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An ERP study of recognition memory for concrete and abstract pictures in school-aged children

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Abstract

Recognition memory for concrete, nameable pictures is typically faster and more accurate than for abstract pictures. A dual-coding account for these findings suggests that concrete pictures are processed into verbal and image codes, whereas abstract pictures are encoded in image codes only. Recognition memory relies on two successive and distinct processes, namely familiarity and recollection. Whether these two processes are similarly or differently affected by stimulus concreteness remains unknown. This study examined the effect of picture concreteness on visual recognition memory processes using event-related potentials (ERPs). In a sample of children involved in a longitudinal study, participants ($N = 96$; mean age = 11.3 years) were assessed on a continuous visual recognition memory task in which half the pictures were easily nameable, everyday concrete objects, and the other half were three-dimensional abstract, sculpture-like objects. Behavioral performance and ERP correlates of familiarity and recollection (respectively, the FN400 and P600 repetition effects) were measured. Behavioral results indicated faster and more accurate identification of concrete pictures as “new” or “old” (i.e., previously displayed) compared to abstract pictures. ERPs were characterised by a larger repetition effect, on the P600 amplitude, for concrete than for abstract images, suggesting a graded recollection process dependant on the type of material to be recollected. Topographic differences were observed within the FN400 latency interval, especially over anterior-inferior electrodes, with the repetition effect more pronounced and localized over the left hemisphere for concrete stimuli, potentially reflecting

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different neural processes underlying early processing of verbal/semantic and visual material in memory.

Keywords

abstract; children; concrete; event-related potentials; familiarity; recognition memory

1. Introduction

In visual recognition memory paradigms, concrete pictures of familiar and meaningful objects are typically recognized faster and more accurately when compared with abstract, unfamiliar and meaningless pictures (Belhouse-King and Standing, 2007; Smith et al., 1990). An explanation for this phenomenon is provided by the dual-coding theory, according to which concrete pictures are processed into both verbal and image codes, whereas abstract pictures are primarily processed only in image codes (Paivio, 1975). Consequently, the connection between these two systems, visual and verbal, enhances the memory trace and allows a concrete object to be more easily recognized than an abstract one. Although several studies have examined the temporal dynamics of material-specific effects in recognition memory (e.g., Ecker et al., 2007; Galli and Otten, 2011; Küper et al., 2012; Küper and Zimmer, 2015), to our knowledge, none has focused on the picture concreteness effect.

The neuropsychological dissociation between verbal and visual memory is well established. These separate memory systems appear to be asymmetrically represented in the human brain, in such a way that, memory for verbal material is generally associated with the recruitment of brain regions that are located within the dominant hemisphere (in most cases, the left hemisphere), whereas memory for visual/non-verbal material is believed to rely on the nondominant (right) hemisphere (Banks et al., 2012; Golby et al., 2001; Goldstein et al., 1988; Powell et al., 2005; Wagner et al., 1998; Weber et al., 2007). However, some studies have suggested that the lateralization effect is more pronounced in or is restricted to specific brain areas (e.g., Guerin et al., 2009; Kelley et al., 1998; Wagner, 1999), depending on the specific memory processes that are solicited (Banks et al., 2012; Kennephol et al., 2007).

Current models of recognition memory posit that judgment of a prior occurrence of a stimulus relies on two distinct processes, namely familiarity and recollection (Jacoby, 1991; Mandler, 1980). Familiarity refers to simply knowing that something previously occurred or was experienced, whereas recollection involves the retrieval of specific details about something recognized (Mandler, 1980; Yonelinas, 2002). Consistent with this “dual process model” of recognition memory, studies using event-related potentials (ERPs) during visual recognition paradigms have revealed the existence of two successive, topographically distinct components that are modulated by stimulus repetition and are differently affected by experimental manipulations aimed at modulating familiarity and recollection, respectively (Curran, 2000; Rugg et al, 2007; Wilding, 2000). Specifically, the “mid-frontal” (also termed FN400) repetition effect is a reduction in amplitude of a negative component (less negative) that occurs 300–500 ms after the onset of a repeated stimulus and has been proposed to reflect familiarity, although alternative explanations, based on its temporal and topographical

similarity with the N400 component, link it to conceptual priming (Voss et al., 2010a; Voss et al., 2011). The “parietal” (or P600) repetition effect, occurring from 400–500 ms to 700–800 ms after the stimulus, manifests as a larger positive component (more positive) for recognized than new items and is considered a neurophysiological marker of the active recollection of information in memory. The FN400 and P600 repetition effects have been observed in response to several types of stimuli, including concrete pictures and abstract designs (Curran et al., 2003; Maillard et al., 2010). The existence of these two neurophysiological markers of recognition memory processes offer the opportunity to study, simultaneously, the impact of stimulus concreteness on both the familiarity and recollection processes that underlie judgements of recognition. Moreover, they make it possible to examine whether stimulus concreteness influences the lateralization of the ERP repetition effects observed during visual recognition paradigms, and whether this laterality effect differs according to the specific process measured (i.e., familiarity vs. recollection).

ERPs obtained from children may show qualitative and quantitative differences compared to those obtained from adults. For instance, the well-known late ‘P3b’ component elicited by attended target stimuli tends to appear at longer latencies and has been described as more posteriorly distributed in children as compared to adults (Flores et al., 2010; Johnstone et al., 1996; Picton, 1992). There is ample evidence from developmental ERP studies on recognition memory that the parietal repetition effect – the putative ERP correlate of recollection – can be reliably recorded at an early school age (Cycowicz et al., 2003; van Strien et al., 2009), albeit at a longer latency relative to young adults (Czernochowski et al., 2004). However, with respect to the midfrontal FN400 repetition effect – the putative correlate of familiarity – the picture is less clear (Czernochowski et al., 2009; Friedman et al., 2010; Hepworth et al., 2001; Mecklinger et al., 2011). For instance, comparing the ERPs obtained during continuous recognition memory paradigms aimed to assess item and source memory in 10- to 12-year-old children and in adults, Czernochowski et al. (2009) found that only adults showed the typical reduction (less negative) of the early frontal negative component for repeated compared to new stimuli; in children, the repetition effect was reversed in polarity (more negative for old than for new items). By contrast, Mecklinger et al. (2011) reported that the typical early frontal repetition effect (reduced negativity) could be elicited in 8- to 10-year-old children and adults under speeded response conditions (Mecklinger et al., 2011). The scarcity of developmental ERP studies on recognition memory, the relatively small sample sizes used in these studies leading to low statistical power, and the heterogeneity in study methodology may have contributed to the lack of consensus on the presence of the FN400 repetition effect in children that has been observed in adults.

In order to improve our understanding of children’s recognition memory, this study examined the effect of stimulus concreteness on visual recognition memory using ERPs recorded during a continuous recognition protocol employing pictures of common objects and abstract sculpture-like three-dimensional images. We studied a sample of school-aged Inuit children residing in Arctic Québec, Canada, who were participating in a longitudinal study on child development that was designed primarily to study effects of environmental contaminants and seafood nutrients on cognitive function (Jacobson et al., 2015; Muckle et al., 2001). We have previously reported beneficial effects of polyunsaturated fatty acids

(PUFAs) on the ERP components recorded during this task (Boucher et al., 2011). The present study is a re-analysis of a subset of those previously published data, with a focus on the ERP correlates of the concreteness effect on visual recognition memory. Our main objectives here were 1) to compare the repetition effects obtained from concrete vs. abstract images on the FN400 familiarity and the P600 recollection ERP effects in a large sample of children; and 2) to explore hemispheric differences in these two ERP components obtained from concrete and abstract stimuli.

2. Methods

2.1 Subjects

An ERP continuous recognition memory task was administered to 192 school-aged Inuit children, who participated in the Nunavik Child Development Study (Jacobson et al., 2015; Muckle et al., 2001). Nunavik is a region of Québec located north of the 55th parallel, about 1,500 km from Montréal. About 12,000 residents, mostly Inuit, live in 14 villages scattered along a 2,000-km seashore line along Hudson Bay, Hudson Strait, and Ungava Bay. This population is exposed to relatively high levels of environmental contaminants, including methylmercury, lead (Pb), and polychlorinated biphenyls (PCBs), due to their traditional diet based on fishing and hunting products, but also have high body concentrations of beneficial PUFAs due to their diet. The study was conducted in the three largest communities (Kuujuuaq, Puvirnituk, and Inukjuak). Children residing in other villages were transported by plane with their parent on the day prior to testing.

Written informed consent was obtained from a parent of each participant; oral assent, from each child. The research was approved by the Laval University and Wayne State University ethics committees and was performed in accordance with ethical standards of the Helsinki Declaration (World Medical Association, 2008). A total of 165 children were eligible for the current study based on the following inclusion criteria (numbers of children excluded because they did not meet these criteria in parentheses): age between 10.0 and 13.0 years ($n = 2$), right-handed ($n = 21$), birth weight ≥ 2.5 kg, gestation duration ≥ 35 weeks, no known neurological or clinically significant developmental disorder [multiple sclerosis ($n = 1$), history of traumatic brain injury requiring > 1 day of hospitalisation ($n = 1$), history of epilepsy ($n = 1$), history of meningitis ($n = 1$). Left-handers were excluded because of the possible effect of handedness on hemispheric dominance (Basic et al., 2004).

2.2 ERP protocol

Visual recognition memory was assessed in a continuous recognition memory task. Each child was tested individually in a quiet room, seated 57 cm from a 43-cm LCD monitor, on which pictures were displayed centrally within a 7×7 cm space. The child was asked to press one of two response buttons to each individual picture depending on if s/he thought the picture had already been presented (“old”) or not (“new”). Pictures were presented in a continuous fashion over 3 blocks of 80 trials each. “Old” items were presented on 50% of trials, at lags of 2, 5, or 10 intervening items, counterbalanced across blocks, and “New” items were presented on the other 50% of the trials, for a total of 120 items presented twice with lags of 2 ($n = 40$), 5 ($n = 40$), or 10 ($n = 40$) intervening items in the whole recognition

task. Each block additionally included 9 trials with pictures that were not repeated or that were repeated with different lags, which served as distractors. Stimuli were presented for 500 ms, with an offset-to-onset inter-stimulus interval of 3000 ms plus 100–300 ms stimulus-onset asynchrony (200-ms average). All correct responses occurring between 100 and 2,000 ms poststimulus onset were considered valid.

2.3 Stimuli

Stimuli were 120 coloured pictures taken from a stimulus pool provided by C. Nelson (Güler et al., 2012), and originally taken from online picture databases. All images were of similar overall size. Half the pictures were everyday concrete/nameable objects (e.g., dog, truck, fork, plant); the other half were three-dimensional abstract sculpture-like objects, including such as fribbles, geons, and greebles (Biederman et al., 1999; Gauthier et al., 1997; Hayward et al., 1997) (Figure A). Pictures from each category were counterbalanced across trials so that both categories had the same number of trials having 2, 5, and 10 intervening items between two presentations of the same picture. All of the selected concrete pictures were objects that could be named in Inuktitut (the native language of the Nunavik Inuit), and none are uncommon in these Inuit villages.

2.4 EEG recording and analyses

EEG data acquisition was performed with Model 15 Grass Neurodata Acquisition System. The electro-oculogram (EOG) was recorded with tin electrodes placed at the supra-orbital ridge of one eye and the infra-orbital ridge of the other. The EEG was recorded with 30 Ag-AgCl electrodes placed according to the extended 10–20 system (Chatrian et al., 1985) (sites: Fz, F3, F4, F7, F8, AF3, AF4, AF7, AF8, FCz, FC1, FC2, Cz, C3, C4, T3, T4, T5, T6, Pz, P3, P4, POz, Oz, O1, O2, M1, M2, A1 and A2) referenced online to Cz, with forehead ground. The impedance was kept below 10 k Ω . EOG and EEG gain were amplified with a gain of 5,000 and 50,000 respectively. The digitization rate was 200 Hz.

Event-related potentials (ERPs) were derived and analysed using Analyzer 2.0 (Brain Vision©) software. EOG correction (Gratton et al., 1983) was performed from the vertical EOG electrode. EEG channels were re-referenced offline to linked mastoids. High and low pass filters were set at 0.1 and 30 Hz, respectively. Artifact rejection ($\pm 100 \mu\text{V}$) and baseline correction (100 ms pre-stimulus) were applied. Responses between 100 and 2000 ms post-stimulus onset were tabulated, and trials with errors (“new” items incorrectly identified as “old” and vice versa) were excluded from averaging. After artifact rejection, 20 epochs from each condition (i.e., new concrete, new abstract, old concrete, old abstract) were randomly retained from each participant for further analysis, ensuring an equal number of trials for each condition.

Visual inspection of the grand averaged waveforms showed two separate components: the frontal FN400 (300 to 500 ms) and parietal P600 (500 to 800 ms). Scalp distribution and latencies of these two components were highly similar to those reported in another group of school-aged children tested on a continuous recognition task using word stimuli (Congdon et al., 2012). Mean amplitude was thus computed for the FN400 (300–500 ms) and P600 (500–800 ms) windows at each electrode site. Participants were retained in the analyses if their

behavioural performance exceeded chance level on the task and if they had a sufficient number of acceptable ERP trials (20) in each of the four conditions.

2.5 Assessment of pre- and postnatal exposures and other background characteristics

A blood sample (30 mL) obtained from the umbilical cord was used to determine prenatal exposure to mercury (Hg), Pb, and PCBs, as well as concentrations of PUFAs; a venous blood sample (20 mL) obtained from each child was used to document the body burden of these contaminants and nutrients at the time of testing. Umbilical cord and child whole blood samples were analysed for concentrations of total mercury and lead, whereas concentrations of PCBs were determined in corresponding plasma samples. Concentrations of docosahexaenoic acid (DHA) were expressed as percentages of the total area of all fatty acid peaks from C14:0 to C24:1 (percent weight). Details regarding quantification of contaminants and nutrients in biological samples have been described elsewhere (Boucher et al., 2011; Dallaire et al., 2014). Maternal interviews were also conducted to estimate maternal tobacco and alcohol use during pregnancy.

2.6 Statistical analyses

Each variable was checked for skewness and kurtosis (normality range: -2.0 to 2.0) and visually inspected for normality of distribution. All ERP variables were normally distributed. Contaminant variables (Hg, Pb, and PCBs in cord and child samples) exhibited log-normal distributions and were, therefore, log-transformed.

Repeated-measures analyses of variance (RM-ANOVAs) with the factors repetition (old vs. new) and stimulus concreteness (concrete vs. abstract) were first conducted to examine the effect of task condition on behavioral performance (mean reaction time and % correct) and on mean ERP amplitude at the midline frontal (Fz; FN400) and parietal (Pz; P600) electrodes. These regions were selected based on prior evidence that old/new effects can be reliably recorded at these sites in both children and adults (Mecklinger et al., 2011), and midline electrodes were used in order to minimize the potential impact of stimulus-specific laterality effects in this first set of analyses. Laterality effects were then examined by performing a series of RM-ANOVAs with an additional hemisphere factor (left vs. right) for the following regions of interest: anterior-inferior (average of AF7+AF8 vs. average of AF8+AF7), anterior-superior (average of F3+FC1 vs. average of F4+FC2), posterior-inferior (T5 vs. T6), and posterior-superior (P3 vs. P4). Regions of interest at frontal sites combined two electrodes in order to limit the number of statistical comparisons and thus to decrease the likelihood of type I errors, given the larger number of electrodes covering the anterior compared to the posterior region. Then, topographic differences were explored separately for the FN400 and P600 repetition effect latency intervals, with a 4 factor [2 presentation conditions (old vs. new) $\times$ 2 stimulus types (concrete vs. abstract) $\times$ 3 anterior-posterior $\times$ 5 lateral electrodes (F7-F3-Fz-F4-F8 vs. T3-C3-Cz-C4-T4 vs. T5-P3-Pz-P4-T6)] RMANOVA, with Greenhouse-Geisser correction. Vector scaling was performed on electrophysiological data prior to the latter analyses to remove amplitude differences between conditions (McCarthy and Wood, 1985; Picton et al., 2000). To examine the possibility that the results were altered by any of the pre- and postnatal exposures or other background characteristics, models were rerun separately with each of 13 variables (Hg, Pb,

PCB-153, and DHA in cord and child blood samples, maternal cigarette and alcohol use during pregnancy, gender, travelling by plane on the day prior to assessment, and children's age at testing), entered as a covariate to test its direct effect on the outcomes and interactions with task conditions and laterality effects. All data analyses were conducted using SPSS 22.0 (SPSS, Chicago, IL). Effects were considered statistically significant when $p < 0.05$.

3. Results

3.1 Sample description and behavioral results

Of the 165 eligible participants, 5 (3.0 %) were excluded because of a major technical problem during testing, 24 (14.5%) were excluded because their overall performance was equal to or below chance level, and 40 (24.2%) were excluded because of an insufficient (< 20) number of trials in one or more of the four task conditions after artefact rejection. A total of 96 participants were included in the final analyses. There was no significant difference between the included and the excluded children on any of the socio-demographic and exposure covariates (all p 's > 0.10). Descriptive statistics for the final sample are presented in Table A. A large proportion of children were exposed to tobacco or alcohol *in utero*.

Behavioural measures of task performance are presented in Table B. Responses were faster ($\eta^2_{\text{partial}} = 0.34, p < 0.001$) and more accurate ($\eta^2_{\text{partial}} = 0.40, p < 0.001$) for new pictures than for old ones. Compared with abstract pictures, concrete pictures were more quickly ($\eta^2_{\text{partial}} = 0.25, p < 0.001$) and more accurately ($\eta^2_{\text{partial}} = 0.50, p < 0.001$) categorized as new or old. The effects of stimulus concreteness on reaction time and response accuracy were more pronounced for new pictures than for old ones (concreteness $\times$ reaction time: $\eta^2_{\text{partial}} = 0.07, p = 0.009$; concreteness $\times$ response accuracy: $\eta^2_{\text{partial}} = 0.26, p < 0.001$). Interestingly, supplemental analyses indicated that the new abstract pictures were significantly more likely to be identified as old than the new concrete pictures ($F_{(1,95)} = 111.2, \eta^2_{\text{partial}} = 0.54, p < 0.001$), and identification of the old abstract pictures as new was marginally larger than for the old concrete pictures ($F_{(1,95)} = 3.6, \eta^2_{\text{partial}} = 0.04, p = 0.059$).

3.2 ERP Main effects

Average ERPs for the correctly identified concrete and abstract pictures at midline electrode locations are shown in Figure B. FN400 was maximal at the midline frontal electrode (Fz), whereas P600 was maximal at the midline parietal lead (Pz). Mean amplitudes for these two components in each task condition are presented in Table C. As expected, FN400 amplitude was more negative for new than for old stimuli at the midline frontal electrode ($\eta^2_{\text{partial}} = 0.21, p < 0.001$), and P600 amplitude was more positive for old than new stimuli at the midline parietal electrode ($\eta^2_{\text{partial}} = 0.36, p < 0.001$). The interaction between repetition and stimulus concreteness was significant for the P600 at Pz ($\eta^2_{\text{partial}} = 0.07, p = 0.01$), indicating a larger P600 repetition effect for concrete than for abstract stimuli. By contrast, the effect of repetition on the FN400 component at Fz was not significantly altered by stimulus concreteness ($\eta^2_{\text{partial}} = 0.01, p = 0.28$).

3.3 Lateralization of the ERP repetition effects

Results from the RM-ANOVAs testing for laterality effects on these ERP repetition effects at selected regions of interest are summarized in Table D. The repetition effect was statistically significant in each region of interest except over posterior inferior regions during the FN400 interval (300–500 ms), and in all regions during the P600 interval (500–800 ms). There were significant interactions between repetition and stimulus concreteness only at posterior regions during the FN400 interval, and at posterior and anterior superior electrodes during the P600 interval. With respect to lateralization, there was a significant Repetition by Stimulus concreteness by Hemisphere interaction on mean ERP amplitude at the anterior inferior electrode sites during the FN400 latency interval ($\eta^2_{\text{partial}} = 0.09$, $p = 0.02$). Post-hoc RM-MANOVA analyses conducted separately for each type of stimulus indicated that concrete stimuli elicited a greater repetition effect over the left anterior electrodes than over the right electrodes (Repetition by Hemisphere interaction: $F_{(1,95)} = 12.77$, $\eta^2_{\text{partial}} = 0.12$, $p = 0.001$), whereas there was no hemispheric difference for abstract stimuli ($F_{(1,95)} = 0.91$, $\eta^2_{\text{partial}} = 0.01$, $p = 0.342$). These results are illustrated in Figure C. Supplemental analyses using individual electrode sites instead of the average of anterior inferior or anterior superior electrode sites showed that the Repetition by Stimulus concreteness by Hemisphere interaction on mean ERP amplitude was significant at both anterior inferior electrodes (F7 vs. F8: $F_{(1,95)} = 8.41$, $\eta^2_{\text{partial}} = 0.08$, $p = 0.005$; AF7 vs. AF8: $F_{(1,95)} = 8.66$, $\eta^2_{\text{partial}} = 0.08$, $p = 0.004$) whereas it did not reach statistical significance at both anterior superior electrodes (F3 vs. F4: $F_{(1,95)} = 3.52$, $\eta^2_{\text{partial}} = 0.04$, $p = 0.064$; FC1 vs. FC2: $F_{(1,95)} = 1.29$, $\eta^2_{\text{partial}} = 0.01$, $p = 0.259$). No significant lateralization effect was seen during the P600 latency interval.

3.4 Topographic differences

Scalp maps for the repetition effects over the FN400 (300–500 ms) and the P600 (500–800 ms) latency intervals are depicted in Figure D. Vector analyses revealed topographic differences in the repetition effect according to stimulus concreteness during the FN400 interval. There was a significant Repetition $\times$ Stimulus concreteness $\times$ Anterior-to-posterior interaction ($F_{(1,4,128.3)} = 6.20$, $\eta^2_{\text{partial}} = 0.06$, $p = 0.007$) suggesting a more posterior distribution of the repetition effect for concrete stimuli, and a significant Repetition $\times$ Stimulus concreteness $\times$ Laterality interaction ($F_{(2,6,243.4)} = 5.86$, $\eta^2_{\text{partial}} = 0.06$, $p = 0.001$) suggesting that the repetition effect is more left-lateralized for concrete stimuli. Figure E shows that this effect is especially marked over frontal electrodes, although the Repetition $\times$ Stimulus concreteness $\times$ Anterior-to-posterior $\times$ Laterality interaction fell short of statistical significance ($F_{(4,6,428.4)} = 2.09$, $\eta^2_{\text{partial}} = 0.02$, $p = 0.072$). By contrast to the FN400, there was no topographic difference in the P600 repetition effect obtained from concrete and abstract stimuli (all $ps > 0.30$).

3.5 Impact of pre- and postnatal exposures and other characteristics

Among the 13 covariates tested for their main effect on ERP outcomes, only one (postnatal DHA: $F_{(1,92)} = 8.73$, $\eta^2_{\text{partial}} = 0.09$, $p = 0.004$) was significantly associated with FN400 amplitude, and two (postnatal Pb: $F_{(1,92)} = 5.43$, $\eta^2_{\text{partial}} = 0.06$, $p = 0.02$; and postnatal PCB: $F_{(1,92)} = 4.66$, $\eta^2_{\text{partial}} = 0.05$, $p = 0.03$) were associated with P600 amplitude. Child

DHA levels were associated with larger FN400 amplitudes, whereas child Pb and PCB levels were associated with a smaller P600. There was a significant interaction between child blood Pb concentrations and the Repetition $\times$ Stimulus concreteness effect on the P600 component ($F_{(1,92)} = 5.69$, $\eta^2_{\text{partial}} = 0.06$, $p = 0.019$) suggesting that the effect of stimulus concreteness on the repetition effect was larger in children with higher Pb exposure. Nevertheless, excluding children with blood Pb levels $\geq 5\mu\text{g/dL}$ (i.e., the reference level used by the Centers for Disease Control and Prevention to identify children with elevated blood Pb levels) from the initial RM-ANOVA model did not alter our conclusions, as the repetition by stimulus concreteness interaction effect on the P600 remained significant ($F_{(1,83)} = 5.64$, $\eta^2_{\text{partial}} = 0.06$, $p = 0.020$). There was no other significant interaction between covariates and the repetition by stimulus concreteness effect on the FN400 or P600 components, or on its lateralization (all p s > 0.10).

4. Discussion

The aim of this study was to examine the effect of stimulus concreteness on visual recognition memory using ERPs in a sample of school-aged children. We found that concrete pictures were better and more rapidly recognized in comparison to abstract pictures, which replicates the results obtained in other studies with participants from different age groups (Belhouse-King and Standing, 2007; Smith et al., 1990). This “concreteness-superiority” effect was accompanied by a larger posterior P600 repetition effect for correctly identified concrete pictures than for abstract images. Concrete pictures also elicited a larger familiarity-FN400 repetition effect in the left hemisphere over anterior inferior electrodes than in the right hemisphere, whereas the repetition effect obtained from abstract designs showed no significant hemispheric lateralization. Topographic differences in the repetition effect during the FN400 latency interval were confirmed, suggesting the involvement of different neural generators according to stimulus concreteness during early memory processes. The P600 repetition effect was not lateralized and showed no topographic difference according to stimulus concreteness. Although this sample was recruited due to its relatively high levels of contaminant and nutrient exposures from environmental sources, examination of the potential impact of 13 covariates on the two ERP components yielded evidence of effect modification (i.e., significant interaction with the Repetition $\times$ Stimulus concreteness effect) by only 1 (3.8%) of the 26 comparisons—a result likely due to chance. The data thus suggest that the ERP responses seen on this task were likely to be similar to those that would be found in other populations.

The present study suggests that the frontal FN400 and the posterior P600 repetition components of the ERPs are differently affected by stimulus concreteness in Inuit children. Indeed, concreteness altered mean amplitude of the posterior P600 repetition effect, which was greater for concrete compared to abstract designs. This suggests that the “concreteness-superiority” effect observed on recognition memory performance occurs at later stages of memory processing, i.e., when the information is being consciously retrieved from memory. Similar findings have been seen with protocols employing verbal material in adult groups. Comparing repetition effects obtained from words and pseudowords retrieved either incidentally or intentionally, Curran (1999) found FN400 repetition effects that were similar for both types of verbal stimuli, whereas the P600 repetition effect was larger for words than

for pseudowords. In remember/know paradigms, higher confidence in recognizing a repeated item has been associated with larger P600 repetition effects, whereas the preceding FN400 repetition effect is not influenced by degree of confidence (Curran, 2004). The larger P600 repetition effect suggests a graded recollection process dependent on the type of material to be recollected (Wilding, 2000), and may reflect one's enhanced confidence in his/her judgements of recognition with increased "verbalizability" of a visual stimulus. Another possibility is that concrete objects are easier to bind to the encoding context than abstract pictures due to the pre-existent stable memory representations, thereby making recollection more efficient.

It has been proposed that the FN400 repetition effect reflects semantic/conceptual priming effects that cannot be distinguished from the language-related N400 component, raising questions about the interpretation that this ERP component reflects 'familiarity' (Voss et al., 2010a; Voss et al., 2011; Strozak et al., 2016). In our study, however, the effect of abstract designs on the FN400 component was comparable in amplitude to that elicited by concrete, meaningful pictures, although topographic differences indicate at least partly different neural sources. Thus, our results support the view that the FN400 effect reflects memory processes that are not entirely related to language/semantic processing (Bridger et al., 2012; Groh-Bordin et al., 2006; Sternberg et al., 2009) and illustrate the value of using concrete and abstract stimuli to address this debate. Although we cannot exclude the possibility that even abstract designs are semantically categorized based on their physical similarity with existing, meaningful objects (Voss et al., 2010b), the differential effects of concrete vs. abstract stimuli on behavioral performance and on the P600 suggests that our abstract stimuli elicit relatively little verbal representation.

Our examination of lateralization effects revealed that concrete pictures elicited greater repetition effects over the left inferior frontal region during the FN400 latency interval. Few previous studies have reported material-specific lateralization of the FN400 repetition effect. In a study contrasting words and abstract pictures during an ERP recognition task in a group of 16 healthy adults, Maillard and colleagues (2010) found no effect of stimulus nature on the lateralization of the late FN400 and P600 components. The larger sample size in our study may explain why we were able to find subtle lateralization effects. That our marker of familiarity showed material-specific hemispheric and topographic differences suggests that different neural processes are involved in familiarity for verbal and abstract stimuli, which is consistent with a case report of a specific familiarity impairment for verbal material in a patient with left anterior temporal lobe lesion (Martin et al., 2011). The absence of a material-specific lateralization effect or topographic difference on the P600 repetition component is consistent with previous studies in which the laterality of this component did not differ between word and face stimuli (Guerin et al., 2009; Yick et al., 2008) and suggests that the neural substrates underlying recollection processes are independent of stimulus concreteness.

We observed a left-lateralized FN400 repetition effect elicited by concrete pictures. However, contrary to our expectations, abstract shapes were not associated with a significant right lateralization of this component. Previous clinical studies have also demonstrated that left-lateralization of memory for verbal material is more easily observed than the right-

lateralization of memory for non-verbal stimuli (Boucher et al., 2015; Lee et al., 2002; Vaz, 2004; Vingerhoets et al., 2006). Nevertheless, a study using functional near-infrared spectroscopy during a recognition task with abstract shapes has recently reported a right-lateralization of the repetition effect over the right ventrolateral prefrontal cortex (Sanefuji et al., 2007). It is possible that the relatively poor spatial resolution of scalp ERPs compared to functional near-infrared spectroscopy makes it more difficult to detect a right-lateralized repetition effect for abstract pictures. Another possibility is that, despite precautions taken in the picture selection, the similarity of some abstract items with real objects in our set of pictures may have led to left hemisphere activation. Furthermore, the right hemisphere lateralization of visuo-spatial memory may not be fully matured at the age at which our participants were tested (Groen et al., 2012). Previous ERP studies have also demonstrated time-dependent material-specific lateralization effects in visual recognition memory in adults by using a divided visual field technique (Küper et al., 2015; Küper and Zimmer, 2015). For instance, Küper and Zimmer (2015) found that the P600 effect was larger when the same stimulus was repeated as compared to when two different exemplars of the stimulus were presented, but only when the second stimulus was presented in the left visual hemi-field (processed in the right hemisphere) and not when it was presented in the right hemi-field (processed in the left hemisphere). This technique could be used to reveal crucial information on the lateralization of recognition memory processes for concrete and abstract pictures.

Some studies have failed to observe the classical FN400 repetition effect in children (Czernochowski et al., 2005; Friedman et al., 2010; Sprondel et al., 2011), but others have also reported clear FN400 and P600 repetition effects (Congdon et al., 2012; Mecklinger et al., 2011; Van Strien et al., 2011). Larger sample size, shorter repetition lags, and pressure to respond quickly are characteristics that might have allowed the observation of FN400 repetition effects in children in the latter studies. In our sample of children, we were able to measure significant FN400 and P600 repetition effects, and these occurred at latencies comparable to those previously reported in other children of the same age tested with a similar task (Congdon et al., 2012) and within the expected latency range. However, the topographical distributions of the repetition effects in our study were somewhat surprising. Indeed, the maximal amplitude difference observed during the FN400 latency was observed at the midline parietal electrode, which is much more posterior than the midfrontal electrodes, where it is typically observed in adults. During the P600 latency interval, the maximal amplitude difference between new and old items is typically observed at left parietal electrodes whereas in our study it was maximal at midline centro-parietal leads. Whether these unexpected results are attributable the young age of our study participants or to other task-related (e.g., stimuli, repetition lags) or sample-related (i.e., the Inuit population) factors remains uncertain, and replication in another pediatric sample with different stimuli and repetition lags is warranted.

One limitation of this study is that we used a sample of children who were assessed for another purpose, i.e., detecting the effects of environmental contaminants and seafood nutrients on cognitive function, and that a large number of these children were exposed to other neurotoxic substances during their fetal development, such as maternal tobacco smoking and alcohol. It is uncertain whether the findings would be generalizable to other,

non-exposed populations. However, among all the tested covariates, only postnatal Pb exposure altered the effect on stimulus concreteness at one component, P600. As noted above, given the large number of interactions tested in our models, this finding was likely due to chance. Moreover, the effect of stimulus concreteness on the P600 repetition effect was seen even when the children with higher Pb exposures were excluded from the analysis. Thus, it seems unlikely that the pattern of findings seen here results from environmental or substance exposures found in this population. Using more stimuli of each category in our task could have prevented us from rejecting several participants who did not have enough trials in their averaged ERP waveform. Also, since our ERP protocol used short and longer lags (i.e., lags of 2, 5, and 10), we cannot exclude the possibility that our data partly reflect working memory retrieval rather than solely long-time memory retrieval, which might have attenuated the ERP correlates of episodic memory retrieval that we sought to measure. Among the strengths of our study is its large sample size, which provided the statistical power needed to detect subtle material-specific effects on the electrophysiological markers of recognition memory.

Conclusion

The present study suggests that the “concrete-superiority” effect observed on recognition memory performance in children is related to two distinct neurophysiological events. One of these events is reflected by a larger repetition effect on the P600 amplitude for concrete pictures as compared to abstract ones. The other event occurs earlier, within the FN400 latency interval, and is characterized by a distinct topographic distribution, especially with a more pronounced and localised recruitment of the left frontal region for concrete pictures. These findings provide evidence for a material-specific effect on the memory processes in children. Further studies comparing neural activity of adult, adolescent and child groups during a recognition memory paradigm employing abstract and concrete picture, are required to identify the developmental trajectories of these memory processes.

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Appendices

Table A

Descriptive statistics of the study sample.

	<i>N</i>	Mean $\pm$ SD	Range	%
Child characteristics				
Age (years)	96	11.3 $\pm$ 0.6	10.2 – 12.9	
Sex (% female)	96			59.4
School grade	94	5.3 $\pm$ 0.8	3 – 7	
Travelled by plane (% yes)	96			49.0
Prenatal exposures				
Mercury (ng/L)	95	21.6 $\pm$ 17.2	1.0 – 88.6	
Lead (μ g/dL)	95	4.4 $\pm$ 3.1	1.0 – 20.9	
PCB congener 153 (μ g/kg fat)	94	124.1 $\pm$ 93.1	9.7 – 653.6	
DHA (% phospholipids)	94	3.6 $\pm$ 1.2	1.2 – 6.4	
Maternal tobacco (% yes)	92			78.1
Maternal alcohol (% yes)	75			50.7
Postnatal exposures				
Mercury (μ g/L)	94	4.5 $\pm$ 4.7	0.1 – 28.1	
Lead (μ g/dL)	94	2.6 $\pm$ 2.4	0.4 – 12.8	
PCB-153 (μ g/kg fat)	94	78.4 $\pm$ 78.0	4.6 – 426.8	
DHA (% phospholipids)	94	2.4 $\pm$ 0.9	1.1 – 5.5	

Table B

Mean $\pm$ SD behavioural performance on the continuous recognition task (*N* = 96).

	New		Old		<i>F</i> -value		
	Concrete	Abstract	Concrete	Abstract	Repetition	Concreteness	Interaction
Mean reaction time (ms)	726.9 $\pm$ 121.0	755.2 $\pm$ 135.4	765.5 $\pm$ 131.1	778.9 $\pm$ 146.9	49.3**	32.1**	7.1**
Accuracy (% correct)	84.8 $\pm$ 12.6	73.3 $\pm$ 14.5	71.2 $\pm$ 14.7	69.1 $\pm$ 15.4	63.7**	94.6**	32.7**

Note. Values are mean (standard deviation). *F*-values from repeated-measures ANOVAs with Repetition (old vs. new) and Concreteness (concrete vs. abstract) as within-subject factors (degrees of freedom: hypothesis = 1, error = 95).

**
p < 0.01;

*
 $p < 0.05$.

Table C

Mean $\pm$ SD amplitude (μ V) for ERP components recorded during the continuous recognition task ($N = 96$)

	New		Old		F-value		
	Concrete	Abstract	Concrete	Abstract	Repetition	Concreteness	Interaction
FN400 (Fz; 300–500 ms)	-11.7 ± 5.9	-10.5 ± 6.3	-9.1 ± 6.1	-8.7 ± 7.2	24.8**	2.1	1.2
P600 (Pz; 500–800 ms)	11.1 ± 6.8	10.2 ± 7.6	16.3 ± 7.2	12.8 ± 6.2	53.2**	18.0**	7.3**

Note. Values are mean (standard deviation). F -values from repeated-measures ANOVAs with Repetition (old vs. new) and Concreteness (concrete vs. abstract) as within-subject factors (degrees of freedom: hypothesis = 1, error = 95).

**
 $p < 0.01$;

*
 $p < 0.05$

Table D
Mean $\pm$ SD amplitude (μ V) for ERP components according to region of interest for the examination of laterality effects.

Region of interest	New				Old				F-values		
	Concrete		Abstract		Concrete		Abstract		Repetition Concreteness	Repetition × Concreteness × Hemisphere	
	Left	Right	Left	Right	Left	Right	Left	Right			
FN400 (300–500 ms)											
Anterior-inferior	-8.9 ± 5.5	-9.2 ± 5.2	-7.8 ± 5.6	-8.3 ± 5.7	5.9 ± 5.2	-7.9 ± 5.6	-6.2 ± 6.1	-6.1 ± 6.5	36.7**	0.1	9.7**
Anterior-superior	-10.8 ± 5.3	-11.1 ± 5.4	-9.0 ± 5.7	-9.4 ± 5.6	-7.4 ± 5.7	-8.6 ± 5.6	-6.9 ± 6.4	-7.5 ± 6.4	39.1**	1.7	3.1 [†]
Posterior-inferior	6.2 ± 6.0	8.3 ± 6.4	8.9 ± 6.2	12.2 ± 7.3	7.6 ± 6.5	9.4 ± 6.8	8.5 ± 5.4	11.8 ± 7.0	1.3	8.0**	0.1
Posterior-superior	3.1 ± 7.5	5.0 ± 7.5	6.9 ± 7.1	9.7 ± 6.8	7.2 ± 7.4	8.8 ± 7.7	8.1 ± 6.6	10.7 ± 7.7	31.6**	10.8**	0.1
P600 (500–800 ms)											
Anterior-inferior	-1.0 ± 4.6	-0.6 ± 5.3	0.1 ± 5.8	0.4 ± 5.8	2.4 ± 5.1	2.3 ± 5.3	2.0 ± 5.2	2.6 ± 6.0	47.9**	2.6	1.5
Anterior-superior	2.0 ± 5.0	2.3 ± 5.6	2.5 ± 6.3	2.7 ± 6.3	6.4 ± 5.7	6.4 ± 5.7	4.9 ± 5.2	5.2 ± 5.9	65.6**	5.6*	0.6
Posterior-inferior	4.0 ± 4.5	3.2 ± 5.1	3.1 ± 5.1	3.4 ± 5.4	5.2 ± 5.8	5.9 ± 5.2	4.3 ± 5.1	4.2 ± 5.0	8.9**	6.5*	2.1
Posterior-superior	8.2 ± 6.0	7.0 ± 6.2	6.9 ± 6.8	7.0 ± 6.6	12.2 ± 7.0	12.6 ± 6.9	8.5 ± 6.3	9.4 ± 5.9	53.0**	13.8**	1.5

Note. Values are mean (standard deviation). F-values from repeated-measures ANOVAs with Repetition (old vs. new), Concreteness (concrete vs. abstract), and Hemisphere (left vs. right) as within-subject factors (degrees of freedom: hypothesis = 1, error = 95).

*** $p < 0.01$;

* $p < 0.05$;

† $p < 0.10$

Highlights

- Memory performance was better for concrete than for abstract pictures
- Both concrete and abstract pictures elicited FN400 and P600 repetition effects
- Concrete pictures elicited larger P600 repetition effects than abstract designs
- The FN400 repetition effect showed left-lateralization for concrete pictures
- Topographic differences were observed during the FN400 repetition interval

Figure A.

Examples of items presented during the continuous recognition memory task. Participants pressed the “New” button to the first presentation of an item, and the “Old” button to each subsequent presentation of that item. Half stimuli were concrete (meaningful) pictures, the other half were abstract pictures.

Figure B.

Grand average ERPs for new (thin) and old (thick), concrete (black) and abstract (grey) pictures obtained during the continuous recognition task at midline electrode locations for the final sample ($N = 96$). Frontocentral electrodes show a negative deflection occurring 300–500 ms post-stimulus and reaching maximal amplitude at the Fz electrode, which is referred to as the FN400 component. This component is followed by positive activity in the 500–800-ms interval and reaching maximal amplitude at the parietal electrodes, the P600 component.

Figure C.

Mean amplitude during the FN400 latency (300–500 ms) interval for left (average of AF7+F7) and right (average of AF8+F8) anterior inferior (top) and for the left (P3) and right (P4) posterior superior electrode sites (bottom) according to stimulus concreteness ($N = 96$). The figure illustrates the lateralization of the repetition effect for concrete stimuli over anterior inferior electrodes, which was not observed at posterior electrodes.

Figure D.

Scalp maps of the repetition effect (old minus new) for concrete (left) and abstract (right) pictures during the FN400 (top) and the P600 (bottom) latency intervals ($N = 96$).

Figure E.

Mean normalized amplitude, during the FN400 latency interval (300–500 ms), obtained from new and old concrete and abstract stimuli, as a function of coronal electrode site for the frontal, central, and parietal electrode positions.