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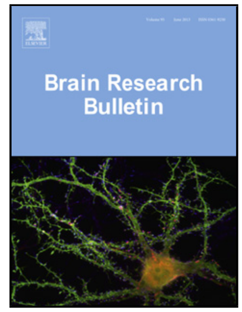

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Research report

Event-related potential correlates of stimulus equivalence classes: A study of task order of the equivalence based priming probes with respect to the stimulus equivalence tests, and among the distinct trial types with each other.

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A R T I C L E I N F O

Article history:

H I G H L I G H T S

►Two groups of healthy subjects received successive tasks in different order.
►Associations between pseudo-words were selected by feedback.
►EEG was recorded during presentations of related and unrelated stimulus pairs.
►Response times to related stimuli were faster than those to unrelated stimuli.
►Two ERP waveforms were sensitive to the relatedness among the stimulus pairs.

A B S T R A C T

This study investigates the influences of: 1) the task order of two stimulus equivalence classes (SEC) probes, and 2) the possible differences within the equivalence trial types. These factors were analyzed together on both behavioral and event-related potentials (ERP) data. Two groups of normal subjects participated in two successive sessions. In the first session, all participants were trained in the baseline relations among visual stimuli (pseudo-words). In the second session, one group performed the matching-to-sample (MTS) equivalence tests before the equivalence-relatedness-priming (EBRP) task, while the other group performed both tasks in reverse order. In the EBRP task related trial types included trained, symmetrical and equivalence relationships while the unrelated trial types included the same stimuli but without relationships. Event related potentials were recorded separately for related and unrelated conditions during the EBRP task. Results showed that response times to related trials were shorter than those to unrelated ones. At the electrophysiological level, two late waveforms were sensitive to the differences among the stimulus pairs of the EBRP task: Both waveforms were larger for the unrelated than the related conditions. Conversely, there were no main influences of the task order or of the trial types with each other. These results provide evidence that 1) the EBRP task exhibits priming effects among the SEC stimuli, 2) the behavioral and electrophysiological effects were similar regardless of whether the EBRP task was done before or after the MTS tests, and 3) there were no differences within the baseline and derived trial types in the EBRP task

Keywords: Stimulus equivalence
Matching to sample
Priming effects
Event-related potentials
Semantic processes

1. Introduction

It has been proposed that stimulus equivalence research is relevant to the understanding of semantic processes (e.g., [1]). In this paradigm, a series of conditional relations between arbitrary stimuli are initially trained. Subsequently, another series of relationships that have not been directly trained are tested: reflexivity, symmetry and transitivity [2]. For example, in a first phase stimuli usually designated $A_{1,\ldots,n}$, $B_{1\ldots,n}$ and $C_{1,\ldots,n}$ are employed in a matching-to sample task, so that accurate selection of stimuli receives differential consequences ($A_{1,\ldots,n} \rightarrow B_{1,\ldots,n}$; $B_{1,\ldots,n} \rightarrow C_{1,\ldots,n}$). In a second phase, the function/role of these stimuli is reassigned in a different matching-to sample (MTS) test, in which reinforcement is not provided: $A_{1,\ldots,n} \rightarrow A_{1,\ldots,n}$ (*reflexivity*), $B_{1,\ldots,n} \rightarrow A_{1,\ldots,n}$ (*symmetry*), $A_{1,\ldots,n} \rightarrow C_{1\ldots,n}$ (*transitivity*), $C_{1,\ldots,n} \rightarrow A_{1,\ldots,n}$ (*combined symmetry-transitivity or Equivalence*). If the experimental subject successfully performs these tests, it is said that the established classes among stimuli fulfill the relational properties of stimulus equivalence [3]. Given that stimuli for each of the stimulus equivalence classes (SEC) become substitutable for one another, the formation of SEC relationships is considered analogous to the formation of object-referring or "semantic" relationships (e.g., [4]). A striking feature of the SEC protocol is that several relationships between stimuli are not directly trained; nonetheless, the SEC relations paradigm was included as an item of the "associative concept" learning type (e.g., [5]).

If SEC can serve as a behavioral model to study semantic processes, the pattern of findings that have been observed using semantic stimuli should also be found when using stimuli from SEC. This postulate motivated Hayes & Bissett [6] to test whether priming in a lexical decision task occurs in derived stimulus relations. The authors used letter strings with no significant meaning (pseudo-words) as arbitrary stimuli in order to train baseline relations. In a preliminary stage, participants had to develop A-B and A-C associations among stimuli through feedback. In an intermediate stage, the MTS tests were performed without feedback. In a final stage, participants performed an equivalence-based-relatedness-priming (EBRP) task in which they had to assess which stimuli were associated, which of them were not, or which ones were not presented before. Participants were faster to respond to stimuli if they had learned the A-B and A-C associations. In other words, they found that A primed both B and C if they had been directly paired together during training. Hayes and Bissett [6] also found that B primed C. As the B and C items were never explicitly paired during training, the authors have considered that the A stimuli "mediated" the facilitation effect. This "mediated priming effect" refers to the priming effect that is sometimes obtained when the prime and target are semantically related via an indirect word or concept is taken into consideration (e.g., [7]). Accordingly, Hayes and Bissett's study was cited in the "semantic priming" literature (e.g., [8]). Thus, these results provided additional support for the idea that the SEC paradigm is useful as a behavioral model of semantic relationships.

1.1 Event related potentials and SEC

The event related potential (ERP) technique is an electrophysiological measure constituted from averaged electroencephalogram (EEG) segments, time-locked to a repeatedly-presented stimulus event. The use of ERP technology has allowed the expansion of research on the EBRP task as a model of "semantic priming" using the SEC paradigm, as will be discussed below.

The first reference on ERP correlates of the stimulus equivalence formation was a communication published by Warren & Mcilvane [9]. This study focused on the idea that certain ERP waveforms (i.e. the "N400") would reflect the degree to which distinct stimuli share common semantic features (e.g., [10]). Since then, only 15 studies have been published that investigated the ERP correlates of the stimulus equivalence formation (see Appendix A). Most of these studies had measured electroencephalogram (EEG) signals during an EBRP task, since this task was considered similar to the "lexical decision task" which was performed in most N400 experiments. Other studies have recorded the EEG during the MTS tests (Appendix A).

***** INSERT FIGURE 1 ABOUT HERE *****

1.2 Test order effects

Sidman, Kirk, and Willson-Morris [11] suggested that the prerequisites for stimulus classes formation might include not only the critical baseline training but also the exposure to the MTS tests themselves. Sidman's proposal that classes might not exist prior to the tests (e.g., [12]) had as a consequence the advent of studies aiming to gather evidence of class formation prior to the MTS tests (e.g., [13]).

Since then, the question of whether the EBRP task must be done before or after the MTS tests has become a topic of interest in and of itself. Di Fiore and colleagues [14] performed the EBRP task before the MTS tests. On the other hand, Barnes-Holmes et al.[15] perform a MTS tests before the EBRP task, arguing that evaluation of the derived relation could result in the stimuli being directly associated, rather than indirectly associated. The arguments given to support this claim were that the stimuli contained within each of the equivalence classes would be repeatedly matched with each other in the different relationships. Accordingly, these authors asserted that the MTS tests should be presented only after the EBRP task if unequivocal mediated priming is to be observed across indirectly related elements of an equivalence class [15]. Recent behavioral and ERP studies have focused on whether the order of the EBRP task with respect to the MTS test has a significant impact on response times and ERP waveforms. Haimson et al. [16], investigated if prior exposure to outcome MTS tests would be critical to obtain the "N400-like" waveform. Half of the participants were exposed to the MTS tests followed by the EBRP task whereas the remainder experienced these procedures in reverse order. Their results showed that only those participants who performed the EBRP task after MTS tests exhibited clear ERP differentiation. The opposite effect was found by Wang and Dymond [17]: only those participants who had not received the prior MTS tests exhibited an "N400-like" effect that differed between related and unrelated trials. Hence, whether the EBRP task must be done before or after the MTS tests remains a topic of controversy.

1.3 *Trial type differences*

Differences in performance within trial types is another relevant topic within the scope of stimulus equivalence research (e.g. [18]). In a behavioral study O'Hora et al [19] found that response times were longer in symmetry-transitivity combined trials compared to symmetry and directly trained ones. The authors justified their results based on theoretical aspects of the stimulus equivalence research field: According to the Relational Frame Theory, [20] there could be differences in performance as the symmetry-transitivity combined relationships increased in complexity compared with the other ones. In a recent study, O'Regan et. al. [21] compared ERPs elicited by the distinct equivalence trial types (symmetry and symmetry-transitivity combined) and found a delayed positive waveform, "P300-like" waveform, for the symmetry-transitivity trials only. This delayed waveform was interpreted as evidence of the relational strength between symmetry-transitivity combined stimuli. O'Regan et. al. [21] claimed that their study may constitute a first demonstration of differences in brain electrophysiology in the "transformation of stimulus functions" through derived relations of hierarchical levels of complexity.

In another study, Tabullo et al. [22] performed an ERP comparison of the derived stimulus relations in stimulus equivalence classes. A "P300-like" waveform was observed in related trial types while an "N400-like" waveform was found in unrelated ones. Additionally, the "P300-like" related effect was earlier for symmetry trial types than for symmetry-transitivity-combined ones. These authors interpreted their findings as evidence that relational strength within equivalence classes is inversely related to the number of logical operations required to link the stimuli. Furthermore, Tabullo et al. [23] directly addressed the question of whether the N400 priming effects observed within the context of stimulus equivalence classes were comparable to those typically found in semantic priming between actual words. The authors found similar (but not identical) N400 priming effects when comparing unrelated vs related word pairs a and stimuli related (or not) via stimulus equivalence. This finding was interpreted as indicative of at least partially overlapping patterns of brain activity during processing of semantic word relations and indirect associations between non-lexical items derived from equivalence class formation

1.4 Study objectives

To our knowledge, there are no studies that investigate test order effects and trial type together on both behavioral and ERP data. As these issues are relevant on the "semantic quality" of the stimulus equivalence paradigm, we re-examine them together in order to verify the findings reported by previous research. Thus, the objectives of this study are to analyze in the same experiment: 1) The influence of the order of presentation of tasks (MTS tests and EBRP probes), and 2) the possible differences among the distinct trial types with each other (directly trained, symmetry and symmetry-transitivity combined). These factors will be analyzed jointly on behavioral and electrophysiological data.

ERP findings related to the EBRP task will be discussed in order to provide an interpretation of their possible functional meaning in the context of semantic and associative processes.

2. Method

2.1. Participants

The study sample consisted of 52 healthy subjects (28 women). All participants were right handed with normal or corrected to normal vision, and they had finished high school. The age range was between 20 and 30 years: Mean = 24.38; standard deviation = 3.6. The subjects spoke Spanish as their first language and were not taking any medication at the moment of the study. None of the subjects had previous exposure to the stimulus equivalence classes protocol or the priming task, and none of them were familiar with the ERP technique. Participants were randomly assigned to two groups (26 subjects each): Group 1, participants who performed the EBRP task (with electrophysiological recording) first and the MTS tests second; Group 2, participants who performed these procedures in reverse order. The study was conducted in complete accordance with the Ethical Principles for Medical Research Involving Human Subjects (WMA Declaration of Helsinki) [24] and was approved by the local ethics committee. All subjects signed an informed consent for their participation.

2.2. Apparatus and setting

The study was carried out in an 2 × 3 m laboratory room. Sessions were approximately 90 minutes long. The SEC task was performed in a PC (microprocessor Intel ® Core -™-, CPU i5-4430 - 3.0 GHz), developed with Python software and synchronized with an additional PC that controlled the electrophysiological recording (when used). The stimuli used in the study were bisyllabic pronounceable pseudowords [25].

Previous studies allow us to establish that the stimuli were easily discriminating each other and that they have no previous semantic or perceptual associations [22-23]. These stimuli are shown in the appendix B.
Instructions, stimuli and feedback messages (when used) were provided by the software and presented on the screen of a 14-inch monitor. The visual angle of the stimuli was 3.27°. Feedback messages were the words “Correct” or “Error” (in Spanish in the original).

2.3. Procedure

The experiment was performed on two consecutive days. On the first day, the subjects began the baseline relations training of the SEC task, and they were scheduled again the next day to complete the experiment. Training was divided in two days to facilitate learning the baseline relations (e.g., [15]). The next day the subjects were re-trained in the baseline relations and those who met the learning criterion continued with the experiment. Figure 1 schematizes the stimulus equivalence paradigm in the training and testing phases (a, b), and shows typical trials of the baseline relations training and the EBRP task (c, d).

***** INSERT FIGURE 1 ABOUT HERE *****

On the second day, Group 1 successively performed the MTS tests and then the EBRP task with electroencephalogram, while Group 2 first performed the EBRP task with electroencephalogram and then the MTS tests.

2.3.1. Baseline relations learning

Stimulus–stimulus relations were trained through matching-to-sample procedures. Participants were seated 80 cm away from the center of the screen, with the right index finger in contact with the mouse’s left button. Behavioral responses were registered by the mouse button. They were told that the stimuli would be meaningless artificial words and that their relation would be arbitrary. Participants were instructed to decide which of the three comparison stimuli presented at the bottom of the computer screen corresponded to the sample stimuli presented at the top, making their choice by using the PC mouse. They were also informed that they would receive corrective feedback after they made their choice.

We chose a "Sample as Node" (also known as "One to many") training protocol because this training protocol has been shown to result in better outcomes in stimulus equivalence tests (e.g., [26, 27]). This procedure was also used in the studies of Haimson et al., ([16], experiment 2), and Wang & Dymond [17]. This protocol consists of training a series of conditional discriminations using the same stimuli as sample in all trials. Therefore, this training protocol consisted of three training blocks: AB, AC (presented in a counter-balanced order to all subjects) and a final combined block of the mixed AB–AC baseline relations.

The former two blocks were composed of 18 trials each. In those AB and AC blocks the relations A_1–B_1, A_2–B_2, A_3–B_3; A_1–C_1, A_2–C_2, A_3–C_3, were trained on each one, respectively. The third block was composed of 36 trials. In this "mixed AB and AC block" all previously trained relations were presented again, in a pseudo-randomized order (in which two identical trials would not occur). Each training block was preceded by instructions that were displayed on a computer screen.

Each trial began with the presentation of a sample stimulus at the center of the upper half of the screen. When subjects clicked on the sample stimulus, it remained on the screen followed by the simultaneous presentation of three comparison stimuli on the lower part of the screen. The positions of the comparison stimuli that matched correctly with the sample stimuli were determined according to a randomized sequence. Comparison stimuli remained on the screen until a response was made by the participant. Subjects could make their choice at any time after the presentation of the comparison stimuli, and it was immediately followed by the feedback messages which were maintained for 500 ms (ms), after which a new trial began. The inter-trial interval lasted 1500 ms. If the percentage of correct responses was below 90%, training was automatically restarted up to 3 consecutive times. There were short breaks between the training blocks. If the subject had not reached the learning criterion, she or he was dismissed. The mastery criterion for training was 95% correct or higher in the final combined block (e.g. [28]).

2.3.2. Matching-to-sample tests

The formation of three member-stimulus equivalence classes was assessed by MTS tests of the combined symmetry-transitivity relations (from here “equivalence” relations). This stage consisted in a single block of 36 trials in which derived relations BC (B_1–C_1; B_2–C_2; B_3–C_3) and CB (C_1–B_1; C_2–B_2; C_3–B_3) were tested without differential reinforcement. These trials were presented in a pseudo-randomized manner (in order to prevent the same trial from appearing two times in a row). The position of the correct comparison stimuli was randomized across trials, such that it would appear with equal probability at each one of three places at the back of the screen.

Instructions for the subjects and stimulus presentation format were the same as in the training task, although this time they were informed that they would not receive feedback messages. The test criterion was 90% correct or higher [28]. Subjects who did not reach this criterion were discarded from further analysis of the behavioral and electroencephalographic data that were obtained through the EBRP task.

2.3.3. Equivalence-based-relatedness-priming task

In this task, participants were informed that they would see a pair of successive stimuli appear at the center of the screen, and would have to decide whether they were related or not. They were told that they would not receive feedback messages this time, but that the correct answers were based on previously learned relationships. They were also told to make their responses after the presentation of the second stimulus in the pair, using the Ctrl keys of the keyboard. The relationship between response type and Ctrl key side varied for each participant (i.e. right for “related” and left for “unrelated”). Finally, they were instructed to respond as fast and accurately as possible.

A total of 288 trials were presented, divided in four trial blocks (72 trials in each) with a short break between them. Half of the stimulus pairs were related through the baseline relations, the symmetry relations and the combined symmetry-transitivity relations, while the other half of the stimulus pairs were unrelated. In these cases, the stimuli pairs were according to the not-trained baseline relations, and not-symmetry and not-combined symmetry-transitivity derived relations. So in our EBRP task were evaluated training and test stimuli, whereas Haimson et al. [16] used only test stimuli in their priming task. We have preferred to include training and not trained trials (as the Wang and Dymond’s study [17]), because in this way the number of trials of the task is greater. The trials were presented in a pseudo-randomized order (in order to prevent the same trial from appearing two times in a row). Each trial was initiated with the presentation of a fixation cross at the center of the screen, for 500 ms and was followed by a 500 ms blank screen. Then the first stimuli of the pair appeared (prime), which disappeared after 350 ms and was followed by a 100 ms blank screen. After that, the target stimulus appeared for 350 ms. In this way, stimulus onset asynchrony (SOA) was 400 ms, similar to that used in most semantic priming studies (i.e., [28]). Subjects were able to make their response for a period of 1500 ms after target stimulus presentation. The inter-trial interval was 3000 ms.

Subjects’ accuracy was calculated as the amount of correct responses. As Wang and Dymond [17] suggested that the EBRP task could function as a form of equivalence test itself, the criterion to consider that the task was performed consistently, was the same (90% correct or higher [28]). Response times were measured from the onset of target stimuli in each trial. Only the response times of the successful trials were taken into account. During this task, EEG activity was recorded and synchronized with the onset of target stimuli.

2.3.4. Electrophysiological recording and processing

EEG signals were recorded from 30 cap-mounted TiN electrodes (extended international 10/20 system, Electro-Cap International Inc.) with a binaural reference. Seven regions were considered based on the location of electrodes on the scalp: One region corresponding to the midline electrodes and the other six on regions of interest (ROIs), each containing the average value of a group of four electrodes (e.g. [30]). The six ROIs were grouped in both hemispheres (left and right) as following: left anterior (LA) the average between Fp1, F3, FC5, F7 electrodes, left central (LC) the average between FC1, C3, CP5, T7 electrodes, left posterior (LP) the average between CP1, P3, P7, O1 electrodes, right anterior (RA) the average between Fp2, F4, FC6, F8 electrodes, right central (RC) the average between FC2, C4, CP6, T8 electrodes, and right posterior (RP) the average between CP2, P4, P8, O2 electrodes (figure 2). Electrode impedances were kept under 10 kΩ. An AKONIC BIOPC system was used to obtain de EEG signals. EEG signals were sampled at 256 Hz and filtered offline at 0.1–30 Hz, (6 dB/octave). This range was chosen in order to optimize later ICA decomposition, following expert recommendations (e.g., [31]).

***** INSERT FIGURE 2 ABOUT HERE *****

The beginning of each trial was marked with a signal in the EEG file. EEG preprocessing and ERP analysis were carried out using EEGLAB software v11.0.3.1 [32]. ERP epoch length was 2000 ms, and a 200 ms pre-stimulus baseline correction was applied. Ocular artifacts were removed from the data by means of the ADJUST ICA-based correction algorithm (e.g., [33]). Epochs containing other kinds of artifacts were detected by visual inspection and excluded from the analysis (resulting in a trial loss of less than 5%).

Time-windows of interest for ERP analysis were based on previous literature. An earlier time window from 70 to 150 ms was considered in order to ascertain that participants discriminated the target stimuli similarly, despite that these stimuli belonged to different conditions and trial types (e.g., [34]). Two later time windows of interest were established in order to identify negative and positive waveforms reported in correlation with the lexical decision tasks (e.g. [35]). These time windows were established in 200-300 and 400-550 ms respectively, in close match with the Wang & Dymond study [17].

In order to identify the "N400 effect" a "difference ERP" (dERP) was created via a point-by-point subtraction of waveforms between the related and unrelated conditions (e.g. [36], p. 623). Time-window of interest for the dERP analysis was established from 300 to 500 ms which followed the second stimulus of each pair (e.g. [37], p. 1745).

2.3.5. Data analysis

Behavioral and electrophysiological data were analyzed by separate ANOVAs. In these analyses, the Greenhouse–Geisser correction was applied in cases of sphericity violations, and the Bonferroni adjustment was used for post hoc pairwise comparisons. The Effect sizes were estimated by the partial eta-squared coefficient [38, 39].

3. Results

3.1. Behavioral data

There was no significant difference between groups in the number of hits (max. amount possible 36) in the equivalence test (means and standard deviations = 32.65 $\pm$ 7.4 versus 33.46 $\pm$ 5.3); t $(_{51})$ = -0.440, p = 0.662). In group 1, 18 of 26 subjects reached the test criterion for the formation of equivalence classes, while in group 2, 22 of 26 subjects reached the test criterion for the formation of equivalence classes (90% correct or higher). In the EBRP task, 17 of 26 subjects in group 1 and 17 of 26 subjects in group 2 reached the criterion to consider that the task was done consistently. There was no significant difference between groups in the number of hits in the EBRP task either (means = 259.1 $\pm$ 35.93 versus 247.84 $\pm$ 37.74); t $(_{51})$ = -1.008, p = 0. 319). The order in which tasks of MTS tests and EBRP task were carried out did not result in differences in the proportions of subjects achieving criterion in the MTS tests, despite the fact that there was a trend towards a difference ($X^2_{(1, 51)}$ = 3.449, p = 0.063). Nor did the order of tasks influence the proportions of subjects who reached criterion in the EBRP task ($X^2_{(1, 51)}$ = 0.329, p > 0.5).

Based on established criteria for accepting the task data [28], only 32 subjects learned the baseline relations and reached the test criterion of the derived relations (16 from group 1, and 16 from group 2). The data of the remaining subjects (10 from group 1, and 10 from group 2), were removed from the analysis.

Mean values and the standard error of raw response times are shown in figure 3 and table 3 (see Appendix C). These data are displayed separately by each group (groups 1 and 2), different experimental conditions (related and unrelated trials), and type of relationship (trained and derived trials).

***** INSERT FIGURE 3 ABOUT HERE *****

Normalized response times (natural logarithm) of the EBRP task were analyzed with a three factor ANOVA: A) *Group* (1 versus 2); B) *Condition* (related versus unrelated trials), and C) *Trial type* (baseline, symmetry and equivalence versus non-baseline, non-symmetry and non-equivalence). A main effect of *Condition* was found ($F_{(1,30)}$ = 11.457 , p < 0.01, η^2_p = 0.276). *Related stimuli pairs* exhibited faster response times than *non-related stimuli pairs* (1127.6 $\pm$ 289.03 versus 1172.44 $\pm$ 289.14 ms). A main effect of *Group* was not found ($F_{(1,30)}$ = 0.03, p > 0.863). A main effect of *Trial type* was not found either ($F_{(1,30)}$ = 0.580, p > 0.5, η^2_p = 0,019). There were not interaction effects among the factors *Group* x *Condition* ($F_{(1,30)}$ = 0.99, p = 0.326, η^2_p = 0.032). There was an interaction between the factors *Group* x *Trial type* ($F_{(2,29)}$= 3.33, p < 0.05, η^2_p = 0.1): Only the group of participants who performed the equivalence test prior to the EBRP task exhibited difference in their responses ($F_{(2,29)}$=3.605, *p < 0.04,* , η^2_p = 0.199). Subjects of this group responded faster to the equivalence trial types than the symmetry ones (p < 0.05), meanwhile no difference where observed between symmetry and trained (p = 0.290) nor trained and equivalence (p = 0.99). An interaction between the factors *Condition* x *Trial type* ($F_{(2,29)}$ = 3.554, p < 0.05, η^2_p = 0.106) was also found: Only the group of participants who performed the equivalence test prior to the EBRP task exhibited difference in their responses ($F_{(2,29)}$ = 3.493, p < 0.05, η^2_p = 0.194). Subjects of this group responded faster to Not Trained than Not Symmetry (p < 0.05), meanwhile no difference where observed between Not Trained and Not Equivalence (p = 0.25) nor Not Symmetry and Not Equivalence (p = 0.99). Nevertheless, the triple interaction *Group* x *Condition* x *Type of trial* was not verified in the statistical analysis ($F_{(2,29)}$ = 0.171, p = 0.784, η^2_p = 0.006).

3.2. ERP data

Visual inspection of grand average waveforms in the EBRP task showed several waveforms post target stimulus that showed different distribution in the scalp. These waveforms appeared with greater definition in the three successive time windows previously described: 1) An early positive waveform around 70-150 ms, especially in the frontal region, 2) an intermediate waveform appeared around 200-300 ms in the parietal region, and 3) a late waveform appeared around 400-550 ms in the central regions. Figure 4 displays grand average ERP waveforms at representative sites: In the upper panel, ERP waveforms are shown at central electrodes in separate images for each group: those who completed the MTS tests before the EBRP task and those who performed in the reverse order.

In the middle panel, ERP waveforms are shown at central parietal electrodes in combined images of both groups. In the lower panel, the scalp topographies are shown of each of the three waveforms in the successive separate time windows.

***** INSERT FIGURE 4 ABOUT HERE *****

As in the Ortu et al. study [37], the dERP appeared in the 300 - 500 ms time window in the electrodes which were located over centro-parietal regions. This dERP waveform is shown in figure 5.

***** INSERT FIGURE 5 ABOUT HERE *****

The amplitudes of the dERP in the 300-500 ms time window dERP mean voltages were obtained from the sum of the Cp1, Cz, Cp2, P3 Pz, and P4 electrodes. These dERP amplitudes were analyzed by means of a two factor (one repeated) a 2 × 3

ANOVA: Factor 1, the order in which tasks were done between groups (EBRP task – MTS tests and MTS tests – EBRP task); Factor 2, the trial types (trained, symmetry and equivalence). In this analysis there were not main effects of *Group* ($F_{(1, 27)}$ = 0.731, *p*=.4, η^2_p = 0.026), A trend of statistical significance was observed for the effect *Trial type* ($F_{(2, 26)}$ = 2.868, *p* = 0.069, η^2_p = 0.096). There were no *Group* x *Trial type* interaction ($F_{(2, 54)}$ = 2.049, p = 0.142, η^2_p = 0.071). Complementary ANOVAs were done on raw ERPs' mean voltages considering the three time windows previously described. As mentioned above, these time windows were selected in order to distinguish three ERP waveforms which followed the second stimulus of each pair. These time windows were selected based on the maximal amplitudes in which each of the three waveforms were found over the corresponding scalp regions. Thus, three time segments were considered in order to analyze the amplitudes of three different waveforms: 1) 70-150 milliseconds for an early positive waveform, 2) 200-300 milliseconds for an intermediate negative waveform, 3) and 400-550 milliseconds for a late positive waveform.

The ERP mean voltages were calculated within the mentioned three time windows on different electrodes. Seven regions were considered based on the location of the electrodes on the scalp: One corresponding to the midline electrodes and the other six lateral regions of interest (ROIs) previously described (see figure 2).

The ERP mean voltages were analyzed by means of separate ANOVAs. Therefore, a 2 × 2 × 6 repeated measures ANOVA was performed with the following main factors: 1) Group (equivalence test-priming task versus priming task-equivalence test, according to the order in which tasks were performed), 2) Condition (related, unrelated) as within-subject factors, and Electrode (Fpz, Afz, Fz, Cz, Pz, POz), as the midline electrodes. Another 2 × 2 × 2 × 3 repeated measures ANOVA was conducted with the following main factors: 1) Group, 2) Condition, Hemisphere (left, right), and Region of interest (anterior, central, posterior).

3.2.1. The positive wave around 70-150 ms

Central electrodes: No main effect of *Group* was observed ($F(_{1,27})$ = 0,045, *p* = 0.834, η^2_p = 0.00). Also no main effect of *Condition* was observed ($F(_{1,27})$ = 0.022 , *p* = 0.883, η^2_p = 0.001). A main effect of *Electrode* was observed ($F(_{5,23})$ = 14.11, *p* < 0.001, η^2_p = 0.754), with the *frontal electrodes* being more positive than the *posterior electrodes*. No significant interaction of *Group* x *Condition*, *Group* x *Electrode* or *Condition* x *Electrode* was found ($F(_{1,27})$ = 0.658, *p* = 0.424, η2 = 0.024; $F(_{5,27})$ = 2.199 *p* = 0.132, η^2_p = 0.075; $F(_{5,23})$ = 0.3, *p* = 0.76, η^2_p = 0.011 respectively).

ROIs: No main effect of Group ($F(_{1,27})$ = 0.008, p = 0.927, η^2_p < 0.001) nor *Condition* ($F(_{1,27})$ = 0.128, *p* = 0.723 , η^2_p = 0.005) was observed. On the contrary, main effects of *Region* ($F(_{2,26})$ = 72.119, *p* < 0.001, η^2_p = 0.728) and *Hemisphere* ($F(_{1,27})$ = 14.128, *p* = 0.025, η^2_p = 0.172) were observed. The frontal and central regions were more positive than the posterior regions (p < 0.001 and p <0.001 respectively), while the frontal regions were more positive than the central regions (*p* < 0.001). Also, the right hemisphere was more positive than the left hemisphere (*p* = 0.025). There were no interactions of Group x *Condition* ($F(_{1,27})$ = 2,244, *p* = 0.146, η2 = 0.077), *Group* x *Region* ($F(_{2,54})$ = 2,195, *p* = 0.121, η^2_p = 0.075), *Condition* x *Hemisphere* ($F(_{1,27})$ = 3,86 , *p* = 0.06, η^2_p = 0.125) or *Condition x Region* $F(_{2,26})$ = 0.412, *p* = 0.569, η^2_p = 0.015. A significant interaction of *Group* x *Hemisphere* ($F(_{1,27})$ = 5.988, *p* = 0.021, η^2_p = 0.182) was observed for group 2 (EBRP task former; *p* = 0.002) but not for the group 1 (equivalence tests former; *p* = 0.956).

3.2.2 The negative wave around 200-300 ms

Central electrodes: No main effect of *Group* was observed ($F(_{1,27})$ < 0.001, *p* = 0.997, η^2_p < 0.001). Conversely, a significant main effect of *Condition* was observed ($F(_{1,27})$ = 9.401, *p* = 0.005, η^2_p = ,510) , with the *unrelated condition* more negative than the *related condition* (*p* = 0.005). A main effect of *Electrode* was also observed ($F(_{5,23})$ = 28.128, *p* < 0.001, η^2_p = 0.510), with the *frontal electrodes* being more negative than the *posterior electrodes*. A significant difference between *Pz* and *Poz* electrodes relative to others was also observed (*p* < 0.01). No significant interaction of *Group* x *Condition* or *Group* x *Electrode* was found ($F(_{1,27})$ = 1.608, *p* = 0.216, η2 = 0.056, and $F(_{5,27})$ = 0.498, *p* = 0.570, η^2_p = 0.018 respectively). A significant interaction of *Condition* x *Electrode* was found. The unrelated condition was more negative than the related condition in the electrodes Fz (p = 0.03), Cz (p = 0.003), Pz and POZ (ps <0.001), whereas in electrodes Afz and Fpz significant differences were not observed (*p* = 0.192 and *p* = 0.922 respectively).

ROIs: No main effect of *Group* was observed ($F(_{1,27})$ = 0.008, *p* = 0.93, η^2_p < 0.001). On the contrary, main effects of *Condition* ($F(_{1,27})$ = 13.09, *p* = 0.001 , η^2_p = 0.33), *Region* ($F(_{2,26})$ = 61.381, *p* < 0.001, η2 = 0.695) and *Hemisphere* ($F(_{1,27})$ = 21.65, *p* < 0.001, η^2_p = 0. 445) were found. The *unrelated condition* was more negative than the *related condition.* This difference could be observed both in the left hemisphere and in the right hemisphere (p = 0.001, and p = 0.004 respectively), the left hemisphere being more negative than the right hemisphere (*p* = 0.001). The frontal and central regions were more negative than the posterior regions (*p* < 0.001 and *p* <0.001 respectively), while the frontal regions were more negative than the central regions (*p* < 0.001). There were no interactions of *Group* x *Condition* ($F(_{1,27})$ = 0.552, *p* = 0.464, η2 =0.2), *Group* x *Region* ($F(_{2,54})$ = 0.03, *p* = 0.96, η^2_p = 0.001), or *Group* x *Hemisphere* ($F(_{1,27})$ = 1.4, *p* = 0.246, η^2_p = 0.049), but a significant interaction of *Condition* x *Hemisphere* was found ($F(_{1,27})$ = 2, *p* = 0.169, η^2_p = 0.069). A trend of statistical significance in the interaction *Condition* x *Region* x *Hemisphere* was also observed ($F(_{2,54})$ = 3.193, *p* = 0.064, η^2_p = 0.106). Unrelated stimuli were significantly more negative in the

central and posterior regions (p = 0.001): Central (*p* = 0.001), posterior (*p* < 0.001). But not in the frontal regions (*p* = 0.262).

3.2.3. The positive wave around 400-550 ms

Central electrodes: A trend to significant difference in the main factor *Group* was found ($F(_{1,27})$ = 3.299, *p* = 0.079, η^2_p = 0.074). Conversely, a significant main effect of *Condition* was observed ($F(_{1,30})$ = 37.389, *p* < 0.001, η^2_p = 0.581), with the *unrelated condition* more positive than the *related condition* (p = 0.005). No main effect of *Electrode* was observed ($F(_{5,23})$ = 1.93, p = 0.094 ; η^2_p = 0.067). There were no interactions of *Group* x *Condition* ($F(_{1,27})$= 0.321, p = 0.576, η^2_p = 0.012)*, Group* x *Electrode* ($F(_{1, 27})$ = 2.102, *p* = 0.145, η^2_p = 0.072), or *Condition* x *Electrode* ($F(_{1, 27})$ = 1.967, *p* = 0.159, η^2_p = 0.068). No effects of *Group* x *Condition* x *Electrode* were not observed either ($F(_{5,27})$ = 1.781, *p* = 0.107, η^2_p = 0.083).

ROIs: No main effect of *Group* was observed ($F(_{1, 27})$ = 1.632, p = 0.212, η^2_p = 0.057). A significant main effect of *Condition* was observed ($F(_{1,27})$ = 42.355, *p* < 0.001, η^2_p = 0.611). A trend of statistical significance in the main effect of *Region* was observed ($F(_{2,26})$ = 2.887, *p* = 0.064, η^2_p = 0.019), and a significant main effect of *Hemisphere* was found ($F(_{1,27})$ = 6.924, *p* < 0.05, η^2_p = 0.188). In post-hoc comparisons it was found that the component in the *unrelated condition* was more positive than in the *related condition* (*p* < 0.001). It was also found that the component in the *right hemisphere* was more positive than in the *left* *hemisphere*. No significant differences were found between regions; there was only a trend between the central regions to be more positive than the posterior regions ($p = 0.078$), and there were no differences among frontal and central regions ($p = 0.40$). There were no interactions of *Group* x *Condition* ($F_{(1,27)} = 0.005$, $p = 0.947$, $\eta^2_p < 0.001$), *Group* x *Region* $F_{(1,26)} = 1.465$, $p = 0.24$, $\eta^2_p = 0.051$), or *Group* x *Hemisphere* ($F_{(1,27)} = 1.415$, $p = 0.245$, $\eta^2_p = 0.05$). There were no interactions of *Condition* x *Region* $F_{(2,54)} = 1.526$, $p = 0.227$, $\eta^2_p = 0.054$), *Condition* x *Hemisphere* $F_{(1,27)} = 0.033$, $p = 0.857$, $\eta^2_p = 0.001$), or *Region* x *Hemisphere* $F_{(2,54)} = 2.074$, $p = 0.136$, $\eta^2_p = 0.071$). There were no interactions of *Group* x *Condition* x *Region* ($F_{(2,54)} = 2.815$, $p = 0.1$, $\eta^2_p = 0.094$), *Group* x *Condition* x *Hemisphere* ($F_{(1,27)} = 0.896$, $p = 0.352$, $\eta^2_p = 0.032$), or *Condition* x *Region* x *Hemisphere* ($F_{(2,54)} = 0.720$, $p = 0.469$, $\eta^2_p = 0.026$).

4. Discussion

In the present study, priming effects were observed both at behavioral and electrophysiological levels. Response times to unrelated stimuli were longer than to related ones. ERPs waveforms showed sensitivity to the differences between experimental conditions. Both positive and negative waveforms increased its amplitude for the unrelated conditions. These results are in line with most studies that have investigated the ERP correlates of the stimulus equivalence tasks both in its EBRP version (e.g., [13][15-17][22-24][40-41]) and in the MTS tests version (e.g., [42-44]).

Some differences should be noted between our results and those reported in the literature, regarding the order of the EBRP task and MTS tests and the different trial types with each other We did not find significant statistical differences due to the order of presentation of the tasks (no main effect of *Group*), neither behavioral nor electrophysiological data. In our study there were only two interaction effects among main factors analyzed.

We observed an interaction between the factors *Condition* and *Trial type*: Subjects responded faster to untrained than to not symmetry trials. No difference was observed between untrained and not equivalence trials, nor between symmetry and not equivalence trials. This effect was found only for the unrelated condition. We interpret that this interaction effect could have been due to the previous exposure of the baseline training trials in both groups. The learning of the positive and negative relationships could have enhanced the response to unrelated trials, in comparison to the relationships that were not presented (in this case the *not-symmetry* trials).

Each group of participants showed a different pattern of results. Response times exhibited an interaction between *Group* and *Trial type.* Certainly, there was no priming effect for trained vs. untrained trials in the priming-equivalence test group (group 2). We interpret that this interaction effect could have been due to the previous exposure of the MTS test trials in the equivalence test-priming group (group 1).

Conversely, in Haimson et al. ([16, experiment 2), the authors reported differences in behavioral and electrophysiological effects due to the order of presentation of the tasks. In this study study participants who received the MTS tests before the EBRP task exhibited a "gradual emergence pattern" on the probes, an occurrence that has been contemplated in the literature (e.g. [4]). Other differences in the training and test procedure could have influenced the behavioral and electrophysiological results between experiments: Haimson et al. [16] used trigrams as sample stimuli, and nonsense forms as comparison stimuli in MTS training and testing. In their procedure, multiple sessions of training were conducted per day. Besides, there were two phases of training in which different combinations of sample stimuli, comparison stimuli and probabilities of feedback messages were done. Furthermore, the authors used only test stimuli in their EBRP task and trigrams were not employed. In our experiment we intermixed training and test stimuli in this task. In Haimson et al. [16], the authors found that only participants who performed the MTS tests before the EBRP task exhibited a clear "N400-like" effect. In Wang & Dymond ([17], experiment 1), differences in behavioral and electrophysiological effects due to the order of presentation of the tasks were also reported. In their behavioral results, significant differences on errors and response times were found among the distinct equivalence probes. Furthermore, they found that the ERP waveforms evoked by directly trained and derived trials differed only for those participants who had not received the EBRP task prior to the MTS tests. The differences in the behavioral and electrophysiological results between our experiment and those reported by the aforementioned studies could be due to the experimental procedures. In our experiment all participants learned the baseline relations and established derived relations in a consistent manner. Participants were trained until reaching criterion in consecutive days, and only those subjects that met criteria in both the MTS tests and the EBRP probes were included in the analysis. This procedure might have minimized or suppressed differences between groups of participants. It is also possible that other methodological factors among experiments (e.g. type of stimulus, number of stimuli and classes),could have produced the aforementioned differences.

4.1 Test order effects

In our experiment the absence of task-order-of-presentation effects in both, behavioral and electrophysiological data, suggests that the effects observed at both levels are well correlated with one another. In coincidence with other authors (e.g. [16]), our results suggest that the EBRP task may be a valid test for the formation of equivalence classes as well.The fact that stimulus classes formation could happen before the MTS tests had already been considered by other authors (e.g. [45]). As other procedures in addition to the MTS tests have been used for stimulus equivalence testing (e.g. [46-47]), this claim would have been taken into account, especially for ERP experiments.

Neither behavioral nor electrophysiological effects were found due to differences among related trial types of the EBRP task In our experiment, only an interaction effect was found at the behavioral level. Participants who performing the equivalence test before the EBRP task exhibited a slight difference in response times between symmetry and combined symmetry-transitivity trials. Moreover, no influences of trial type were found on ERP waveforms.

4.2 ERP differences in comparison with other studies

Some other differences regarding ERP correlates of EBRP tasks may be considered between our results and those reported in the literature.

First, in our results two waveforms showed a clear difference between unrelated and related conditions: A negative waveform that began about 200 ms and peaked before 300 ms post target stimulus onset, and a positive waveform that began about 300 ms and peaked before 550 ms. In Barnes-Holmes et al. [15], negative and positive long latency waveforms were also reported. However, their negative waveform reflected a bigger amplitude for nonequivalent trial types relative to directly trained and equivalent trial types. Also, their positive waveform showed a bigger amplitude for the directly trained prime-target pairs relative to the nonequivalent pairs. In Amd et. al. and in Bortoloti et al. (e.g. [48-49]), the authors only reported negative waveforms. The lack of report of any late positive waveform could be due to a special focus on the "N400-like effect" description. In other studies (e.g., [13][16-17][21-23]), authors reported both the negative and the positive waveforms.

Second, in our results the negative waveform appeared earlier than the positive waveform. Similar results were reported by other authors (i.e., [41]). In Wang & Dymond [17], the latency of the positive waveform changed between experiments 1 and 2. In their first experiment, the authors reported a greater positivity that was observed for symmetry trials during the 250–350 ms time-window, and a greater negativity that was observed for equivalence trials during 350–550 ms time-window. They claimed that the greater positivity was observed for within-class trials, and that the greater negativity constituted the "N400-like effect".

In a second experiment, the authors compared directly trained, symmetry and equivalence relations. They reported a late (350–550 ms) posterior waveform which was larger for symmetry and equivalence stimuli compared to those directly trained. In O'Reagan et. al. [21], a succession of several waveforms (P1, N2 and a late positive waveform in the 230–550 ms range that peaked as a P3a and P3b component) were reported. Significantly larger mean amplitudes were found among trial types in both P3a and P3b waveforms. They suggested that these waveforms could be sensitive to the distinct stimulus equivalence relations. In studies that examined ERP correlates of MTS test of stimulus equivalence (e.g.[42-44]), an earlier negative waveform was usually accompanied by a late positive waveform. Yorio et al. [42] reported a "negative waveform difference" ("dN400 effect") that was created via a point-by-point subtraction of waveforms between related and unrelated conditions, which was followed by a late positive waveform. Tabullo et al. [43] reported a negative waveform that was followed by a late positive waveform. In other studies that correlated ERP waveforms with different conditions in semantic classification tasks (e.g. [50-51]), earlier negative waveforms were also followed by a late positive waveform.

Without entering into the debate about whether earlier negative waveforms could actually correspond to any member of the N200 family of ERP components (e.g. [52]), at present, it is considered that the N400 component usually begins about 200 ms and peaks before 400 ms, so it can precede the late positive component (e.g. [53], p. 626). Again, the differences reported between the ERP data could result from differences in the degree of consistency in which the equivalence classes were established among participants of the different studies. Other methodological factors should also be taken into account. A note of caution is required regarding the presence of both N400-like effects and late positive waveforms in an EBRP task with short SOAs. Hill et al. [35] were able to identify an N400 effect for semantically unrelated words as well as a late positive waveform for related words. In van Vliet et. al. [54], the authors considered that the N400 component could be overlapped by ERP components associated with the response preparation in stimulus selection tasks. These technical issues of event-related potentials could explain the distinct patterns of ERP waveforms reported in the literature on electrophysiological correlates of "stimulus equivalence based" tasks. It could be that future replication of experiments with a delayed response paradigm could help minimize the ERP components overlapping and could provide a better discrimination of the N400 and the late positive waveform. Nonetheless, we believe that in our experiment, in which short SOAs were used, the possible existence of an overlay between the N400 and the late positive waveform does not preclude our interpretation of the data, as clear correlations between behavioral and ERP data could be obtained.

Third, in our experiment the effects of different conditions of the EBRP task (related versus unrelated trials), were observed in both negative and late positive waveforms. Both the negative and the positive waveforms were significantly larger for the non-equivalence trial types relative to the equivalence ones. Although it could be a topic for debate to ascribe these late negative and positive waveforms as correlates of the EBRP task to well known "ERP components" (such as the N400 and the "late positive component"), part of the literature should be considered. Several studies have pointed out that some late positive waveforms are sensitive to the behavioral processes of semantic categorization (e.g. [55-59]). The verification of late positive waveforms that are sensitive to differences in the relationships between stimuli experimentally established could complement the electrophysiological correlates of the stimulus equivalence research.

4.3 SEC paradigm as a semantic model

Even though in SEC experiments electrophysiological results are considered relevant to the investigation of semantic processes (e.g. [9-10][13-15][40-41]), other authors (e.g. [60]) have pointed out that the term "semantics" may have been used rather loosely in a great variety of studies in which both negative and positive waveforms are verified. The possibility that stimulus equivalence research can elicit N400 priming effects comparable to those found in language has been recently addressed by Tabullo et al. [22]. These authors compared ERP correlates of priming in semantically related words and pseudo-words related through an equivalence protocol. They found similar behavioral and N400 effects when comparing unrelated vs. related prime-target pairs in language and stimulus equivalence tasks. These results suggest that ERP correlates of semantic priming could engage at least partially overlapping neural mechanisms in language and associative learning. However in Tabullo et al. [22],late positive waveform was found only in the language based semantic priming task.. But the in Wang & Dymond study [17], these authors found a late positive waveform in the EBRP task that was greater for related trials than the unrelated ones. These authors suggested that the late positive waveform that they observed in their experiment 2 could correspond to a "P3" component, that could be functionally similar to P3b components that were recorded by other authors in studies on stimuli categorization (e.g., [50-51][55-59). However, these differences in results suggest that the functional significance of the late positive waveform in the EBRP task should be studied further. Until now, the late positive waveform has not been a semantic-specific correlate, but rather a non-specific effect.

Although the mental processes during the SEC test and the ERPT were not the focus of the present study, some authors have been interested in the role of implicit and explicit processes during similar tasks. (e.g. [61-62]). For example, Reber and colleagues [61] explored the temporal evolution of implicit inference using intracranial EEG, while Gross and Greene, [62] studied the role of awareness in an analogical inference task through the implementation of a Post-experimental questionnaire. While these authors have conducted their experiments under the framework of the nature of the "episodic" or "relational" memory systems, our study instead was focused on the brain correlates of the equivalence based priming, and the influences of the order of tasks and trial probes. Indeed, it would be interesting to know whether the participants of the ERPT task were aware of the relatedness among stimuli or not. This subject would be taken into consideration in future studies and the awareness of the participants would be assessed objectively. According to this perspective, while undisputed that highly repetitive learning of associations at some point leads to semantization, it seems also clear that learning of novel, arbitrary associations requires episodic memory, and that possible mechanisms of this integration may involve a cooperative interaction between the hippocampus and midbrain dopamine regions (e.g. [63]). If this is the case, it could be of interest to study using brain imaging techniques if similar structures are activated during SEC tests.

4.4 Summary

Our results provide support that 1) the EBRP task exhibits priming effects among the SEC stimuli, 2) the behavioral and electrophysiological effects were similar regardless of the order of presentation of the MTS tests, and 3) there were no differences within the baseline and derived relationships with

each other. The behavioral and electrophysiological effects of the EBRP task reflect processes sensitive to the association among distinct elements in the corresponding SEC. The fact that comparable results have been obtained both in the EBRP and in linguistic tasks (e.g. [66]), could substantiate the assumption that the association among elements in the EBRP task could be comparable with the semantic relationships established in pre-experimental conditions. Another issue to be investigated is the contribution of associative learning to the formation of stimulus equivalence classes, semantic and / or linguistic processes (e.g. [67-68]). Future studies will address these issues. Nevertheless, Event-related potential correlates of stimulus equivalence classes seem to be a useful tool to investigate these topics.

5. Limitations of the study

The fact that only 32 of 52 participants reached criteria to be included in the data analysis was based on the convenience of not introducing variations between subjects in the number of training sessions (e.g. [15]). On the other hand, it is well known that some healthy and intellectually normal subjects fail on stimulus equivalence tasks despite extensive training (e.g. [65]).

The delimitation of the time windows for the EEG analysis was made based on time windows used in the analysis of derived relations in priming tasks [17] and visual inspection of the raw data. However, this delimitation is not free of possible situations that increase the type 1 error. One possible solution, for future investigations, would be that the choice of the temporal window was selected by non parametrics analysis, as for example a cluster-based permutation analysis (e.g. [69]).

6. Possible future studies on other topics

Based on several studies (e.g. [70-72]), some authors have proposed that symmetry and transitivity tests may be differentiated in terms of behavioral processes. These studies could involve a questioning about the traditional interpretations of stimulus equivalence processes. Future studies that include electrophysiological techniques could be useful to investigate these issues. The same can be said about the possible influence of other variations on the training of basal relationships (e.g. [73-74]).

Whilst the present work does not deal with the brain structures involved in memory formation, some authors have been interested in them (e.g. [63]). Shohamy & Wagner [63], have proposed that integrating discrete experiences into a cohesive knowledge may depend on generalization of such experiences. One approach to examining generalization is to train an organism on separate events that share common elements (e.g., A–B and B–C) and then test whether the organism demonstrates knowledge about the relation between the elements that were not directly experienced together (e.g., A and C) (e.g. [74-75]).

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***** INSERT APPENDICES A, B & C ABOUT HERE *****

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Figure captions

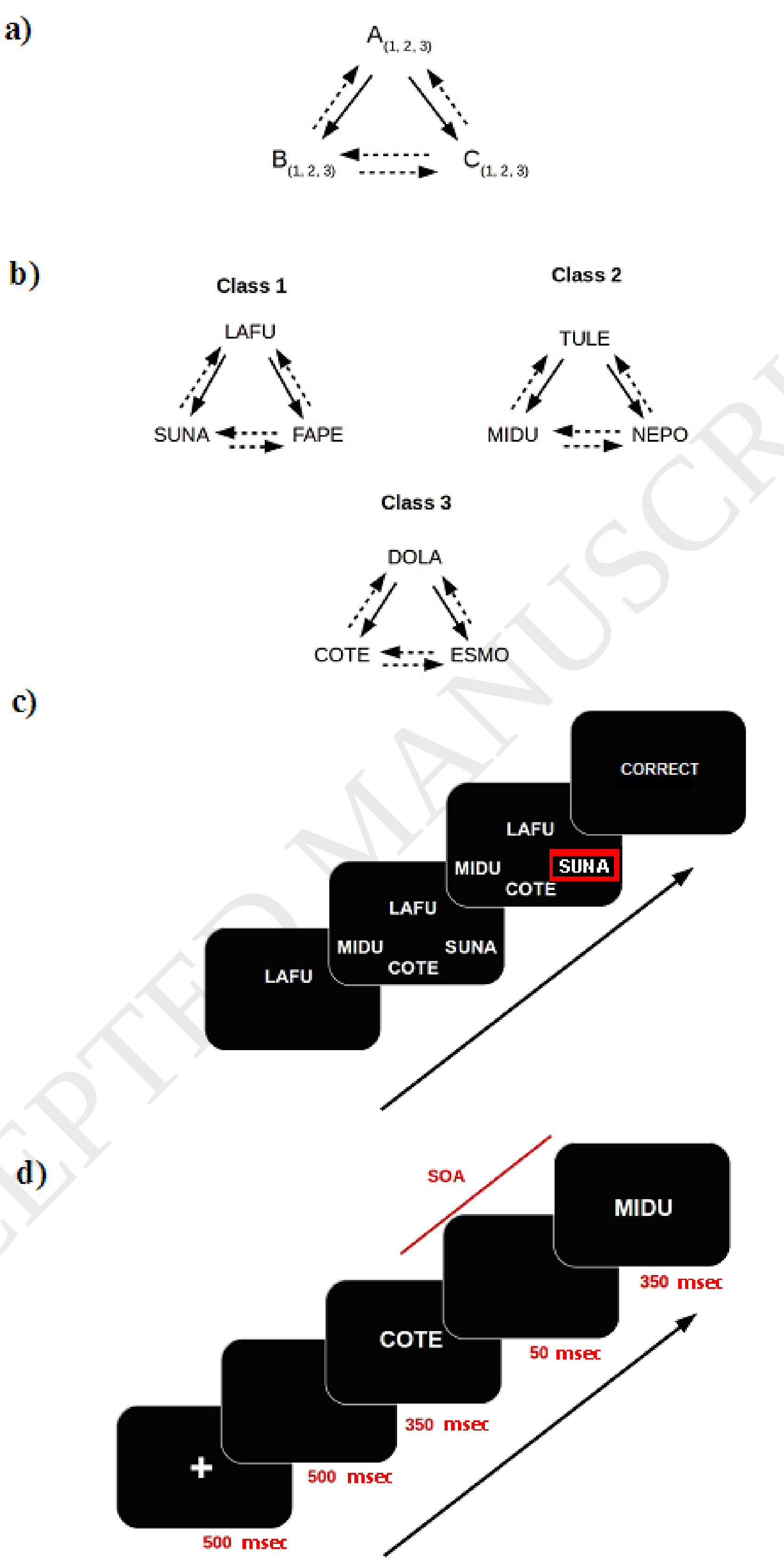


Fig. 1. An outline of the stimulus equivalence classes in which the solid lines show the trained relations and the dotted lines the derived relations **(a)**. Elements of the three stimulus equivalence classes that were used in the experiment **(b)**. A typical trial of the baseline associations training. The red rectangle indicates the comparison stimuli that

had been assigned by the experimenter to the class (in this case the stimulus "SUNA"). This rectangle did not occur in any of training trials **(c)**. A typical trial of the equivalence based-relatedness-priming task. The "stimulus onset asynchrony" (SOA) and the durations for each event are printed in red **(d)**.

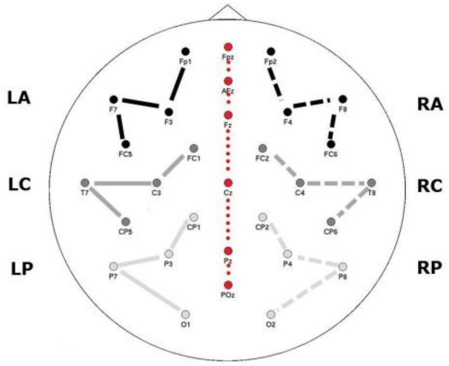


Fig. 2. Placement of the electrodes on the scalp for the EEG recording and processing. Region corresponding to the Midline electrodes was indicated in red dotted lines, and another six regions of interest in black and gray continuous (left ROIs) and dashed lines (right ROIs): LA, left anterior; LC, left central; LP left posterior ; RA, right anterior; RC, right central; RP, right posterior.

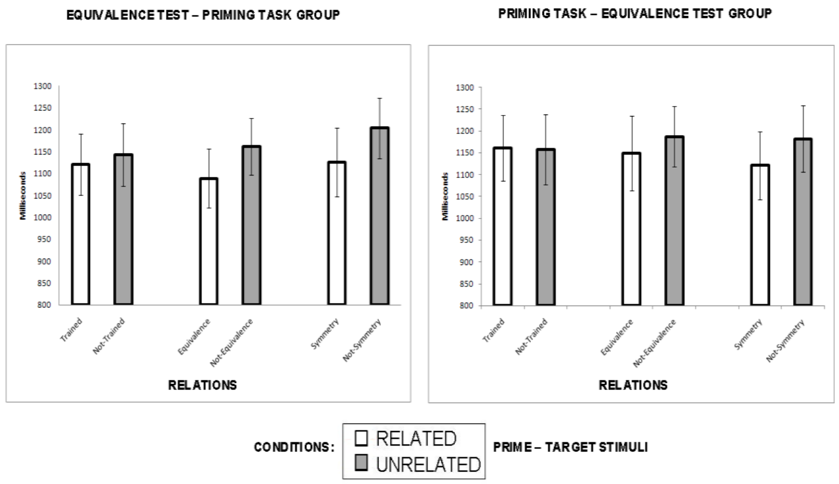
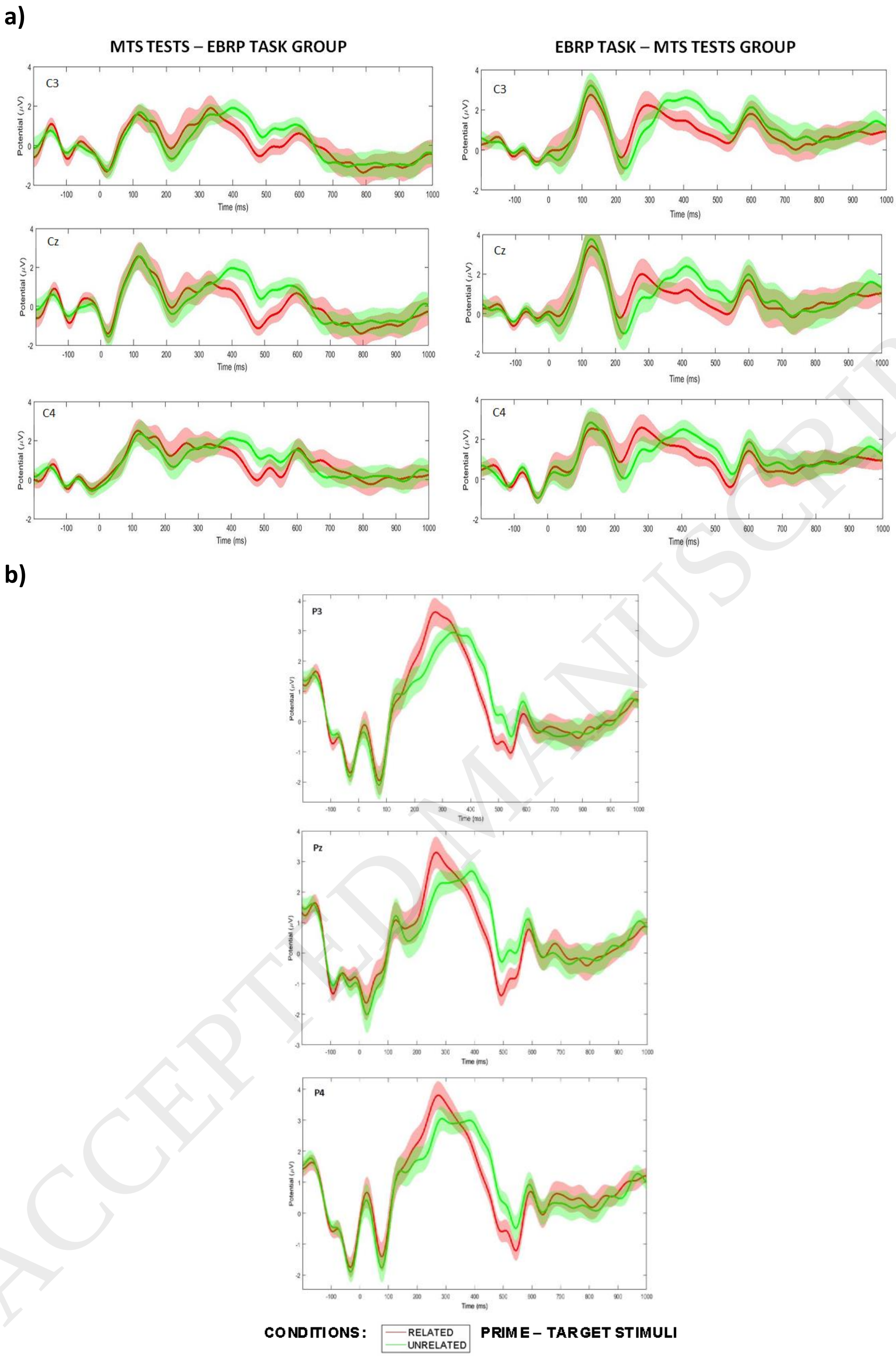


Fig. 3. Raw response times in the relatedness priming task between task order and experimental conditions (related and unrelated trials). Related and unrelated trials are separated according to the type of relationship (trained and derived). The graph shows the mean values and the standard error in each group (N =16). Taken together, the related trials (white bars) were faster than the unrelated ones (green bars) with a p value < 0.05. The main effect between conditions (related vs unrelated) can be observed in both groups. Although significant interactions were observed in the interactions Group x Trial type, and Condition x Trial type, the triple interaction Group x Condition x Trial was not verified verified in the statistical analysis.


a)
MTS TESTS – EBRP TASK GROUP
EBRP TASK – MTS TESTS GROUP
C3
Cz
C4
Potential (μV)
Time (ms)
b)
P3
Pz
P4
CONDITIONS:
RELATED
UNRELATED
PRIME – TARGET STIMULI

c)

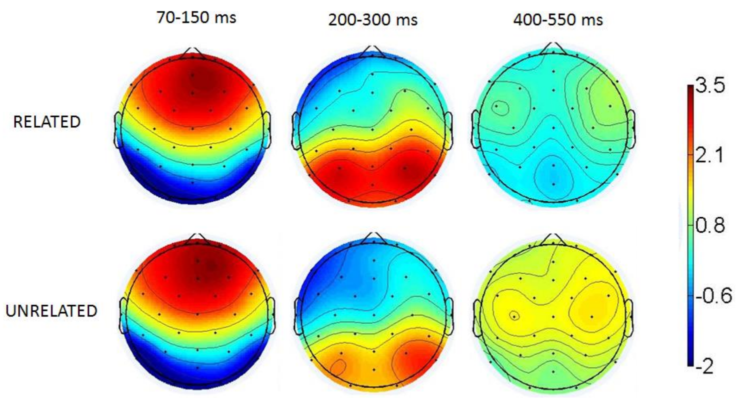


Fig. 4. Mean voltages and standard errors of the grand-average ERPs waveforms at sites C3, Cz and C4 separated by task order and experimental conditions (related and unrelated prime-target stimuli) **(a)**. ERPs waveforms at sites sites P3, Pz and P4 in both unified groups on an adjusted scale for better visualization **(b)**. Brain topography of ERPs waveforms in both unified groups within the three time-windows of interest in related and unrelated conditions **(c)**. (MTS TESTS: matching to sample tests – EBRP TASK: equivalence based priming task).

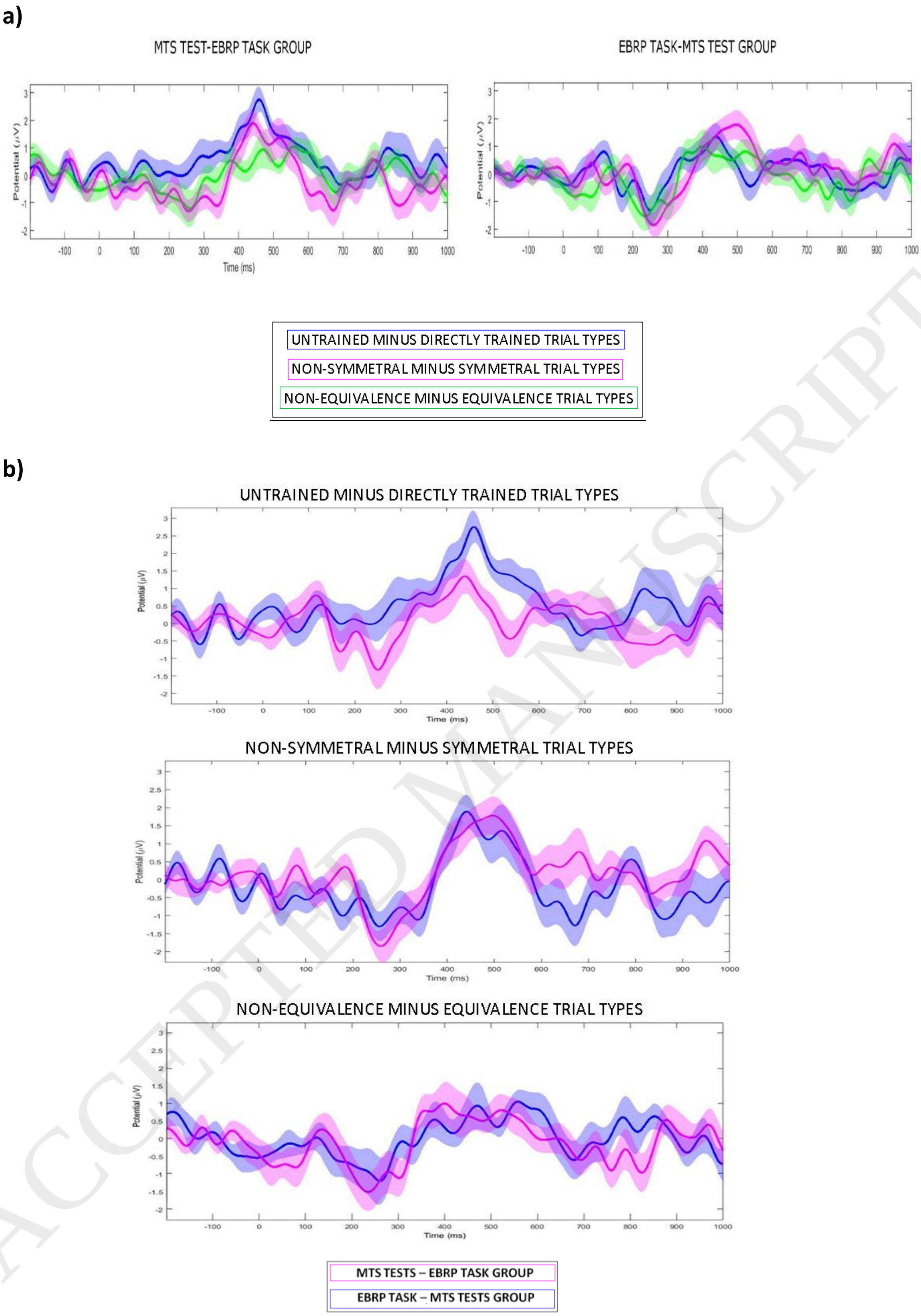


Fig. 5. Mean voltages and standard errors of the difference ERP (dERP) that were obtained by subtracting the waveforms between the related and unrelated conditions in both groups. The graphs show each of the dERP at the centroparietal cluster (Cp1, Cz, Cp2, P3, Pz, and P4 electrodes). The upper portion displays the dERP comparisons between the groups(MTS TESTS: matching to sample tests, EBRP TASK: equivalence based relatedness priming task) in the three trial types, with the subtraction between the unrelated and the corresponding related trial types **(a)**. The lower portion display dERP comparisons among the three related minus unrelated trial types **(b)**.

Appendix A. Electrophysiological studies investigating the event related potentials (ERPs) correlates of behavior on the stimulus equivalence paradigm.

Study	Number of classes and elements in each	Training protocol	Behavioral task	Reported ERPs components or waveforms	Reference Nº
Warren & McIlvane (1998).	Not found	Not found	Equivalence based relatedness priming task	"N400".	9
DiFiore et al. (2000).	3, 6 member classes	Not described	Equivalence based relatedness priming task	"N400".	11
Staunton et al., (2003).	Not found	Not found	Equivalence based relatedness priming task	"N400".	40
Barnes-Holmes et al. (2004)	2, 4 member classes	Linear design	Equivalence based relatedness priming task	"N400"	12
Barnes-Holmes et al. (2005).	2, 4 member classes	Linear design	Equivalence based relatedness priming task	"N400".	41
Tabullo et al. (2006).	2, 3 member classes	Linear design	Matching to sample testS	"N200" and a late positive waveform.	42
Yorio et al. (2008).	2, 3 member classes	Linear design	Matching to sample tests	"dN400" and a late positive waveform.	43
Haimson et al. (2009).	3, 6 member classes	Sample as node design	Equivalence based relatedness priming task	"dN400".	16
Amd et al. (2013).	3, 3 member classes	Linear design	Stimulus recognition task	"N200" and a late positive waveform.	48
Wang &, Dymond (2013).	4, 3 member classes	Sample as node design	Equivalence based relatedness priming task	A positive waveform and a "N400-like effect".	17
Tabullo et al. (2013).	2, 3 member classes	Sample as node design	Matching to sample tests	"N400".	44
Bertoloti et al. (2014).	2, 5 member classes	Sample as node design	Equivalence based relatedness priming task	"N400".	49
O'Reagan et. al. (2015).	2, 3 members classes	Linear design	Matching to sample tests	"P1", "N2", "P3a" and "P3b".	21
Tabullo et al. (2015a).	2, 3 members classes	Sample as node design	Equivalence based relatedness priming task	"N400" and a late positive waveform.	22
Tabullo et al. (2015b).	2, 3 members classes	Sample as node design	Equivalence based relatedness priming task	"N400-like", "P300-like".	23

Appendix B. Stimuli used in both the equivalence and relatedness priming tasks.

	Class 1	Class 2	Class 3
Stimuli A	LAFU	TULE	DOLA
Stimuli B	SUNA	MIDU	COTE
Stimuli C	FAPE	NEPO	ESMO

Appendix C. Response times of the priming task.

Groups	Conditions	Trial types		
		Trained	Symmetry	Equivalence
Equivalence Test – Priming Task	Related pairs	1120.33± 278.26	1125.95 ± 277.95	1089.10 ± 288.44
		Not trained	Not symmetry	Not equivalence
	Unrelated pairs	1142.87 ± 271.56	1203.71 ± 313.02	1161.64± 260.03
		Trained	Symmetry	Equivalence
Priming Task – Equivalence Test	Related pairs	1160.95 ± 300.41	1120.74 ± 304.84	1149.10 ± 323.51
		Not trained	Not symmetry	Not equivalence
	Unrelated pairs	1157.52 ± 339.49	1181.63± 300.41	1187.32 ± 277.62

Note. Mean values and standard deviation in milliseconds, are separated. according to two groups of participants: Group 1, those who perform the stimulus equivalence tests before the relatedness priming task, and Group 2, those who perform the relatedness priming task before the tests of equivalence. Related pairs conditions included trained, symmetry and equivalence trial types. Unrelated pairs conditions included not trained, not symmetry and not equivalence trial types.