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EMPIRICAL STUDY

Electrophysiological Evidence for a Whorfian Double Dissociation of Categorical Perception Across Two Languages

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Abstract: *Taza* in Spanish refers to cups and mugs in English, whereas glass refers to different glass types in Spanish: *copa* and *vaso*. It is still unclear whether such categorical distinctions induce early perceptual differences in speakers of different languages. In this study, for the first time, we report symmetrical effects of terminology on preattentive indices of categorical perception across languages. Native speakers of English or Spanish saw arrays of cups, mugs, *copas*, and *vasos* flashed in streams. Visual mismatch negativity, an implicit electrophysiological correlate of perceptual change in the peripheral visual field, was modulated for categorical contrasts marked in the participants' native language but not for objects designated by the same label. Conversely, P3a, an index of attentional orienting, was modulated only for missing contrasts in the participants' native language. Thus, whereas native labels influenced participants'

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preattentive perceptual encoding of objects, nonverbally encoded dissociations reoriented their attention at a later processing stage.

Keywords linguistic relativity; object perception; terminology; vMMN; P3a

Introduction

Categorization allows individuals to organize objects and abstract concepts that share features into meaningful clusters, thus simplifying, or even enabling, their understanding of the experienced world. The ability to categorize objects in the environment also allows to make meaningful inferences when encountering new objects. For instance, if encountering an animal that appears to be a kind of dog, one can assume that it can bark even if one has never encountered this particular kind of dog before. Thus, although the ability to categorize the environment is innate, the formation and consolidation of conceptual categories can be learned and shaped by experience (Maier et al., 2014). The acquisition of conceptual categories also constrains perceptual processes such that different exemplars from the same category tend to be perceived as more similar than exemplars that belong to different categories despite their physical similarities, a phenomenon known as categorical perception (Harnad, 1987; Rosch, 1978).

Language seems to play a crucial role during the learning and consolidation of new categories since linguistic terminology usually denotes whether

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different things belong within the same or different categorical boundaries (Lupyan, 2008). All languages, however, do not mark categorical distinctions in the same way. For instance, *blue* in English encompasses two basic color categories in Greek, a darker shade called *ble* and a lighter shade called *ghalazio* (Athanasopoulos, 2009). This simple observation raises the question of whether linguistically based categorical distinctions can shape the way that speakers conceptualize and perceive the world. Rooted in Whorf's principle of linguistic relativity (Whorf, 1956), the idea that speakers of different languages perceive the world differently has been extensively debated over the past decade (e.g., Athanasopoulos et al., 2016; Athanasopoulos & Casaponsa, 2020; Lupyan et al., 2020; Thierry, 2016). Existing empirical evidence has suggested that one's native language influences conscious psychophysical processing of verbally aided categorical distinctions (Bylund & Athanasopoulos, 2017), alters memory for fragrances (Speed & Majid, 2019) and motion events (Athanasopoulos et al., 2015; Flecken et al., 2015; Gennari et al., 2002), and facilitates perceptual discrimination of colors (Gilbert et al., 2006; Maier & Abdel Rahman, 2018; Thierry et al., 2009) and objects (Boutonnet et al., 2013; Maier & Abdel Rahman, 2019). However, the extent to which speakers of different languages exhibit differences in the functional organization of cognitive systems traditionally thought to be generic, such as perception, still remains unclear.

In this study, we attempted to test whether automatic, preattentive, and unconscious perceptual processing of unattended everyday objects is affected by categorical distinctions enshrined in the native language. Using a neurophysiological approach to assess unconscious, perceptual, and attentional processing of unattended stimuli, we investigated the effect of crosslinguistic differences in terminology by comparing perceptual category wrapping in native speakers of Spanish and of English. Studies relying on behavioral evidence are highly susceptible to verbal interference (i.e., a reliance on verbal information, whether implicit or explicit, to perform a task), and their results can thus be interpreted as online language activation affecting performance rather than as language fostering long-lasting influences on perceptual encoding (through neural connections resulting from learning). The need for a neurophysiological approach for directly assessing processes at low-level, preattentive, preverbal stages has thus become a methodological necessity (see Athanasopoulos & Casaponsa, 2020; Lupyan et al., 2020; Thierry, 2016).

Background Literature

Thierry et al. (2009) attempted to test neurophysiological differences elicited by crosslinguistic differences in color category terminology using a classic oddball paradigm ubiquitous in the study of visual perception. They targeted early perceptual processing in a visual shape detection task involving a color deviancy manipulation so as to elicit visual mismatch negativity (vMMN). The visual counterpart of the auditory mismatch negativity (Czigler et al., 2002; Winkler & Czigler, 2012), vMMN is considered a reliable neurophysiological index of unconscious change detection. It is a modulation of the visually evoked N1 peak, a negative going deflection peaking at 100 ms poststimulus onset over parietooccipital areas of the scalp observed in experiments using the oddball paradigm in conditions where participants ignore the stimulus stream because their attention is engaged in a secondary, distractor task (Czigler, 2007). vMMN is thought to index automatic and preattentive detection of a deviant stimulus compared to the neural memory representation of preceding repeating stimuli, such that an infrequent stimulus (i.e., deviant) increases amplitude of the N1 peak compared to a frequently repeated stimulus (i.e., standard; Czigler et al., 2004; Kimura et al., 2010; Stefanics et al., 2012; Stefanics et al., 2011).

Thierry et al. (2009) presented their participants with colored shapes varying in luminance (light/dark) within blocks and differing in hue (green/blue) across blocks. Critically, their English native- and Greek native-speaker participants were instructed to attend to object shape (namely, to detect squares among circles), and neither color nor luminance was mentioned while their brain potentials were recorded. Thierry et al. predicted increased vMMN modulation when luminance contrasts were marked by two linguistic terms in the participants' native language (e.g., *ble* and *ghalazio* in Greek) compared to when they were unmarked (e.g., single term *blue* in English). For native speakers of Greek, Thierry et al. observed greater vMMN for the blue contrast compared to the green contrast, congruent with the categorical distinction of the Greek language, whereas native speakers of English showed vMMNs of comparable amplitude for both the green and the blue contrasts. One limitation of this study, however, was that the critical stimulus, despite acting as a filler for the task, was presented at the center of the screen (and therefore at the center of the foveal visual field), meaning that it was directly attended and this precluded a strongly preattentive interpretation of the results.

Several subsequent conceptual replications of Thierry et al.'s study in which colored stimuli were presented in the peripheral visual field obtained results mostly consistent with the those of the original study (Clifford et al., 2010; Mo et al., 2011; Xia et al., 2019; Zhong et al., 2015). These studies, however, tested categorical perception of existing or newly learned color distinctions in a single language, only partially addressing the basic tenet of the Sapir-Whorf hypothesis, namely that speakers of different languages perceive the world differently. To get at this question, one needs to consider a double dissociation, that is a distinction existing in one language and not the other, and vice versa.

In the domain of object recognition, Boutonnet et al. (2013) recorded brain potentials in English native speakers and Spanish native speakers performing an oddball task similar to that conducted with color but focusing on everyday object shapes. They asked participants to press a button when they saw a picture of a bowl in a stream of cups and mugs presented one by one in the center of the screen. Within a given block, either cups or mugs were frequently (i.e., standards) or infrequently (i.e., deviants) presented. Native speakers of English exhibited an early deviant-related negativity for the cup–mug contrast, whereas native speakers of Spanish showed no such modulation, consistent with a reduction of amplitude expected on the bases of the two objects belonging in Spanish to the same linguistic category, *taza*. However, like studies on color perception, this study looked only at a single crosslinguistic dissociation. In our study, we sought to look at a dissociation in both directions.

Boutonnet et al.'s (2013) study provided initial evidence that, akin to the case of color, perceptual processing of everyday objects may also be influenced by language (see also Maier et al., 2014; Yu et al., 2017, for converging evidence with novel objects). However, Boutonnet et al., like others looking at language-induced perceptual encoding at preattentive stages of processing, used repeated exposure to the same exemplars of color (Athanasopoulos et al., 2010; Thierry et al., 2009) or objects (Boutonnet et al., 2013) and, as in the study by Thierry et al. (2009), stimuli were presented at fixation. The lack of stimulus variability inherent to such designs could help the brain establish a baseline and/or entertain perceptual expectations that are constrained by language but that do not reflect attention-independent effects arising in the course of perceptual processing (Maier & Abdel Rahman, 2019). Indeed, using the same stimulus repeatedly can induce N1 adaptation effects—reduction of amplitude with repetition, which could artificially boost vMMN irrespective of language distinctions. If language can indeed permeate preattentive perceptual processes and speed up object recognition, one should be able to observe perceptual effects based on language-induced categorical distinctions even when different exemplars of the same category are presented in each and every trial within the visual stream of stimuli and in the peripheral visual field.

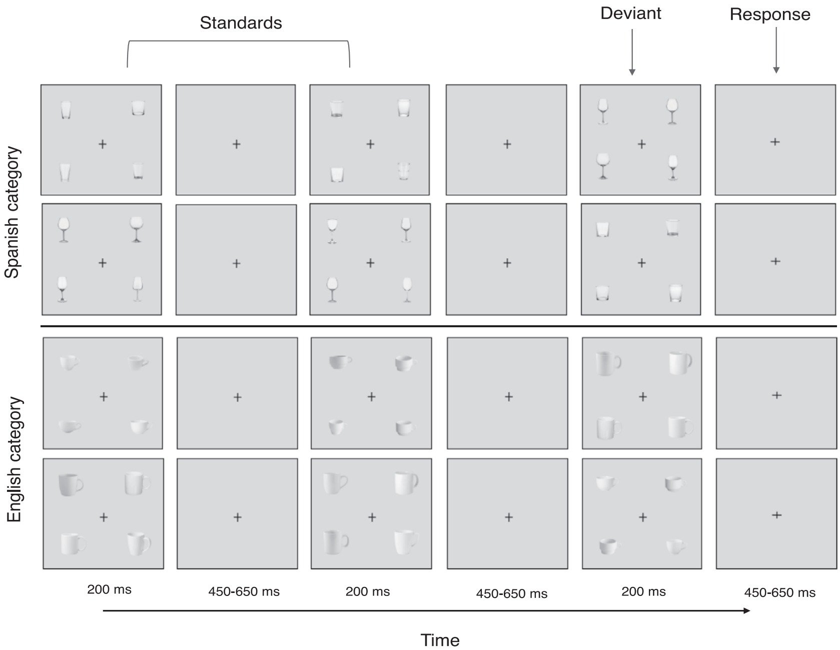

Figure 1 Schematic illustration of the stimuli and paradigm used in the experiment. Four individual images displaying different exemplars of the same object were presented in each trial for 200 ms. Trials were followed by an interstimulus interval randomly varying between 450–650 ms during which the vertical and horizontal lines of the fixation cross could change eliciting participants' responses.

The Present Study

We recorded brain potentials in native speakers of English and Spanish engaged in a visual detection task focused on a change in the appearance of the fixation cross presented in the center of a screen while arrays of four everyday objects were flashed in the peripheral visual field (i.e., a true passive visual oddball task; see Figure 1). Critical object arrays featured different exemplars belonging to one of four sets of objects (cups, mugs, regular water glasses, and wine glasses). These four sets of objects have different conceptual mappings across languages: Cups and mugs are labelled *tazas* in Spanish, and *copas* "wine glasses" and *vasos* "regular glasses" belong to the glass category in English. Importantly, none of the objects' exemplars presented in a given trial were identical to those presented in the previous trial, irrespective of location on the screen, so as to prevent local adaptation effects (Stefanics et al., 2012).

Based on our prediction that early perceptual processing is shaped by linguistic terminology, we expected stimuli featuring exemplars of slightly different physical characteristics to be perceived as more distinct in the presence of distinctive category labels in the participants' native language. Hence, we expected deviants featuring linguistically marked categorical contrasts to elicit a vMMN of a greater magnitude than would linguistically nonmarked categorical distinctions. In other words, we expected mug and cup arrays to elicit greater vMMN deviancy effects in English than in Spanish speakers, and reciprocally, we expected *copa* and *vaso* arrays to drive vMMN modulations in Spanish speakers. Besides assessing the role of language in unconscious preattentive perceptual processing of everyday objects, we also assessed the participants' involuntary attentional shifts to deviant stimuli as indexed by the P3a, a frontocentral positivity (between 200 and 400 ms) that usually follows the vMMN in passive oddball tasks (Czigler et al., 2006; Grundei et al., 2023; Polich, 2007). We measured this P3a component to assess deviancy effects that might be sensitive to language-independent categorization processes. Indeed, on the basis of previous evidence (e.g., Thierry et al., 2009; Boutonnet et al., 2013), such effects do not seem to arise at early stages of processing (i.e., vMMN).

On the basis of the fact that exemplars from standard trials were slightly more physically similar than those from deviant trials, we expected deviant stimuli to elicit P3a modulations in all conditions, that is, independently of the language-marked categorical distinctions. We thus investigated the potential effects of language in shaping early preattentive perceptual processing (vMMN) and subsequent involuntary shift of attentional resources to nonrelevant stimuli (P3a).

Method

Participants

Twenty-eight Spanish native speakers and 25 English native speakers participated in this study. Spanish participants were recruited and tested in Spain at the University of Deusto (Bilbao); English participants were recruited and tested in the United Kingdom at Lancaster University. Most Spanish speakers had some knowledge of English and also Basque given that both languages are mandatory subjects at school. To ensure that the participants were not highly fluent in any other language than their native language, we asked them to complete a picture naming task to assess word knowledge. The task was administered in Spanish, Basque, and English (see BEST in De Bruin et al., 2017). All the participants performed the task first in their native language (either

Table 1 Descriptive statistics for participants' language profile as measured by picture naming and self-rating tasks

		English native speakers		Spanish native speakers	
Task	Language	*M*	*SD*	*M*	*SD*
Picture naming	English	64.14	0.79	29.70	15.60
	Spanish	0.29	0.96	61.40	6.86[b]
	Basque	–	–	22.70	16.15
Self-ratings	English	9.86	0.48	4.15	2.37
	Spanish	0.19	0.51	9.60	0.68
	Basque	–	–	4.50	3.14
	Other[a]	1.43	1.40	1.05	1.61

[a] Other languages included French, German, Italian, Latin, Urdu, Russian, and Welsh.
[b] The large variation in Spanish speakers came from data from two participants whose responses were not entirely recorded due to a technical problem. Their overall accuracy for the recorded stimuli was 94% for Spanish, 32% for English, and 40% for Basque.

Spanish or English), then in Basque (for control purposes), and finally in the foreign language (either Spanish or English).

We excluded data from participants who reported neurological or psychiatric disorders as well as data of participants who scored more than 50 out of 65 in their nonnative language in the picture naming task or who self-reported a proficiency score above 5 out of 10 in any language other than those tested in our study (e.g., German or French). We also excluded participants who had fewer than 40 trials per block and condition due to poor electroencephalogram (EEG) signal or heavy artefact contamination (see EEG data analyses). This resulted in the exclusion of four native English speakers and eight native Spanish speakers, yielding a total of 21 English participants ($M_{\text{age}} = 22.29$ years, $SD = 6.46$, age range: 18–49 years; 8 men) and 20 Spanish participants ($M_{\text{age}} = 28.60$ years, $SD = 8.02$, age range: 19–44 years; 9 men).

Table 1 shows the descriptive statistics for the participants' self-ratings of their proficiency and for the picture naming test. All the participants had normal or corrected-to-normal vision and voluntarily participated in this experiment in exchange for monetary compensation. Prior to the experimental session all the participants gave their written informed consent in accordance with guidelines approved by the Ethics and Research Committees of Lancaster University (reference number: A101873) and the University of Deusto. We also conducted the study in accordance with the ethical standards set out in the

Declaration of Helsinki. All the participants received a compensation allowance of £10 per hour or its equivalent in euros.

Stimuli

We selected four types of objects, two that had different labels in Spanish but the same labels in British English (*copa* “glass” and *vaso* “glass”) and two that had two different labels in British English but one in Spanish (cup [*taza*], and mug [taza]). We refered to these objects as belonging to the English category (two labels in English) or the Spanish category (two labels in Spanish). Stimuli consisted of black and white images of 10 exemplars for each category. We selected exemplars based on object characteristics defined by the Cambridge Dictionary (n.d) for *cups* and *mugs*, where a *mug* is defined as “a large cup with straight sides used for hot drinks,” and by the Diccionario de la lengua española (n.d) for *copa* and *vaso*, where *copa* is defined as a “glass drinking vessel with a stem.” Each stimulus screen consisted of four different exemplars of the same object. The photographs appeared on a light grey background in the upper left, upper right, lower left and lower right part of the monitor at a viewing distance of 0.6 m. Each object subtended 5.6° visual angle horizontally and 7.7° vertically (see Figure 1; stimuli can be consulted at https://osf.io/3n4cr).

Procedure

The participants were tested individually in a quiet room. Visual stimuli were presented using E-Prime software (Version 2.0) on a 17“ CRT monitor for the English participants and a 15” CRT monitor for the Spanish participants set to a refresh rate of 60Hz (which allows for 16.67ms vertical retraces). The resolution of both monitors was set to 1024 × 768 and controlled by E-Prime to match the surface of the screen occupied by the stimuli and the visual angle of the objects from the center of the screen.

We set stimulus duration at 200 ms with a randomized onset asynchrony between 450 and 650 ms. We randomized the presentation order of the exemplars with the restriction that the same exemplar was not presented on the subsequent trial. We presented stimuli from each language category in two experiment blocks, so that each type of exemplar appeared once as a frequent standard stimulus and once as rare deviant stimulus (standard: $p = .85$, deviant: $p = .15$). We presented a total of 850 standard and 150 deviant stimuli for each language category (475 standard and 75 deviant stimuli per block) with block order (four in total) randomized across participants. The duration of each block was approximately 6.25 min.

The participants were asked to detect unpredictable changes in the length of the vertical and horizontal lines of a fixation cross presented in the center of the visual field in a black ink (distractor task). They were instructed to press the space bar as fast as possible whenever they detected that the cross became wider or longer. The frequency of change was randomly set between six to 12 trials with a mean change of 11 changes every 100 trials (~8.7 changes per minute). At the beginning of each block, the participants performed 10 practice trials. Task instructions (and interactions with the participants) were given in their first language—Spanish or English.[1]

Electroencephalography Recording

The EEG from the Spanish group was recorded from 27 electrodes (plus Ground) held in place on the scalp by an elastic cap (Electro-Cap International, n.d.) with the BrainVision Recorder and BrainAmp amplifier system (Brain Products GmbH, n.d.-a, n.d.-b). The EEG from the English group was recorded from 39 electrodes (plus Ground) held in place on the scalp by an elastic cap (Electro-Cap International, n.d.) with the Neuroscan Curry7 software (Compumedics Neuroscan, n.d.-a) and NuAmps amplifier system (Compumedics Neuroscan, n.d.-b). Eye movements and blinks were monitored with four further electrodes providing bipolar recordings of the horizontal (Heog-, Heog+) and vertical (Veog-, Veog+) electrooculogram (EOG). Electrode impedances were kept below 5 kΩ with the exception of eye electrodes (below 10 kΩ). The EEG signal was sampled continuously throughout the experiment at 1 kHz and digitally down-sampled offline to 250 Hz, and it was re-referenced offline to averaged left and right mastoids.

Statistical Analysis

We analyzed the data with EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014). We corrected ocular artefacts using independent component analysis, with the *runica* function and including all electrodes except for the ocular electrodes. We used ICLabel (Pion-Tonachini et al., 2019) to detect and manually remove components related to horizontal and vertical blinks. We applied a high-pass filter of 0.01 Hz before the independent component analysis procedure and applied a low-pass filter of 30 Hz after the independent component analysis. We computed mean ERPs time-locked to target onset off-line from trials free of ocular and muscular artefacts; epochs with activity exceeding ±75 lV at any cap electrode site were automatically discarded. We performed baseline correction using the averaged EEG activity in the 200 ms preceding the onset of the stimuli.

We conducted the vMMN and P3a analyses on individual event-related potentials (ERPs) elicited by passive standard and deviant exemplars. Trials following a fixation cross change or including a response were automatically discarded. The vMMN was maximal over the occipital scalp and studied at electrodes O1, O2, and OZ between 130 and 190 ms after target onset ($\pm$30 ms around the negative mean peak latency between 100 and 220 ms in all conditions, electrodes, and groups). The P3a was maximal over frontocentral regions and studied at electrodes Fz, FC1, FC2, and Cz between 190 and 250 ms after target onset ($\pm$30 ms around the possitive mean peak latency between 200 and 350 ms in all conditions, electrodes, and groups). We subjected mean amplitudes of ERPs from standard and deviant stimuli to a mixed repeated-measures ANOVA with contrast (Spanish category, English category) and deviancy (standard, deviant) as within-subject variables and group (Spanish, English) as a between-subject variable (see https://osf.io/3n4cr for averaged ERP data). We estimated effect sizes using the partial eta squared coefficient ($\eta^2{}_p$) for main effects and interactions and Cohen's d for planned pairwise comparisons. Alpha level of significance was set at 0.05. We performed statistical analyses with the jamovi application (The jamovi project, 2021 Şahin & Aybek, 2019).

Results

Mean accuracy for the distractor task in the English group was 94.43% (SD = 3.47; $M_{\text{reaction time}}$ = 409.70 ms, SD = 62.86) and in the Spanish group was 93.39% (SD = 4.58; $M_{\text{reaction time}}$ = 439.82 ms, SD = 58.95). Mean false alarm rates in the English group were 2.49% (SD = 1.61) and 1.64% (SD = 1.11) in the Spanish group.

Visual Mismatch Negativity Results

As expected in the context of a vMMN paradigm, we found a main effect of deviancy, $F(1, 39) = 19.27$, $p < .001$, $\eta^2{}_p = .33$ (large effect), but also a main effect of contrast, $F(1,39) = 7.67$, $p = .009$, $\eta^2{}_p = .16$ (large effect), and a Contrast × Group interaction, $F(1,39) = 5.07$, $p = .03$, $\eta^2{}_p = .12$ (medium effect). Crucially, the three-way Contrast × Deviancy × Group interaction was significant, $F(1,39) = 9.78$, $p = .003$, $\eta^2{}_p = .20$ (large effect). Planned pairwise comparisons showed that Spanish speakers elicited a significant deviancy effect for the Spanish contrast, $t(19) = 4.04$, $p < .001$, $d = 0.90$ (large effect), 95% CI [0.37, 1.42], but not for the English contrast, $t(19) = 1.14$, $p = .267$, $d = 0.26$ (small effect), 95% CI [−0.19, 0.70], but English speakers elicited a significant deviancy effect for the English contrast, $t(20) = 3.70$,

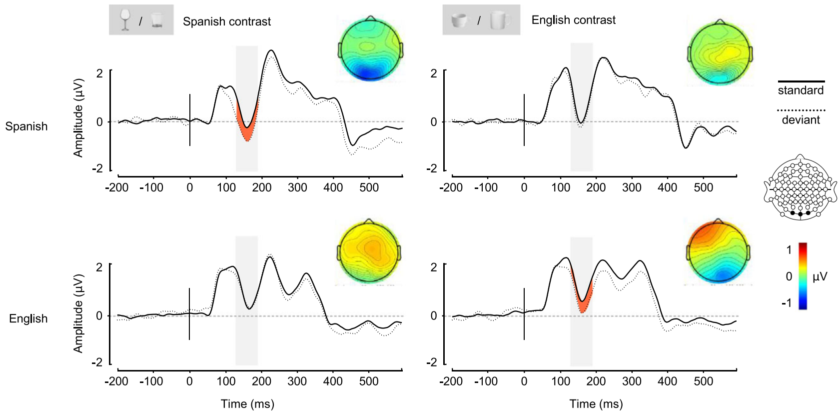

Figure 2 Event-related potentials elicited by standard (plain line) and deviant (dotted line) stimuli by language contrast (Spanish: *copa* vs. *vaso*, English: cup vs. mug) and participant group over occipital electrodes where the vsual mismatch negativity was maximal (linear derivation of O1, O2, and OZ). Mean brain potential amplitude was significantly more negative for deviants than standards between 130–190 ms for the contrast highlighted by Spanish terminology in the Spanish group and the contrast highlighted by English terminology in the English group (shaded interval).

$p = .001$, $d = 0.81$ (large effect), 95% CI [0.31, 1.30], but not for the Spanish contrast, $t(20) = .62$, $p = .539$, $d = 0.14$ (negligeable effect), 95% CI [−0.30, 0.56] (see Figure 2).

P3a Results

The P3a analysis conducted in a later time window (190–250 ms after stimulus onset) over frontocentral regions revealed a main effect of deviancy, $F(1, 39) = 13.76$, $p = .001$, $\eta^2_p = .26$ (large effect), and a main effect of contrast, $F(1,39) = 7.87$, $p = .008$, $\eta^2_p = .17$ (large effect). As was the case in the vMMN analysis, the three-way Contrast × Deviancy × Group interaction was significant, $F(1, 39) = 4.11$, $p = .049$, $\eta^2_p = .10$ (medium effect). Planned pairwise comparisons revealed a pattern mirroring vMMN results: Spanish speakers elicited a significant P3a deviancy effect for the English contrast, $t(19) = 2.40$, $p = .027$, $d = 0.54$ (medium effect), 95% CI [0.07, 1.03], but not for the Spanish category, $t(19) = 0.68$, $p = .502$, $d = 0.15$ (negligeable effect), 95% CI [−0.34, 0.67], whereas English speakers elicited a significant deviancy effect for the Spanish contrast, $t(20) = 3.86$, $p < .001$, $d = 0.84$ (large effect),

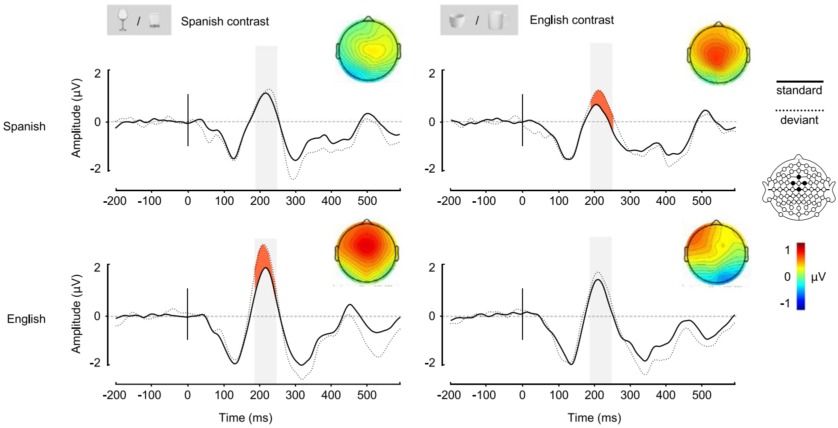

Figure 3 Event-related potentials elicited by standard (plain line) and deviant (dotted line) stimuli by language contrast (Spanish: *copa* vs. *vaso*, English: cup vs. mug) and participant group over frontocentral electrodes where the P3a was maximal (linear derivation of Fz, FC1, FC2, Cz). Mean brain potential amplitude was significantly more positive for deviants than standards between 190–250 ms (shaded interval).

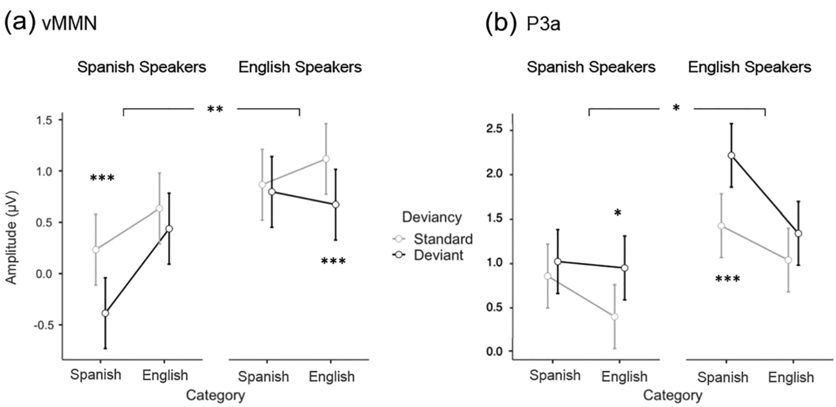

Figure 4 Visual mismatch negativity (vMMN; Panel A) and P3a (Panel B) depiction of the means between standard (grey) and deviant stimuli (black) by group in each category. Error bars represent 95% confidence intervals.

95% CI [0.37, 1.23], but not for the English contrast, $t(20) = 1.22$, $p = .236$, $d = 0.27$ (small effect), 95% CI [−0.21, 0.82] (see Figure 3 and Figure 4).

Discussion

Moving the evidentiary basis of the Sapir-Whorf hypothesis that speakers of different languages perceive the world differently from a more biologically grounded arena has advanced understanding of the extent of these differences in human perception. It appears that such Whorfian phenomena could be attested in early, unconscious stages of visual integration, but the true nature of these effects remained elusive. This study tested the potential crosslinguistic effects of terminology on visual categorical perception of everyday objects using the vMMN, an index of perceptual and preattentive change detection.

As we had predicted on the basis of categorical distinctions of Spanish and English, we found modulations of peripherally elicited vMMNs by corresponding object contrasts in native speakers of these languages. Remarkably, we found a double dissociation, such that vMMN modulation was not significant when object contrasts did not cross a categorical boundary in the native language of the same participants. That is, English speakers showed a vMMN modulation for the category contrast highlighted in English but not the category contrast marked by Spanish, and this finding was reciprocal for Spanish speakers. An explorative analysis of the P3a range further revealed mirror sensitivity of ERPs in a subsequent temporal window: P3a modulation was significant for the Spanish contrast in English speakers and for the English contrast in Spanish speakers, and the native contrast failed to modulate P3a mean amplitudes in either group.

Often, positive evidence for the Sapir-Whorf hypothesis has been dismissed as superficial, on the basis of task ambiguity and strategic conscious use of language during the task. As Pinker (2007) put it: "speakers of different languages tilt in different directions in a woolly task, rather than having differently structured minds" (p.148). Although it is unclear what sort of evidence would qualify as a marker of "differently structured minds," our study shows that if researchers look at the first brain signature of unconscious automatic visual change detection, the vMMN, speakers of different languages show different modulations, mirroring terminological distinctions in their native language.

Importantly, we demonstrate a true categorical effect. Previous studies showing vMMN-like effects driven by terminology have used repeated exposure to one single exemplar for each category (e.g., Boutonnet et al., 2013), and thus ERPs responses could have been driven by item-specific physical differences between the exemplar chosen to represent standard and deviant stimuli. To our knowledge this has been the first study to show crosslinguistic influences on early stages of perceptual processing that can only be accounted by a generalizable categorical distinction in the native language. This is because we used 10 different exemplars for each object category and because we presented arrays of physically different objects in each experimental trial, whether it was a standard or a deviant trial. Hence, our vMMN findings suggest that categorical information can be extracted from each set of objects based on the physical characteristics that form the language-based category rather than from just the common physical characteristics of the objects per se.

Critically, the vMMN generated in our study was elicited by stimuli presented outside the foveal visual field and was thus automatic and preattentive. Because the participants' attention was focused on the fixation cross, the vMMN modulation elicited by peripherally presented and unattended stimuli was highly unlikely to have indexed conscious information processing. This is an important point that has previously occasioned a debate on the penetrability of color perception by color categories (Clifford et al., 2010; Forder et al., 2017; Thierry et al., 2009). In their study investigating the cup/mug contrast, Boutonnet et al. (2013) used an oddball paradigm with only one example of each object presented at fixation. Although Boutonnet et al. found the expected dissociation between native speakers of English and native speakers of Spanish, it could not be concluded from their results that the categorization mechanisms taking place in the early stage of visual object perception were automatically and preattentively engaged because all objects were displayed in the foveal field of view and directly in the focus of attention.

The P3a is classically considered an index of involuntary attention engagement. In our exploratory analysis of P3a mean amplitude in a temporal window immediately following that of the vMMN, we found a perfect reversal of the vMMN response pattern. These results indicate that both English native and Spanish native speakers are not blind to the contextual physical differences between different objects from the same category. However, rather than speakers' detecting these perceptual differences at early stages of perceptual processing, different objects from the same language-based category elicit an involuntary attentional shift for the speakers. Hence, in our study, we observed a sharp dissociation between early preattentive perceptual processes and subsequent automatic shifts of attention. The fact that vMMN and P3a response patterns mirror each other may be an indication that their underlying processes are functionally related. More specifically, when a categorical contrast is marked by a language, change detection between sets of objects occurs very early in the visual processing stream, indicating an acquired categorical distinction. When it is not marked by a language, change detection occurs at a later stage because the categorical distinction has not yet been learned and it thus relies solely on the extraction of objects' physical properties.

A common simplistic interpretation of the Sapir-Whorf hypothesis is to assume that effects of linguistic categories are an all-or-nothing phenomenon: Either language shapes perception or it does not (Regier & Kay, 2009). Also, a misrepresentation of this idea is that speakers are blind to, or unaware of, perceptual distinctions or phenomena that are not encoded in their native language (Casasanto, 2008). Although the degree of determinism assumed in the writings of Whorf has often been a matter of intense philosophical debate and disagreement (Lucy, 2016), our empirical approach makes it possible to answer two questions—Does language shape perception? Can people perceive phenomena not encoded in their native language?—at the same time, in the same populations, in the affirmative. We thus propose that categorical distinctions highlighted by native language terminology warp perceptual processing, allowing physically different objects to be considered as more similar when they fall at preattentive stages of visual perception within the same language-specific category than when they do not. But then, when a given language does not categorically distinguish between objects, such objects still trigger shifts of attention within the next 100 ms or so, enabling the brain to distinguish them based on their appearance and function. When the same objects do not share a label in the native language, common physical characteristics within and between objects are still extracted, but categorization takes place at a later stage of processing.

Limitations and Future Directions

Our study has several limitations that should be addressed in future research. First, the double dissociation that we observed with English and Spanish native speakers should be replicated across different languages and types of objects to ensure the generalizability of our findings. Another issue relates to the fact that the cup/mug or *copa*/*vaso* contrasts may be more culturally relevant in a British context or a Spanish one, although such an idea is speculative and ultimately difficult to test. Indeed, the objects that we tested here might arguably be used in slightly different ways in the United Kingdom and in Spain. Disentangling cultural effect from effects of language terminology would require replicating the experiment reported here in several different language pairs using objects that have highly overlapping cultural associations and habits of usage. Furthermore, in future research it would be interesting to explore whether these early and late dissociations in perceptual processing affect more conscious and subjective perceptions of objects and how this might have an observable effect at a behavioral level. Last but not the least, one question that remains entirely open is whether learning a second language with categorical distinctions different from the native language reshapes early perceptual processes.

Conclusion

This study demonstrated that linguistically sustained categorical distinctions can shape the way people perceive their experienced world within the first 200 ms of visual stimulation. Our findings showed, for the first time, a crosslinguistic double dissociation of categorical perception of everyday objects between native speakers of English and Spanish. Language thus not only acts as a top-down modulator in perceptual processing but also causes speakers of different languages to perceive the world differently. We thus contend that the basic tenets of the linguistic relativity proposal are correct.

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Note

1 At the end of the session, we asked the participants to name one random item from each object set in their native and other languages of which they had knowledge. None of the participants reported knowledge of the two critical labels for the nonnative categories.

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