opposed to objects (Jeffreys, 1989; Kovács, Zimmer, Bankó, Harza, Antal, & Vidnyánszky, 2006). This effect of grammatical gender congruency persisted in the later N300 time window signaling that its impact can extend to later processes of perceptual categorization (Federmeier & Kutas, 2001; Sitnikova et al., 2008).

An issue worth mentioning is that this effect arose even though none of the French-English bilinguals reported being aware that the task manipulation was linked to their L1 French. In fact, the experiment was conducted only in English and the task did not require any verbal-processing, which suggests that the L1 French should not have consciously emerged as a function of lexical selection. These findings thus confirm previous studies that contest for the immediate and automated activation of grammatical gender (Boutonnet et al., 2012; Sato & Athanasopoulos, 2018), and is compatible with previous literature showing unconscious activation of the unselected language of the bilingual during both linguistic (Wu & Thierry, 2010) and cognitive (Athanasopoulos et al., 2015) processing. We also demonstrate for the first time that this activation operates in preferentially shifting perceivers' attention involved in the initial stages of facial categorization. Activating grammatical gender upon seeing an object appeared to have biased the bilinguals in directing attention to the relevant gender features of the target face.

Given that grammatical gender is considered to be an arbitrary grammatical property dissociated from any real-world semantic associations, the mechanism for which information about the object's conceptual (i.e., semantic) gender became linked to grammatical gender information remains an open question. In line with recent accounts (Casasanto, 2008, 2016), we argue that this link may arise in the long term from strengthening links between conceptual and grammatical information via the process of associative learning. In essence, grammatical gender comprises two main functions; the first, operating in a purely grammatical manner categorizing all nouns to either gender class, and the second, assigning biological sex for person-reference nouns. Although these two functions are independent of one another, speakers of grammatical gender languages may begin to establish automatized associations between the uninformative grammatical feature with conceptual femaleness and maleness, generalizing the principle that the grammatical marking is associated with conceptual gender even for inanimate nouns where sex or gender should be irrelevant (Vigliocco, Vinson, Paganelli, & Dworzynski, 2005). In the case of our experimental task, participants anticipated the target face to be either female or male to make their judgments. In this regard, information about conceptual gender may have been automatically associated and even emphasized by the nature of the task goals despite the assumed arbitrary link between grammatical and conceptual gender. Our findings show that, in this manner, grammatical gender, a purely a linguistic feature detached from any real-world connections, may become instrumental in integrating and interpreting perceptual information.

Theoretically, our results are in line with noun production models which view grammatical gender (i.e., syntactic information) as comprising an intrinsic part of a noun's lexical representation (Caramazza & Miozzo, 1997; Cubelli, Lotto, Paolieri, Girelli, & Job, 2005; Levelt, Roelofs, & Meyer, 1999). In particular, the Double Selection model by Cubelli et al. (2005) considers access to the phonological form contingent on the selection of both grammatical gender (i.e., syntactic information) and semantic information, irrespective of its relevance for the given task. Such models may explain the grammatical gender effects that have been reported in past studies (e.g., Boroditsky et al., 2003; Flaherty, 2001; Konishi, 1993; Sera et al., 2002), which allowed participants to covertly name the object, thereby retrieving the grammatical gender during the process of lexical access. Nonetheless, object naming cannot fully account for the effects we observed in our study considering that the task paradigm restricted participants from engaging in covert verbal strategies and given the timing in which our effects emerged. Instead, grammatical gender would have been activated through automatic lexical activation instigated when perceivers encountered the object image even though conscious lexical processing was not necessary. Such a view on lexical activation is fully compatible with Lupyan's (2012) label-feedback hypothesis, an account that assumes the immediate activation of category labels upon perceiving visual stimuli which can subsequently afford top-down feedback impacting perception.

As suggested by Casasanto (2008, 2016), we reason that these mechanisms for which verbal labels become immediately activated is brought about by strengthened associations between the grammatical structures and their representations as a result of the repeated monitoring of these grammatical cues in their L1. This is because contrary to conceptual information provided by labels, grammatical gender is an obligatory grammatical category that forces its speakers to attend to it habitually. If speakers do not, the grammatical rules of their language would be violated. As such, being implicitly exposed to these frequently-occurring associations between an object and its grammatical gender property would essentially enhance the cognitive saliency of these linguistic patterns (Langacker, 1987, 2008). Accordingly, this heightened awareness may preferentially construe the perceiver's attention and expectations to properties encoded within this grammatical feature, a function Wolff and Holmes (2011) refer to as a "spotlight" effect. Our results are thus compatible with the notion that grammatical categories may cognitively structure attentional biases that subsequently impact categorization patterns. Importantly, this effect presented even when the French-English bilinguals were in an environment where only English was spoken, indicating that they had uncontrolled access to both languages independent of their use of a given language (e.g., Abutalebi & Green, 2007; Green, 1986; Marian & Spivey, 2003). Such interpretations align well with models of predictive coding which regard perception as being a product of interactions stemming from bottom-up signals and top-down predictions (Clark, 2013; Lupyan & Clark, 2015). According to these accounts, languages can function as a vehicle to access stored representations, which may then generate predictive biases for how the perceiver should recruit their knowledge to assess the information at hand.

As for conceptual gender relatedness, we did not expect to observe this effect in our early time windows. Generating inferences about the object's associated gender requires perceivers to retrieve stored representations that hinge on their prior experiences and world knowledge of probabilistic biases (Canal, Garnham, & Oakhill, 2015). Rather, access to such knowledge sources was assumed to affect later brain signals linked to the identification and integration of semantic information. Consistent with these predictions, the effect of conceptual gender relatedness emerged exclusively for the monolingual English speakers in the later 250-350 ms time window showing greater negative amplitudes for gender unrelated trials than gender related trials. It is worth noting that the effect of conceptual gender relatedness in this N300 time-window presented a widespread distribution, rather than the prototypical anterior distribution. This could suggest the presence of an early N400-like effect which also reflects conceptual-semantic integration (Kutas & Hillyard, 1980; McPherson & Holcomb, 1999). Additionally, the RT measures of both language groups corroborated this later effect, indicating that conceptual gender relatedness of the image pairs was consciously and strategically identified and employed at later stages during decision-making processes of visual information. These findings indicating the perceivers' reliance on world knowledge or semantic information parallel those of past studies capturing similar gender stereotype mismatch effects between congruent and incongruent words on the N400 reflecting semantic processing (Pesciarelli, Scorolli, & Cacciari, 2019; White, Crites, Taylor, & Corral, 2009). In our case, we observed this effect in an analogous, but earlier activity in the N300 temporal window, specific to picture stimuli and reflecting semantic expectancy and categorization (Barrett & Rugg, 1990; McPherson & Holcomb, 1999).

Note, that although the impact of conceptual gender relatedness appeared on the RT measures for both language groups as would be expected, the effect did not emerge for the French-English bilinguals in their N300. Importantly, however, the effect of grammatical gender congruency showed disparate N300 amplitudes for the bilingual participants. While we cannot precisely speak to the reasons why conceptual gender relatedness did not affect the bilinguals' N300 component, the discrepancies in findings between the ERP and behavioral measures reflect that the two sources of gender information may impact different cognitive mechanisms. Specifically, the N300 modulation showed that at the level of semantic integration of categorical information, grammatical gender mismatch, but not conceptual gender mismatch, appears to have an effect for the French-English bilinguals. Alternatively, conceptual gender appears to only impact later decision-making processes, as indicated by its effect emerging in the behavioral measures.

Why, then would grammatical gender congruency not be reflected in the behavioral measures? Previously, it has been argued that grammatical gender congruency effects are more likely to be observed in experimental paradigms using explicit measures (e.g., voice/sex attribution) as opposed to those using implicit paradigms such as ours (Beller, Brattebø, Lavik, Reigstad, & Bender, 2015). In fact, the absence of the grammatical gender congruency effect in the RT measures is reminiscent of the same lack of effect in Boutonnet et al.'s (2012) behavioral measures. Yet rather than being instigated by the task, these results could allude to the transient nature in which language drives these top-down mechanisms during specific tasks (Lupyan, 2012), with the effect of grammar rapidly decaying after initial attentional modulations. After grammatical information was no longer active, the bilinguals could have relied on the overt conceptual gender information to resolve the task, a strategy which was equally employed by the monolingual English speakers.

Discussions regarding Whorfian effects have, for many years, evaluated whether or not language affects human cognition in an all-or-nothing manner. However, current questions surrounding linguistic relativity have evolved, and are now tailored at unraveling a more fine-grained picture of how and at what moment in time language-specific features interact in guiding perceptual experiences, or as what Athanasopoulos and Casaponsa (2020) describe as understanding "language-driven behavior". Bearing these questions in mind, the evidence presented in our study contributes to this current discussion on Whorfian effects by demonstrating that linguistic properties such as grammar can contribute not only to later processes of semantic integration but also to early visual processes that have been considered to be unaffected by higher-level cognitive functions such as language. As implied by Lucy (2016), perceivers can draw on grammatical gender information and make use of its structural relations regarding gender to process perceptual information.

To conclude, our findings reinforce recent assumptions that languages modulate cognition and provide empirical support for the top-down influence of morphosyntactic structures on categorical perception. Grammatical gender cues regulated predictive, attentional mechanisms for visual integration, highlighting features relevant to the task. Our study thus lends further evidence against discussions contesting for encapsulated models of perception and justify views of linguistic relativity that render language as a fully integrative component of human cognition. Future research may broaden our understanding of how our conceptualizations are influenced and subject to shift by the presence of two languages with distinct grammatical categories within an individual.

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Table 1

Language profile for the French-English bilinguals for their L1 French and L2 English. All means are based on self-ratings (Standard deviations are indicated in parentheses).

	French-English bilinguals	
	L1 French *M* (*SD*)	L2 English *M* (*SD*)
Age of Acquisition	0	7.75 (2.93)
Duration of English immersion (months)	-	18.45 (31.74)
Self-reported language proficiency (1 [Extremely bad] – 10 [Extremely good])		
Overall	9.70 (0.57)	7.70 (1.57)
Reading	9.85 (0.37)	8.3 (1.56)
Comprehension	9.85 (0.34)	8.35 (1.27)
Speaking	9.65 (0.59)	7.45 (1.23)
Writing	9.60 (0.75)	7.60 (1.57)
Current usage of the language (%)		
Overall	38.65 (24.01)	61.35 (24.01)
Reading	39.35 (25.01)	60.65 (25.01)
Comprehension	38.15 (28.24)	61.85 (28.24)
Speaking	38.30 (29.36)	61.70 (29.36)
Writing	39.95 (25.66)	60.05 (25.66)

Table 2

Conceptual gender and grammatical gender combinations of object and face image pairs in each experimental condition.

Experimental Conditions		Conceptual Gender of Object	Grammatical Gender of Object	Face Sex
Conceptual Gender Relatedness	Grammatical Gender Congruency			
Conceptually Related	Grammatically Congruent	Female	Feminine	Female
		Male	Masculine	Male
	Grammatically Incongruent	Female	Masculine	Female
		Male	Feminine	Male
Conceptually Unrelated	Grammatically Congruent	Female	Masculine	Male
		Male	Feminine	Female
	Grammatically Incongruent	Female	Feminine	Male
		Male	Masculine	Female

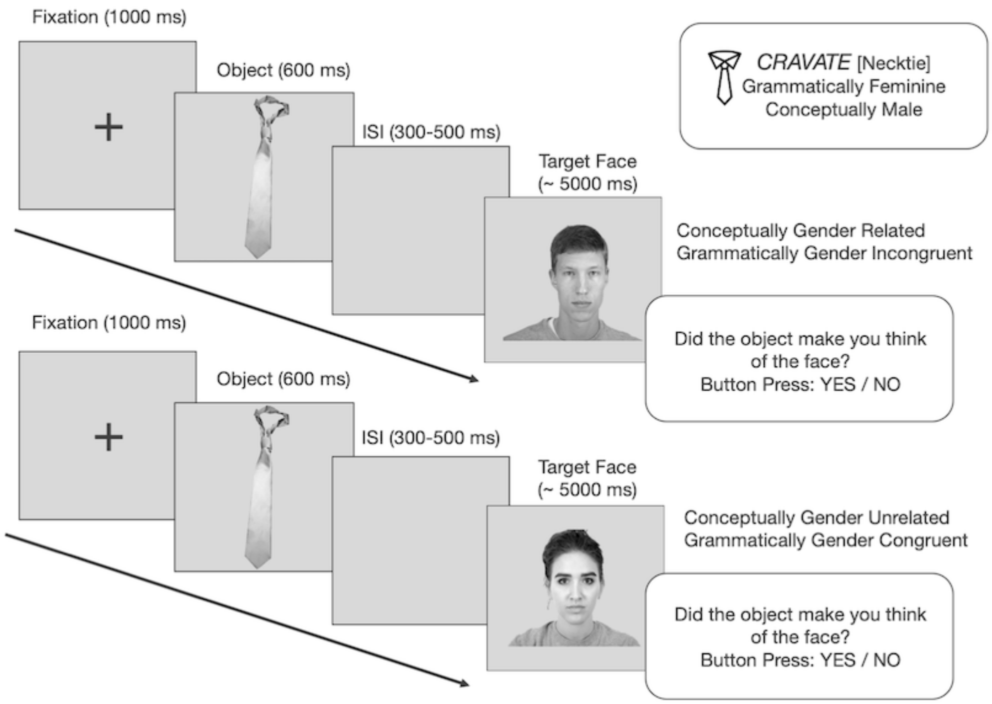

Fig 1. Illustration of a sample trial sequence

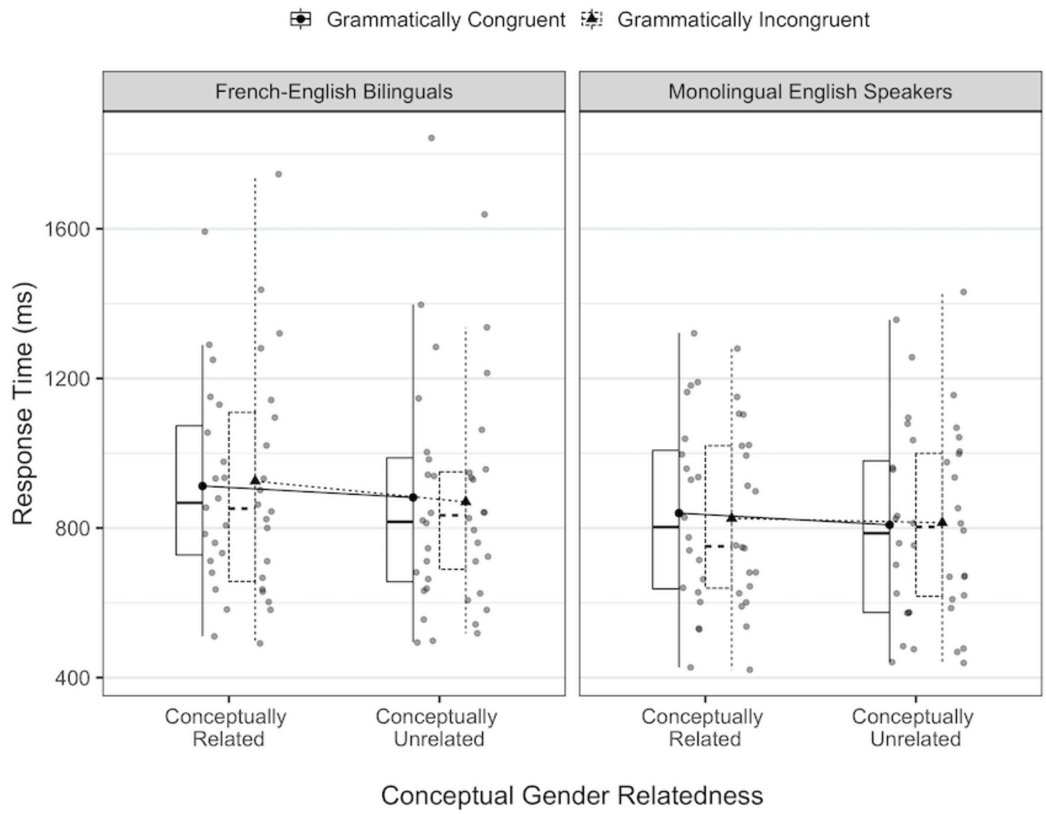

Fig. 2. Response time as a function of Conceptual gender relatedness and Grammatical gender congruency for each language group. Boxplots show the median (horizontal line), mean (central point), first and third (25th and 75th) percentile of the distribution (borders), and the 1.5 x IQR (whiskers). Data from each participant are shown individually.

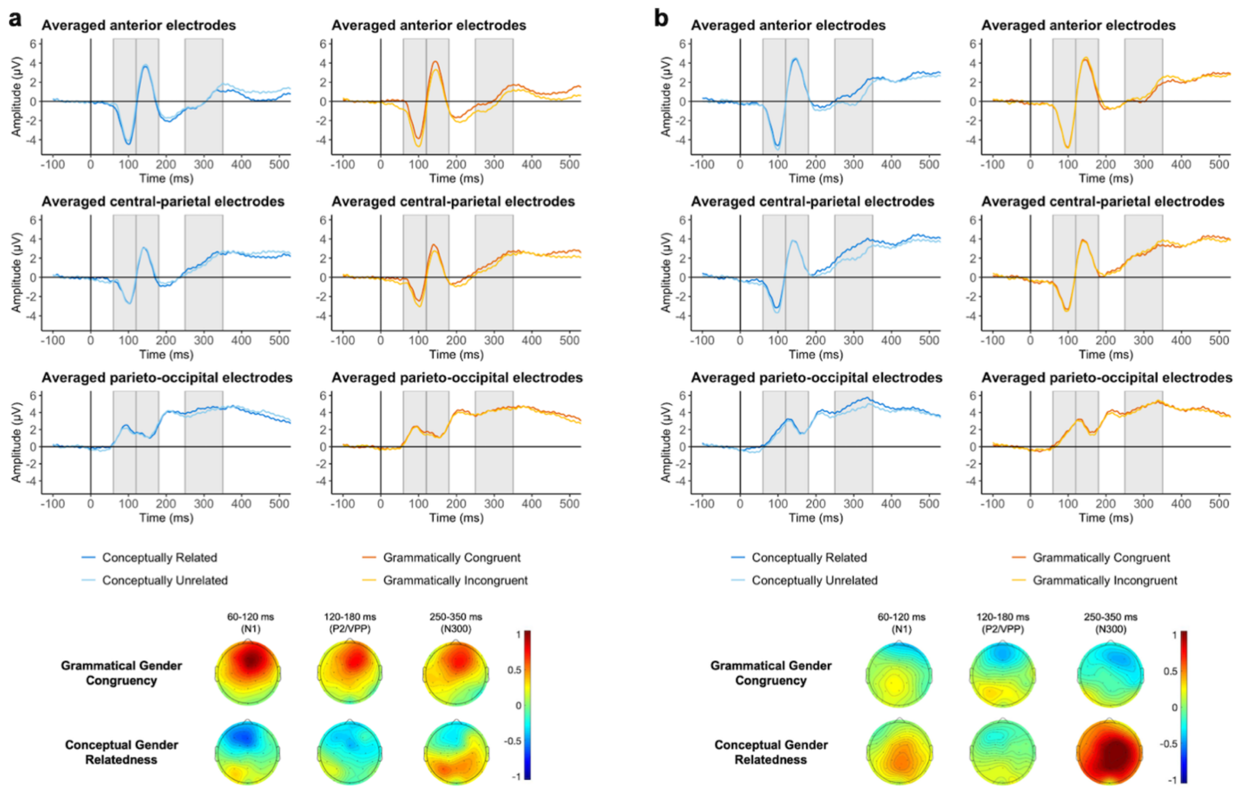

Fig. 3. Grand average ERP waveforms of the N1, P2/VPP, and N300 (shaded in gray) of the effects of Grammatical gender congruency and Conceptual gender relatedness for each language group (a: French-English bilinguals; b: Monolingual English speakers) included in the analyses at the anterior (Fz, F3, F4, FC1, FCZ, FC2), central-parietal (C3, CZ, C4, CP1, CP2), and parieto-occipital (P3, PZ, P4, O1, IZ, O2) regions. Average ERPs are calculated from pooled electrodes, with the onset of the target face image indicated by time zero. For Grammatical gender congruency, the dark orange line indicates the grammatically gender congruent condition and the light orange line for the grammatically gender incongruent condition. For Conceptual gender congruency, the dark blue line indicates the conceptually gender related condition and the light blue line for the conceptually gender unrelated condition. Scalp topographies represent the effects of the Grammatical gender congruency and the Conceptual gender relatedness as differences obtained between the grammatically gender congruent and incongruent conditions and between conceptually gender related and unrelated conditions.