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THE USE OF N400 IN STUDIES OF STIMULUS EQUIVALENCE: A REVIEW OF METHODS AND PARAMETERS

O USO DE N400 EM ESTUDOS DE EQUIVALÊNCIA DE ESTÍMULOS: UMA REVISÃO DE MÉTODOS E PARÂMETROS

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ABSTRACT

The N400 is defined as an event-related brain potential that is sensitive to the semantic relations between stimuli. For instance, when a pair of words belong to the same semantic domain (e.g., monkey-banana), the N400 will be significantly reduced in comparison to the N400 evoked by unrelated words (e.g., monkey-carburetor). Notably, the N400 responses are also sensitive to the arbitrary stimulus-stimulus relations formed by matching-to-sample procedures (MTS), supporting the notion that stimulus equivalence is a behavioristic model of semantic relations. In this study, we presented a methodological review of studies on stimulus equivalence that used the N400 as dependent measure of “equivalent” and “non-equivalent” stimulus-stimulus relations formed by MTS procedures. First, we searched on databases for studies that used the descriptive terms “equivalence relations”, “matching-to-sample”, “MTS”, “N400”, “relational learning”, and “derived relations” on the title and the abstract. Then, we categorized the number of experiments in each study, population, nature of stimuli, the event-related brain potential used as a dependent measure and whether the critical probes comprised baseline, reflexive, symmetric or transitive relations. We found that the MTS variables differed substantially from one study to another. Considering that most of these MTS variables may be critical to the establishment of stimulus equivalence, we encourage follow-up studies that aim at verifying whether and to what extent they can be related to the N400 outcomes.

Key-words: Matching-to-sample, equivalence-relatedness-based-procedure, stimulus equivalence, N400, semantic relations, methodological review.

RESUMO

O N400 é um potencial cerebral relacionado a eventos que é sensível às associações semânticas entre estímulos. Por exemplo, se um par de palavras pertencerem ao mesmo domínio semântico (e.g., macaco-banana), o N400 será significativamente reduzido em comparação ao N400 evocado por palavras não relacionadas (e.g., macaco-carburador). Chama a atenção o fato de que as respostas de N400 são também sensíveis às relações arbitrárias estímulo-estímulo, formadas a partir de procedimentos de *matching-to-sample* (MTS), o que suporta a noção de que a equivalência de estímulos é um modelo behaviorista das relações semânticas. Neste estudo, nós apresentamos uma revisão metodológica de estudos sobre equivalência de estímulos que empregaram o N400 como medida dependente de relações estímulo-estímulos “equivalentes” e “não-equivalentes” estabelecidas por procedimentos MTS. Primeiramente, nós procuramos nas bases de dados por estudos que usaram, no título ou no resumo, os termos descritivos em inglês “*equivalence relations*”, “*matching-to-sample*”, “MTS”, “N400”, “*relational learning*” e “*derived relations*”. Em seguida, nós categorizamos o número de experimentos em cada um dos estudos, a população, a natureza dos estímulos, o tipo de potencial relacionado a eventos que foi tomado como medida dependente e se os pares de estímulos apresentados em testes críticos foram formados por relações de linha de base e relações derivadas reflexivas, simétricas e transitivas. Verificamos que as variáveis de MTS diferiram substancialmente de um estudo para outro. Ao se considerar que a maioria dessas variáveis de MTS são críticas para o estabelecimento da equivalência de estímulos, nós encorajamos a condução de uma série de outros estudos que visem verificam em que medida tais variáveis estariam relacionadas com os resultados de N400.

Palavras-Chave: *Matching-to-sample*, equivalência de estímulos, N400, relações semânticas, revisão metodológica.

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The discovery of the N400 component by Kutas and Hillyard (1980) fostered the investigations on the brain responses to semantic relationships between stimuli (i.e., meaning). The N400 is an event-related potential (ERP) conceived as part of an ongoing neural activity that peaks at approximately 400 ms after the presentation of a stimulus. Some researchers have stated that the N400 appears to be more robust at the centroparietal regions of the brain, with a bias towards the right brain hemisphere (e.g., Coulson, Federmier, Van Patten, & Kutas, 2005; Kutas & Federmier, 2011). However, there are prior evidence of more diffused lateral distributions of brain activity as a result of the type of task used to elicit the ERPs, the nature of stimuli and participants' age (e.g., Kutas and Hillyard, 1982; Harbin, Marsh and Harvey, 1984; Kutas, Van Petten and Besson, 1988). To date, investigators have used the ERP technique for detection of measurable changes in the brain's responses that are into functional relations with environmental stimulation mostly because of its temporal precision. Thus, the experimenter becomes capable of relating specific brain responses to the presentation of a given antecedent or consequential stimuli (cf., Luck, 2014).

Several types of visual and auditory stimuli are likely to evoke the N400 in a wide range of experimental paradigms. In one of the most frequently used, sequences of sentences – written or spoken – are presented, while the participants' brain activity is being continuously registered with an electroencephalogram. In some cases, the experimenter controls the contextual cues that determine whether or not a given set of stimuli are semantically related or not. For example, in the sentence "In the zoo, a girl looked at the *monkey* that was eating a *banana*"**,** the nouns "monkey" and "banana" are within the same semantic context (i.e., congruous). From an observer's perspective, this sentence brings valid meaningful information. Notwithstanding, the awkward combination of "monkey" and "carburetor" in the sentence mentioned above can be considered marginally significant in the context of being in the zoo (i.e., "In the zoo, a girl looked at the *monkey* that was eating a *carburator*"). The imagery of a monkey biting and swallowing auto parts can be funny. However, it is not meaningful in the same sense as the imagery of a monkey eating the fruit. In this context, the electroencephalogram will show that the brain's response to "congruence" is discriminable from its responses to "incongruence" (see Figure 1, for an example).

The electroencephalogram recordings depict series of waves representing the activity of groups of cortical neurons in a given time window. The wave-forms can be altered when the participant is exposed to a relevant source of stimulation. If the relevant source of stimulation is conceived as unrelated nouns (e.g., "monkey-carburetor") the waves will exhibit a steep slope at approximately 400 ms after the presentation of the stimulus. The waves will peak at around 500-550 ms and return to its regular levels at around 600-620 ms. On the contrary, if the relevant source of stimulation is conceived as related nouns (e.g., "monkey-banana") the waves will be flatter, starting at 420 ms, peaking at approximately 550-580 ms and returning to regular levels at around 650-680 ms (Hamm, Johnson, & Kirk, 2002; Kutas & Federmeier, 2011; Kutas, Kiang, & Sweeney, 2012). The differences in the waveforms topographies that are observed 400 ms after the presentation of the stimulus are taken as the measures of "the brains point of view" (cf. Kutas & Federmier, 2011) of meaningfulness or semantic relations (see Figure 1).

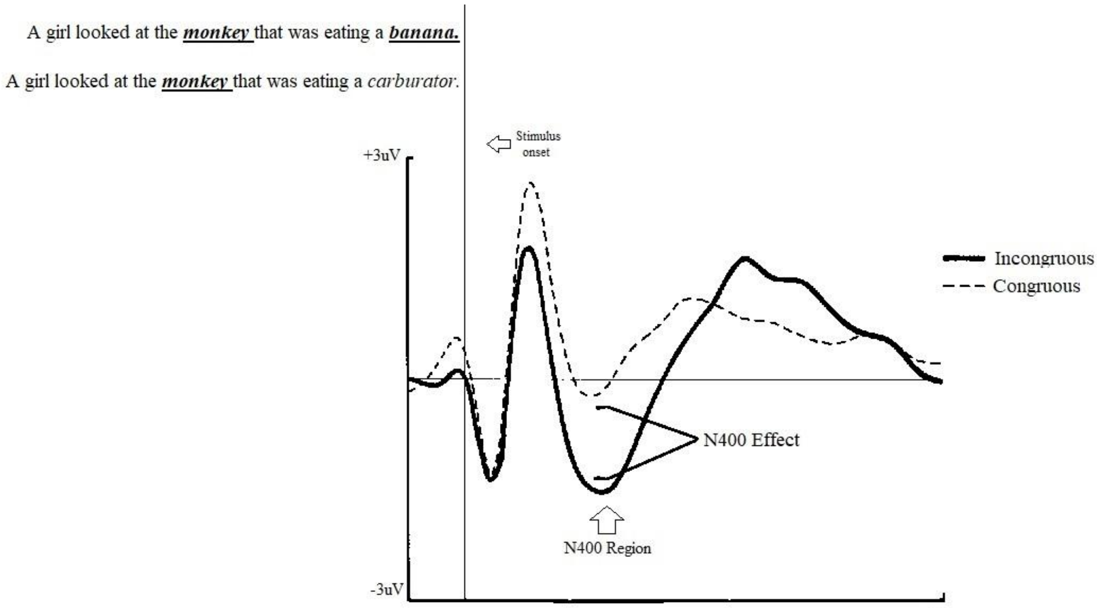

Figure 1. Schematic representation of stimulus presentations (upper left portion of the figure) and the ERP format (central right portion of the figure). The reader should note that the N400 is the negative waveforms that peak 400 ms following the presentation of the last noun (N400 region). The negativity is related to congruous and incongruous stimulus-stimulus relations (see legends). However, the negativity peak is significantly larger for incongruous relations. The N400 effect refers to the distance between the N400 negativity peak for congruous and incongruous (see the lines forming an acute angle).

Recently, behavior analysts employed electrophysiological techniques in order to testify that derived stimulus-stimulus relations represent instances of semantic relationships as those occurring in natural languages (e.g., DiFiore, Dube, Oross III, Wilkinson, Deutsch, & McIlvane, 2000, Donahoe, 2017). In general, these experiments consist of two phases. On the first phase, the participants are exposed to series of Matching-to-Sample (MTS) procedures to engender equivalence relations comprised by the arbitrary forms A (A1 and A2), B (B1 and B2) and C (C1 and C2) (cf. Lazar, 1977; Sidman & Tailby, 1982; Sidman, 1994, 2000). To illustrate, the conditional discriminations A1B1 and A2B2 are established by programmed feedback which follows the matching of stimulus B1 to the sample A1, and stimulus B2 to the sample A2. Similarly, matching of stimulus C1 to A1 and stimulus C2 to A2 establishes the conditional discriminations A1C1 and A2C2. Then, the participants are likely to exhibit the emergence of symmetrical relations BA (B1A1 and B2A2) and CA (C1A1 and C2A2); transitive relations BC (B1C1 and B2C2); and combined tests for the emergence of symmetry and transitivity CB (C1B1 and C2B2) without being trained to do so. These observations lead to the inference that training established the equivalence classes A1B1C1 and A2B2C2. Upon completion of MTS procedures, the participants progress to the second phase, in which they are exposed to an equivalence-based-relatedness-priming task[1] - EBRP task (cf. Menéndez, et al, 2018) – that presents some potentially unrelated (e.g. B1C2, B2C1, C2B1 and C1B2) and related (e.g. B1C1, B2C2, C1B1 and C2B2) stimulus pairings. The prediction here is that N400 with greater amplitudes will follow the presentation of the "non-equivalent" (unrelated) pairs and smaller N400 will occur after the "equivalent" (related) pairs. So far, the experimental data has evidenced robust N400 effects related to equivalence relations. (e.g., Ortu, 2012).

To date, several studies reported robust N400 effects related to equivalent and non-equivalent relations produced by MTS procedures that is analogous to the N400 ERPs related to words in the natural language (see Palmer, 2009 and Ortu, 2012 for brief review and discussion). Thus, it is plausible to assume that such observations provide external validity to Murray Sidman's stimulus equivalence paradigm as a behavioristic model of semantic relations. Also, the combination of behavioral and electrophysiological techniques may have broad theoretical implications for the behavioristic understanding of complex behaviors – especially those responses that involve meaning comprehension and symbolic-like behaviors – by expanding our current comprehension of this very subject matter. As Skinner (1989) pointed out:

> "There are two unavoidable gaps in any behavioral account: one between the stimulating action of the environment and the response of the organism and one between consequences and the resulting change in behavior. Only brain science can fill those gaps. In doing so, it completes the account; it does not give a different account of the same thing" (p. 18).

Following Skinner's rationale, we emphasize the relevance of studies on the electrophysiological measures of brain responses to external stimulation embedded in semantic-like relations formed by MTS procedures in the human laboratory. So, in the current study, we reviewed the current empirical data of studies on the electrophysiological correlates of stimulus equivalence. Our first goal was to provide readers with information regarding the nature of the N400 effects observed in electrophysiological measures that followed MTS procedures. Then, we outlined some possible pathways for future research. We aimed at providing relevant information regarding the experimental routines that have been implemented for studying the neural correlates of stimulus equivalence and to depict the types of variables and parameters that were manipulated in the studies that we analyzed.

METHOD

This study reviewed the behavior-analytic experimental literature on the electrophysiological correlates of stimulus equivalence. To achieve our goals, we searched in the current databases in order to find and elect studies. Second, we elaborated the criteria for election and exclusion of papers. Finally, analyzed the aims, methods, and results described in each study (see Results). The bibliographic research was finished in 2017.

Procedures for Search

We searched on the Scopus, Web of Science, Redalyc, Research Gate and Scientific Electronic Library Online (Scielo) with no restriction to period. We consulted on these databases from May 2017 to May 2018, using the descriptive terms in English: "Equivalence Relations," "Matching-to-Sample", "MTS", "EEG", "N400", "ERP" and "Event-related potentials." To select an article, we looked for at least three of these terms in the abstract and keywords. We excluded from analysis all the articles that did not attain these criteria.

Procedures for Analysis

We started the analysis by reading the abstracts and keywords, searching for the descriptive terms. Then we read the articles and proceeded to an analysis their contents aiming at categorizing the structures of the experimental design and determining the experimental variables that are considered critical for the formation of

[1] Stimulus presentation and behavioral requirements of the EBRP paradigm are similar to those that are being used in the electrophysiological studies of semantic relations (e.g., semantic priming, lexical decision and semantic judgment). In this study, however, we will use the term EBRP because the MTS contingencies shaped the semantic status of the prime and target stimuli relations.

[2] The terms "prime" and "target" reffers to the temporal and functional properties of stimuli presented in a kind of experimental preparation that is used by experimental cognitive psychologists to study many types of behavioral processes controlled by stimulus-stimulus relations such as memory and semantics. Procedurally speaking, the names prime and target are

stimulus equivalence: Training structure, training procedure, number of classes, class size, and the nature of stimuli (see Arntzen, 2012; for broader review and discussion). We included other variables that are not directly related to the participants' performances in MTS or EBRP tasks such as sample size, participants' age, and nationality. Finally, we looked for the information regarding the year of publication, the number of experiments and the journals in which the studies were published.

We categorized the articles considering the sequences of training and testing procedures and whether or not the participants had experienced MTS trials that probed for derived relations. Category A comprised articles in which participants were given to MTS procedure 1) to establish baseline relations, 2) to test for derived stimulus-stimulus relations and then, 3) given to ERPT tasks. Category B comprised articles in which participants were exposed to EBRP without been exposed to the standard tests for derived relations on MTS procedure. Figure 2 schematized the sequence of training and testing phases of the experiments in each category. The diamonds represent the phases in which MTS procedures were used for training and testing, and the rectangles with rounded corners represent the phases in which the EBRP was used, and the EEG recordings occurred.

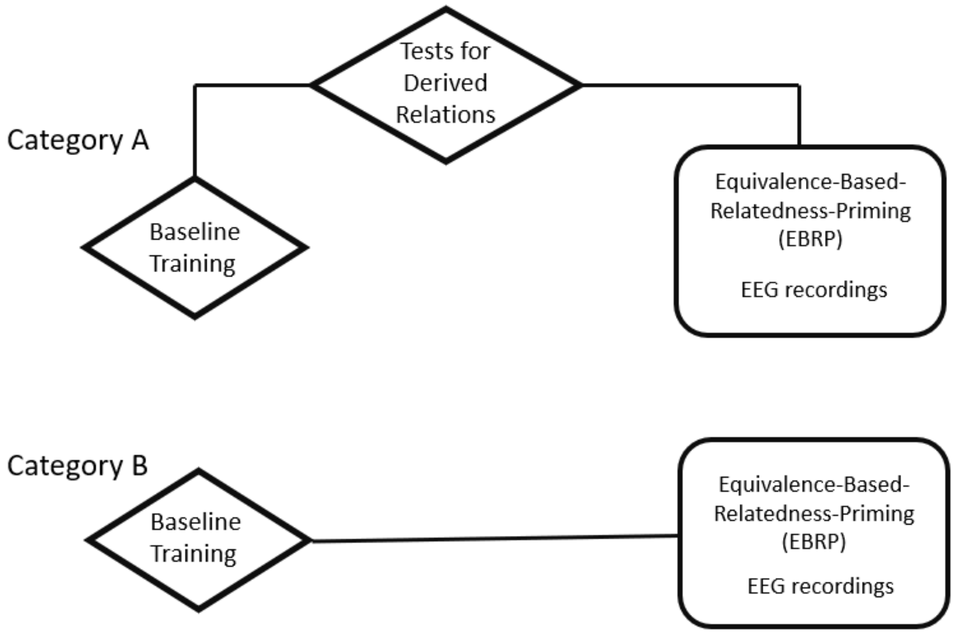

Figure 2. Sequences of training and testing procedures. Category A refers to the experiments comprised of three stages (training and testing with MTS procedures and EEG recordings with EBRP tasks). Category B refers to the experiments comprised of two stages (training with MTS procedures and EEG recordings with EBRP tasks).

Finally, we evaluated the characteristics and parameters of the EBRP task. First, we summarized the temporal parameters involved in stimuli presentation, inter-stimulus intervals, intertrial intervals, whether participants had to respond covertly or overtly and the stimulus presentation procedures. After that, we verified whether EBRP presented related and unrelated baseline trials, related and unrelated reflexive trials, related and unrelated symmetry trials and related and unrelated transitivity trials.

RESULTS AND DISCUSSION

We found a total of 15 articles that addressed the electrophysiological correlates of stimulus equivalence. Six out of the 15 articles did not achieve criteria regarding the use of descriptive terms in the abstract and keywords and were excluded from analysis. In four of these excluded articles, we found interesting experimental work regarding the correlations between the N400 and stimulus equivalence. However, extensive descriptions of the experimental procedures lacked for two of them (DiFiore et al., 2000; Deutsch, Oross III, DiFiore, & McIlvane, 2000), making the analysis unfeasible. Two experiments studied adults with cognitive impairments. The first one sought to verify the relations between general brain activities in elders diagnosed with neurodegenerative disorders and the acquisition of stimulus equivalence (Arntzen & Steingrimsdottir, 2017) and the other investigated the N400 effects in poststroke patients (Paranhos, Paracampo, Souza, Galvão, & Brino, 2018). These experiments were not analyzed in this research because the participants' performances on the MTS procedures may have been related to the clinical condition (see Mandler, 1959 for a discussion). Moreover, the study by Paranhos et al., (2018) was published after completion of this literature review. One experiment analyzed all ERPs potentially related to stimulus equivalence (O'Reagan, Farina, Hussey, & Roche, 2014), which was out of the scope of this analysis. Two theoretical articles explored the conceptual advances in the face of growing evidence that covert brain responses evoked by external stimulation can be measured, predicted and controlled by behavioral scientists (Palmer, 2009; Ortu, 2012). The study by Granerud-Dunvoll, Arntzen, Elvashagen, Hatlestad-Hall & Malt (2019) was published after we had concluded our research.

Thus, we considered nine articles for analysis in which we were able to found the relevant information regarding the MTS and EBRPtasks used to assess the electrophysiological correlates of stimulus equivalence. According to Figure 3, the first experiment using N400 measures related to stimulus equivalence procedures was published at the beginning of the second half of the last decade, indicating that this topic of investigation appeared very recently in the history of Behavior Analysis. More precisely, the empirical work on this topic started approximately twenty years after Murray Sidman has assumed that stimulus equivalence is related to semantic in naturally occurring languages as "one way that words can come to mean what they stand for" (cf. Sidman & Tailby, 1982, Sidman, 1994, p. 563). Figure 3 also shows rapid growth of publications around 2013 and 2018. This growth supports an inference of the increased interest in the measurement of brain activity related to derived stimulus control among behavior analysts.

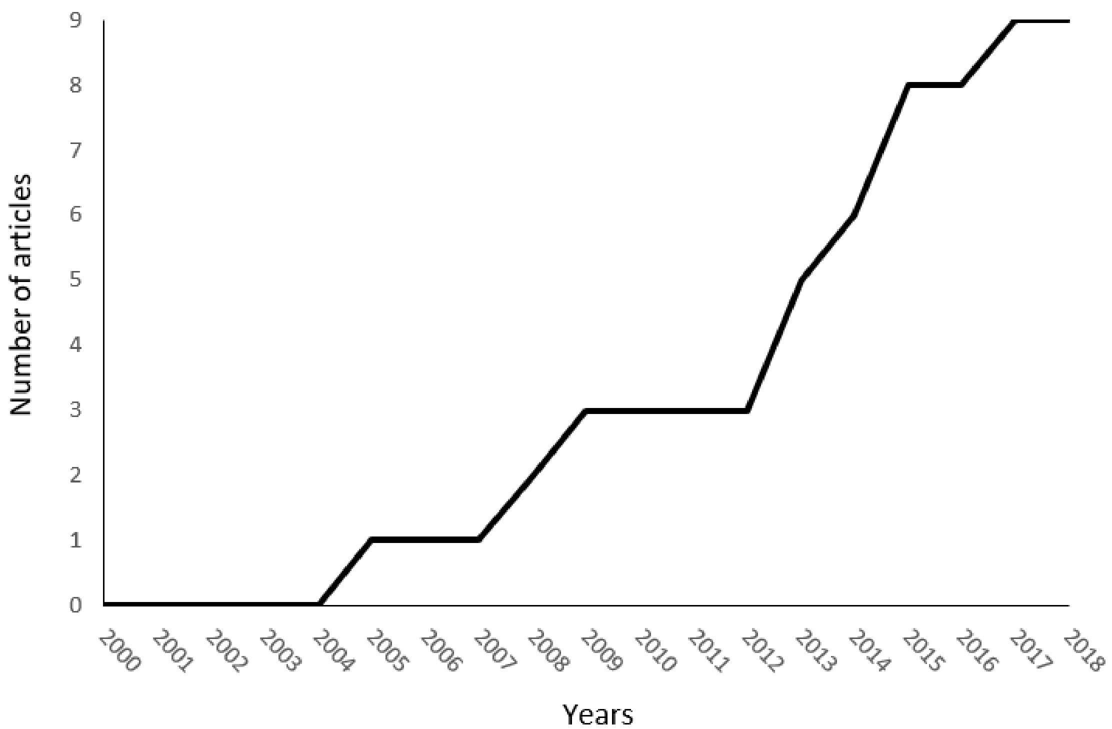

Figure 3. Cumulative record of the publications of studies since the year 2000 that used an electrophysiological technique in the study of stimulus equivalence that met our inclusion criteria.

The data presented in Table 1 shows that the interest in this kind of measure is currently concentrated by research groups in four different countries (Ireland, United States, Argentina, and Brazil). Notably, the majority of studies were conducted in South American countries. From the nine studies that we analyzed in this research, five were conducted in Argentina. Second, Table 1 shows that most of the articles were published in journals that are addressed to the neuroscientific community (e.g., Psychology and Neuroscience). These data are relevant because it suggests that studies on the electrophysiological correlates of stimulus equivalence could foster the dissemination of Behavior Analysis to a broader and more diverse audience.

Table 2 depicts the list of studies and their respective authors that were ascribed to Category A (n=4) and Category B (n=6). Remember that participants from Category A studies were exposed to MTS procedures to train the baseline conditional discriminations and to test for the establishment of equivalence relations before been exposed to EBRPprocedures. Participants from Category B studies progressed from MTS baseline training to the EBRPprocedure without been given to tests for derived relations in the MTS procedure. Please, note that the study by Haimson et al., (2009) was ascribed in both categories because their participants were assigned to two different groups: One group was exposed to probe trials in MTS format prior to EBRPtesting (Category A), and other group advanced to EBRPfollowing the MTS training (Category B). According to Haimson et al. (2009), this very manipulation aimed at verifying whether N400 wavelengths were sensitive to prior experience with equivalence testing.

Table 3 shows the MTS training and testing parameters used in each study. Five studies used Simultaneous MTS (SMTS) procedures, and four studies used Delayed MTS (DMTS) procedures. The ranges of the delays varied from 0.5 s, 2 s. and 2.5 s. Eight studies employed Sample-as-Node (SaN) training structure. The researchers' preference for SaN may be related to the improved equivalence outcome that follows from baseline training with this structure in comparison to the equivalence outcome that usually follows training with Linear Structures (LS). Notably, the LS was used in the study conducted by Barnes-Holmes et al. (2005).

Table 1.
Lists of authors, sample, country, number of experiments and the name of the journals.

Casuistry					
Year of publication	Authors	Sample size and participants' age	Country	Number of experiments with electrophysiological technique	Journal
2005	Barnes-Holmes, Stauton, Whelan, Barnes-Holmes, Comins, Walsh, Stewart, Smeets & Dymond	54 adults between 17 to 24 years old	Ireland	01 (Experiment 2)	Journal of the Experimental Analysis of Behavior
2008	Yorio, Tabullo, Wainselboim, Barttfeld & Segura	12 adults with a mean age 24 years old	Argentina	01	Neuroscience Letters
2009	Haimson, Wilkinson, Rosenquist, Ouimet & McIlvane	12 adults (ages were not informed)	United States of America	01 (Experiment 2)	Journal of the Experimental Analysis of Behavior
2013	Wang & Dymond	46 adults between 19 to 29 years old	Ireland	01	Behavioral Brain Research
2013	Tabullo, Sevilla, Segura, Zanutto & Wainselboim	15 adults between 19 to 34 years old	Argentina	01	Brain Research
2014	Bortoloti, Pimentel & de Rose	20 adults between 18 to 26 years old	Brazil	01	Psychology & Neuroscience
2015	Tabullo, Zanutto & Wainselboim	16 adults between 22 to 30 years old	Argentina	01	International Journal of Psychophysiology
2015	Tabullo, Zanutto & Wainselboim	18 adults between 19 and 34 years old	Argentina	01	Psychology and Neuroscience
2018	Menéndez, Sánchez, Polti, Idesis, Avellaneda, Tabullo & Yorio	54 adults between 20 and 30 years old	Argentina	01	Behavioral Brain Research

The number and size of the classes also differed from one study to another (see, Table 3). However, the majority of studies used two three-members equivalence classes. The remaining studies employed two-four members, two six-members, two five-members, and three four-members equivalence classes. It seems that the size of classes is related to the need for balancing the EBRPtrials aiming at exposing the participants to the same number of related and unrelated pairs. Finally, we observed variations in the nature of stimuli: six studies used pseudowords, two studies used abstract forms, one study used pseudowords and abstract forms, and one study used pictures of faces portraying emotions and abstract forms.

We also observed that MTS contingencies were programmed for establishing three-members classes (ABC) and four-, five- and six-members classes (ABCD, ABCDE, ABCDEF). It follows that the MTS procedure was used to test the emergence of derived symmetry and transitivity in four out of nine studies (i.e., Barnes-Holmes, et al., 2005; Haimson et al., 2009; Wang & Dymond, 2013; Bortoloti, Pimentel & de Rose, 2014). It seems that the experimenters are likely to program test conditions before conducting EEG recordings to guarantee that the baseline conditional discriminations are equivalence relations (cf. Sidman & Tailby, 1982; Sidman 1994; 2000) and use the levels of equivalence yields as criteria to advance from one phase to another. However, it is important to clarify if the N400 is related to the performances on equivalence tests or whether the patterns of N400 responses can be related to the different types of equivalence testing to which the participants were exposed.

The parameters of the EBRPtasks employed (duration of stimulus presentation, response type, and stimulus presentation) and the related and non-related pairs used in each study are depicted in Table 4. We observed that the duration of stimuli presentations and inter-stimulus interval (ISI) varied unsystematically from one study to another. Nevertheless, in all studies, the duration of stimulus presentations were smaller than or equal to 500 ms, and the inter-stimulus interval smaller than 2000 ms.

In most studies, the participants had to press two buttons on a keyboard regarding related and unrelated stimuli pairs. For instance, the button "R" goes for the related pairs, and the button "U" goes for the unrelated pairs. Besides, the prime and target stimuli[2] were presented successively in most EBRP tasks. The exception is the study by Barnes-Holmes et al. (2005) that applied an EBRPtask in which both prime and target stimuli were presented simultaneously, and the participants were required to emit covert specific naming responses for the related and unrelated pairings.

Table 2.
Articles ascribed to Category A and Category B.

	Category A	**Category B**
Authors Lists	Barnes-Holmes et al., (2005)	Yorio et al., (2008)
	Haimson et al., (2009)	Haimson et al., (2009)
	Wang & Dymond (2013)	Tabullo et al., (2013)
	Bortoloti, Pimentel & de Rose (2014)	Tabullo et al., (2015a)
		Tabullo et al., (2015b)
		Menendez et al. (2017)
Total	4	6

In two studies, the target stimulus remained available until the participant responded. This type of ERPT tasks contrasts with the majority of studies in which the target stimulus was kept available only for a few milliseconds (e.g., Yorio et al., 2008; Tabullo et al., 2013; Tabullo et al., 2015a, 2015b). Also, ultimately, we verified that baseline relations were used in the EBRPtasks of two studies, symmetric relations were used on five studies and, notwithstanding, transitive relations were employed in all studies. A common feature in all studies was the use of typically developing young adults (mostly, undergraduate students). For that reason, we recommend further investigations with children and older adults, for example (see Table 2), also, with people with developmental disabilities.

In this study, we revised several studies on the electrophysiological correlates of derived relations with careful attention to the experimental variables in the MTS and EBRP tasks. Regarding the MTS procedures, we observed a predominance of the training structure SaN and pseudowords as stimuli. We verified other differences in the sizes, the number of classes, and usage of delay interval interposed between sample and comparison stimuli. Several studies demonstrated that training baseline conditional discriminations with the DMTS procedure is critical for obtaining higher levels of equivalence yields (cf. Arntzen, 2012; Bortoloti & de Rose, 2009; 2011; Holth & Arntzen, 2008; Lian & Arntzen, 2013). Recently, Bortoloti, Pimentel, and de Rose (2014) suggested that the N400 effects obtained in their study were more comparable to the effects typically observed in studies that used words from participants' natural languages because the experimenter used the DMTS to train for the baseline conditional relations. To date, however, no study was conducted to determine whether the N400 is sensitive or not to prior experience with baseline training with SMTS or DMTS.

We also observed that five studies did not conduct the standard tests for derived relations with MTS procedures. Nevertheless, the EEG signals reported by Yorio et al. (2008), Tabullo et al., (2013), and Tabullo et al. (2015a, 2015b) showed clear differentiation in the N400 wavelengths associated with related and unrelated stimulus pairs. The exception was the study by Menendez et al., (2017) whose EEG data showed unclear differentiations.

The participants were exposed to probe trials with MTS procedures before EBRPin four studies. In two of them, the participants were tested for the emergence of symmetry and transitivity (cf. Haimson et al., 2009; Wang & Dymond, 2014) and the remaining studies, participants were only tested for transitivity (Barnes-Holmes et al., 2005; Bortoloti et al., 2014). The experimenters observed robust N400 effects in three studies (Barnes-Holmes et al., 2004; Haimson et al, 2009; Bortoloti et al., 2014). The study by Wang & Dymond (2014) reported the smallest N400 effects.

Taken together, the EEG data from all studies are showing that the N400 effect is likely to be observed despite prior experience with tests for derived relations with MTS procedure. Moreover, as Menéndez et al. (2018) observed, different testing order did not affect the N400 topographies in their study. However, if we are assuming that the N400 effect is a type of equivalence outcome, then we think it is likely that the ERPs evoked in participants extensively exposed to the

[2] The terms "prime" and "target" reffers to the temporal and functional properties of stimuli presented in a kind of experimental preparation that is used by experimental cognitive psychologists to study many types of behavioral processes controlled by stimulus-stimulus relations such as memory and semantics. Procedurally speaking, the names prime and target are related to their temporal allocations. Thus, the prime is presented before the target. Functionally speaking, however, it is said that the prime stimulus alters the functions of the target stimulus. We strongly recommend the reading of Spruyt, Gast and Moors (2011) for a comprehensive review of the sequential priming task terminology, procedures and results.

standard equivalence testing should be different from the ERPs of participants without prior exposure to testing.

Table 3.
MTS variables used in each study.

	Training Procedure	Training Structure	Number of classes and Class size	Nature of stimuli	Baseline relations	Symmetry probes	Transitivity Probes
Barnes-Holmes et al., (2005)	0.5 s DMTS	LS	Two-four members classes	A, B ,C, and D: pseudowords	AB, BC, and CD	--	DA, DB, CA
Yorio et al., (2008)	2.5s DMTS	SaN	Two-three members classes	A, B and C: abstract forms	AB and AC	--	--
Haimson et al., (2009)	SMTS	SaN	Two-six members classes	A: pseudowords B, C, D, E and F: abstract forms	AB, AC, AD, AE, and AF	Not described	Not described
Tabullo, et al. (2013)	2.5s DMTS	SaN	Two-three members classes	A, B and C: pseudowords	AB and AC	--	--
Wang & Dymond (2013) Exp. 1	SMTS	SaN	Three-four members classes	Pseudowords	AB and AC	BA and CA	BC and CB
Wang & Dymond (2013) Exp. 2	SMTS	SaN	Three-four members classes	Abstract forms	AB and AC	BA and CA	BC and CB
Bortoloti et al., (2014)	2s DMTS	SaN	Two-five members classes	A: facial expressions B, C, D, and E: abstract forms	AB, AC, AD, and AE	--	BC, CB, BD, DB, BE and EB
Tabullo et al., (2015a)	SMTS	SaN	Two-three members classes	A, B and C: pseudowords	AB and AC	--	--
Tabullo et al., (2015b)	SMTS	SaN	Two-three members classes	A, B and C: pseudowords	AB and AC	--	--
Menendez et al. (2017)	SMTS	SaN	Two-three members classes	A, B, and C: pseudowords	AB and AC	--	--

We shall reconsider here the finding reported by Haimson et al., (2009) as an exemplary case. These researchers reported that participants who experienced equivalence probes in the MTS procedure exhibited a robust N400 effect in comparison to the participants that progressed from MTS training to EBRPtask. According to the authors, the differentiation of the N400 wavelengths has occurred only in the last block of trials. As Haimson et al., (2009) pointed out, the gradual appearance of N400 differentiation is analogous to some types of derived performances that have been characterized as delayed emergence (cf., Sidman, 1994). Therefore,if the delayed emergence in MTS paradigms are evidencing weaker equivalence outcomes, can we relate the delayed N400 effects to the delayed emergence of the derived MTS relations? Furthermore, we think it is likely that the N400 ERPs for baseline, reflexive, and transitive relations can be distinctive from each other. Our argument is two-folded: first, the conditionality of baseline relations was shaped by differential reinforcement procedures. The derived relations, on the contrary, were exhibited in the absence of programmed consequences or instructions. In this regard, the functional properties of the derived stimulus control may depend on the contextual cues embedded in the testing trials. As Sidman and Tailby (1982) noted earlier:

> "successful generalized matching will prove the relation reflexive, a property that must hold for each stimulus. Sample-comparison reversibility (Lazar, 1977) will prove symmetry, a property that must hold for each pair of related stimuli. Emergence of a third relation, in which the subject matches the sample from one of two prerequisite relations to the comparison from the other, will prove transitivity, a property that must hold for at least three interrelated stimuli" (p. 6).

To date, only Barnes-Holmes et al. (2005)'s data indicated that the N400 effect observed for the baseline pairs was distinctive from the N400 effect observed for symmetric and transitive pairs, respectively. Thus, we encourage follow-up studies for clarification of this question.

The data reported in eight out of nine studies analyzed in this research replicated the N400 effects. These results are comparable to the electrophysiological correlates of semantic relations in naturally occurring languages. Taken together, these studies provide external validity to Murray Sidman's equivalence paradigm as a laboratory model of semantic processing in humans.

Table 4.

Equivalence Based Relatedness Procedures (EBRP) used in each study.

		Temporal, response, and stimulus parameters of ERPT paradigms					Related Pairs				Unrelated Pairs			
		S1	ISI	S2	Response	Stimulus presentation	Baseline	Reflexivity	Symmetry	Transitivity	Baseline	Reflexivity	Symmetry	Transitivity
Barnes-Holmes et al., (2005)		100 ms	---	1675 ms	Pressing one of two buttons	Simultaneous	A1B1, A2B2, B1C1, B2C2, C1D1, C2D2	---	B1A1, B2A2, C1B1, C2B2, D1C1, D2C2	A1C1, A2C2, A1D1, A2D2, C1A1, A2C2, D1C1, D2C2	A1B2, A2B1, B1C2, B2C1, C1D2, C2D1	---	B1A2, B2A1, C1B2, C2B1, D1C2, D2C1	A1C2, A2C1, A1D2, A2D1, C1A2, A2C1, D1C2, D2C1
Yorio et al., (2008)		Not described			Pressing one of two buttons	Not described	---	A1A1, A2A2, B1B1, B2B2, C1C1, C2C1	---	B1C1, B2C2, C1B1, C2B2	---	A1A2, A2A1, B1B2, B2B1, C1C2, C2C1	---	B1C2, B2C1, C1B2, C2B1
Haimson et al., (2009)		400 ms	750 ms	400 ms	Judging silently whether stimulus pairs were related or not	Successive	---	---	Not described	Not described	---	---	Not described	Not described
Tabullo et al., (2013)		250 ms	---	250 ms	Pressing one of two buttons	Not described	---	---	B1A1, B2A2, C1A1, C2A2	B1C1, B2C2, C1B1, C2B2	---	---	B1A2, B2A1, C1A2, C2A1	B1C2, B2C1, C1B2, C2B1
Wang & Dymond (2013)	Exp 1.	200 ms	400 ms	1500 ms	Pressing one of two buttons	Successive	A1B1, A2B2, A3B3, A4B4, A1C1, A2C2, A3C3 A4C4	---	B1A1, B2A2, B3A3, A4B4, C1A1, C2A2, C3A3, C4A3	B1C1, B2C2, B3C3, B4C4, C1B1, C2B2, C3B3, C4B4	A1B4, A1B4, A2B3, A2C3, A3B2, A3C2, A4B1, A4C1	---	B1A4, C1A4, B2A3, C2A3, B3A2, C3A2, B4A1, C4A1	B1C4, C1B4, B2C3, B3C2, C2B3, C3B2, B4C1, C4B1
	Exp 2.	200 ms	400 ms	200 mms										
Bortoloti et al., (2014)		600 ms	500 ms	600 ms	Pressing one of two buttons	Successive	---	---	---	C1D1, C2D2, C1E1, C2E2, D1C1, D2C2, E1C1, E2C2 D1E1, D2E2, E1D1, E2D1	---	---	---	C1D2, C2D1, C1E2, C2E1, D1C2, D2C1, E1C2, E2C1 D1E2, D2E1, E1D2, E2D1
Tabullo et al., (2015a)		250 ms	100 ms	∞	Pressing one of two buttons	Successive	---	---	---	B1C1, B2C2, C1B1, C2B2	---	---	---	B1C1, B2C2, C1B1, C2B2
Tabullo et al., (2015b)		250 ms	100 ms	∞	Pressing one of two buttons	Successive	---	---	---	B1C1, B2C2, C1B1, C2B2	---	---	---	B1C1, B2C2, C1B1, C2B2
Menendez et al. (2017)		350 ms	100 ms	350 ms	Pressing one of two buttons	Successive	---	---	B1A1, B2A2, C1A1, C2A2	B1C1, B2C1, C1B1, C2B2	---	---	B1A2, B2A1, C1A2, C2A1	B1C2, B2C1, C1B2, C2B1

DECLARATION OF CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

CONTRIBUIÇÃO DE CADA AUTOR

Through this statement, we certify that all authors participated sufficiently in the work to make public their responsibility for the content. The contribution of each author can be attributed as follows: Silveira, Cortez, and de Rose participated in the conception of the work anticipating the contributions of the review to stimulate studies in the area; Silveira and Cortez were responsible for formulating the methodology of the work. The collection and analysis of data were carried out by Sbrocco and Sarmento. These authors also contributed to the description of the results and discussion. Ramos supported the conceptualization and explanation of electrophysiology and the N400. All authors participated in the writing of the manuscript.

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