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# Event-related potential correlates of perceptual and functional categories: Comparison between stimuli matching by identity and equivalence

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ABSTRACT

Event-related potentials (ERPs) correlates of two test criteria of an abstract category task were dissociated. In a stimulus equivalence task, 10 subjects observed pairs of figures presented serially in three conditions: reflexivity (generalized identity), equivalence (arbitrary derived relations from a previous training), and unrelated pairs. They were instructed to decide whether the second item in a pair matched or mismatched the first one. Participants' performance in reflexivity matching tests was faster and more accurate than in equivalence matching or mismatching responses. In the three conditions, an occipital P2, a frontal N2 and a parietal P3 ERP component were elicited. The earlier components P2 and N2 exhibited reflexivity matching effects, while the later component (P3) exhibited the only equivalence matching effect. In addition, the subtracted ERP components from unrelated minus identity and unrelated minus equivalence trials were computed within two time windows: 150–250 ms (dN300) and 350–450 ms (dN400). While both dN300 waves were not significantly different, the comparison of both dN400 waves showed statistical differences. Correlates of partially perceptual (but contextually abstract) concepts are elicited earlier than those of pure abstract concepts. These ERPs correlates of stimulus equivalence relation tests of semantic categories are in concordance with the behavioral data.



Functionally speaking, a concept or category is defined as a stimuli class that elicits a common behavior within a given context independently of the physical properties of the stimuli [7,14]. In contrast, perceptual categories are characterized by perceptual similarity among stimuli. In either case, there is no general agreement on how conceptual knowledge is represented within the brain [5,6]. Evidence from brain imaging studies can be interpreted in favor of an amodal symbolic system [15], or a sensory-motor perceptual system [18]. Few functional magnetic resonance imaging studies (fMRI) have investigated concept learning by means of an experimental paradigm of stimulus equivalence (SE) by matching-to-sample [10,11,27]. In an initial phase stimuli without perceptual similarity or previous semantic relation are used to train participants in conditional discrimination tasks (non-identical matching to sample). Stimuli are arbitrarily assigned by the investigator to two or more classes (if An then Bn and if Bn then Cn). To rule out the assumption that subjects learn to build associations between stimuli according to particular physical features they must pass, without feedback, the tests of reflexivity, symmetry and transitivity, that are the behavioral criteria of stimulus equivalence [29].

The SE paradigm is a valid paradigm for the functional analysis of semantic relations because it shows how correspondences among stimuli that have not been directly trained can be established [33]. One of these studies compared cerebral haemodynamic response during matching in reflexivity and equivalence trials, reporting differences in cerebral activity between conditions, which were ascribed to the distinction between perceptual and functional categories [12].

In the SE paradigm the reflexivity test (generalization of the identity) is analogous to the identity test between stimuli. In this condition subjects' answers may be based on the functional relation as well as on perceptual similarity. Behavioral experiments have verified differences in reaction times and error rates between reflexivity matching trials and equivalence matching trials [31].

ERP studies using the SE paradigm have reported differences in negative components between trials with related and unrelated stimuli [3,4,9,30], but no comparison effects have been reported with reflexivity trials. The goal of this work is to compare ERP recordings between reflexivity, equivalence and unrelated stimuli

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trials within two temporal windows. Our predictions are that ERP components will present early differences between pairs of identical stimuli compared to pairs of arbitrary stimuli, and that late differences will be found between pairs of related arbitrary stimuli compared to unrelated arbitrary stimuli.

12 healthy voluntaries from undergraduate psychology courses (mean age 24.8), participated in this study. All participants were right handed with normal or corrected to normal vision. Participants signed a written consent for their participation and the experiments were conducted in accordance with the Declaration of Helsinki.

Matching tasks were carried out in individual 45 min sessions, during which participants were seated with the right and left index fingers in contact with two different keys from a response box, 50 cm away from the center of a 14-in. PC screen. Each trial started with the sample stimulus in the center of the screen (duration 500 ms), followed by a delay (2500 ms), after which the comparison stimuli were presented (until a response was given by the participant). The inter-trial interval was 3000 ms. Sample and comparison stimuli were figures of artificial objects [32].

During the training phase, arbitrary relations were trained between figure pairs A1–B1, A2–B2, A1–C1, and A2–C2. Relations between figures A1, 2-B1, 2 and A1, 2-C1, 2 were trained in successive blocks, each consisting of 30 randomly presented consecutive trials. Acquisition criterion was nine consecutive correct responses for each 30 trial block. The sample stimulus was presented in the center of the screen while the comparison stimuli were presented at the left and right sides of the center. Participants responded by pressing the key of the response box that corresponded to the side of the chosen stimulus. Feedback messages ("correct" or "error") were presented immediately after the response.

During the test phase, a single comparison stimulus was presented following the sample stimulus in three different types of trials according to the relation between sample and comparison stimuli: (a) reflexivity (40 trials with identical sample and comparison stimuli), equivalence (40 trials with sample and comparison stimuli in combined symmetry and transitivity relations), and "unrelated" (40 trials with sample and comparison samples incongruent with the trained relations). The response consisted in pressing a "unrelated" or a "related" labeled key of the response box. During this phase no feedback messages were presented (Fig. 1). The task was programmed in DMDX and synchronized with an additional PC that controlled the electrophysiological recording.

Voltage recordings were performed on the scalp in accordance with the 10–20 system in Fp1–2, F3–4-Z, C3–4-Z, P3–4-Z, F7–8, T3–4, T5–6, and O1–2 sites (bi-mastoid reference) by means of a 21 channel elastic Electro-cap. Recordings of the horizontal and vertical EOG were taken to monitor possible artifacts. The EEG was recorded during the test phase of the experimental task using an AC computerized amplifier system (Akonic model Bio-PC). The bandwidth of the recording was 0.5–30 Hz (6 dB/octave). The EEG signal was digitized and sampled at a 256 Hz frequency. During the recording the impedance of all the electrodes was kept beneath 50 kΩ. The beginning of each trial was marked with a signal in the EEG file.

After the recording 1000 ms periods were separated, corresponding to each trial including 100 ms prior to the onset of the comparison stimuli. Recording periods that showed artifacts, or corresponded to omitted or incorrect answers were eliminated. The remaining segments (about 75% in the three conditions) were averaged separately by condition starting at the synchronization mark. Averaged ERPs were corrected according to the 100-ms period preceding comparison stimulus onset.

ERP amplitudes were defined as the average value of the signal in each electrode in two temporal windows (150–250 and 350–450 ms). To evaluate possible incongruence effects between the sample and comparison stimuli in both temporal windows [16], wave differences (dN300: 150–250 ms, dN400: 350–450 ms) were

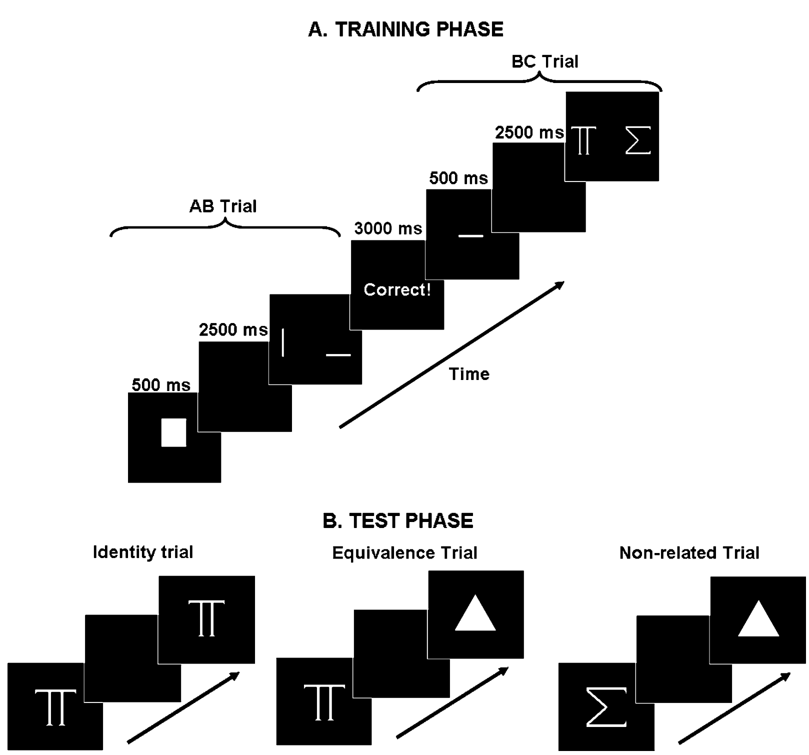


**Fig. 1.** Matching-to-sample-task. (A) Training phase. Two successive trials are shown as examples of the training protocol. (B) Test phase. An example of each of the three possible trial types is shown: reflexivity, equivalence, and "unrelated". Subjects classified the comparison stimulus as related (reflexivity and equivalent), or unrelated, according to trial type.