RESEARCH ARTICLE

Exploring the Event-Related Potentials' Time Course of Associative Recognition in Autism

Pierre Desaunay ⓘ, Patrice Clochon, Franck Doidy, Anna Lambrechts ⓘ, Prany Wantzen, Fabrice Wallois, Mahdi Mahmoudzadeh, Jean-Marc Guile, Fabian Guénolé, Jean-Marc Baleyte, Francis Eustache, Dermot M. Bowler ⓘ, and Bérengère Guillery-Girard ⓘ

Behavioral data on episodic recollection in autism spectrum disorders (ASD) point limited relational memory functioning. However, the involvement of successive memory processes in the profile of episodic memory in ASD needs more study. Here, we used event-related potentials (ERP) to investigate the time course of episodic recollection with an associative recognition paradigm with picture pairs. Twenty-two participants with ASD and 32 with typical development (TD), all right-handed, were included. Behavioral results confirmed difficulties in correctly recognizing identical pairs in the ASD relative to TD group. We found an unexpected amplitude decrement on the P2 (220–270 msec) and FN400 (350–470 msec) potentials, suggesting diminished priming and familiarity effects in the ASD relative to TD group. However, ERP data revealed that the recognition of associative information relies on the same electrophysiological process (old/new effect in the 600–700-msec late positive component) in ASD participants as in TD ones, with a parietal extension in the ASD group. These results suggest that the electrophysiological processes of associative recognition are qualitatively similar in individuals with and without ASD but may differ quantitatively. This difference may be driven by the reduced early processing of picture pairs that may in turn lead to their diminished integration into the semantic memory system, being partially compensated by a greater involvement of associative memory during the recollection process. Other studies would be useful to go further in identifying these cognitive processes involved in atypical recognition in ASD and their neural substrates. *Autism Res 2020, 00: 1–19.* © 2020 International Society for Autism Research and Wiley Periodicals LLC

Lay Summary: We identified diminished performance on the associative recognition of picture pairs in adolescents and young adults with autism when compared to typical development. Electrophysiological data revealed qualitative similarities but quantitative differences between-group, with diminished priming and familiarity processes partially compensated by an enhanced parietal recollection process.

Keywords: autism; episodic memory; associative memory; recollection; EEG; event-related potentials; late positive component

Introduction

Studies of episodic memory in autism spectrum disorder (ASD) have consistently identified a dissociation between diminished free recall while a relative preservation of recognition, possibly resulting from altered functional interactions between semantic and episodic memory systems [see Cooper & Simons, 2019, for a review]. This ability to correctly recognize previously seen items, in conjunction with preserved cued recall, has been theorized by Bowler, Gaigg, and Gardiner [2010] as the *Task Support Hypothesis* that posits a normalization of memory performance in ASD in situations providing a memory support, which consist of part of the to-be-memorized information being available during retrieval [e.g., Phelan, Filliter, & Johnson, 2011; Ring, Gaigg, & Bowler, 2015].

In typically developed (TD) individuals, cognitive and neuroimaging studies converge to propose a model of recognition based on two successive and independent processes: familiarity and recollection (*dual-process theory of recognition*) [see Diana, Reder, Arndt, & Park, 2006; Oberauer, 2008; Yonelinas, 2002, for reviews]. Familiarity is relatively automatic, supported mainly by the semantic memory system, and associated with noetic awareness

("knowing"); it allows recognition of single items or multiple items interactively encoded [see Oberauer, 2018, for a review]. In contrast, recollection appears as a more controlled process, supported by the episodic memory system, and associated with autonoetic awareness ("remembering"); it requires binding of information, including contextual one, for successful remembering of an episode [Boywitt & Meiser, 2013].

The putative correlates of relatively preserved recognition in ASD are intact familiarity (assessed in remember/know paradigms) [e.g., Souchay, Wojcik, Williams, Crathern, & Clarke, 2013], and intact functioning of the semantic memory system [Crane & Goddard, 2008; Gaigg, Bowler, & Gardiner, 2014]. In contrast, the diminished remembering reported by Bowler, Gardiner, and Grice [2000] and Gaigg, Bowler, Ecker, Calvo-Merino, and Murphy [2015], in conjunction with reduced involvement of controlled cognitive processes [Camodeca & Voelker, 2015], and diminished memory for associations [Bowler, Gaigg, & Gardiner, 2014] in ASD, point toward a reduced functioning of the episodic memory system. As a consequence, it is not yet possible to extend the *dual-process theory of recognition* to ASD. Instead, other models have been postulated, such as *the fuzzy trace theory*, which suggests a lower reliance on general (fuzzy) rather than detailed memory traces in ASD relative to TD [Miller, Odegard, & Allen, 2014].

Visual memory is a critical cognitive ability in daily life, and is thought to present specificities in ASD. We have previously shown in a meta-analysis that visual modality was more affected than the verbal one in ASD; however, performance normalized with recognition [Desaunay et al., 2020]. These difficulties in visual memory may result from a more detail-focused style (the *Weak Coherence Account*) [Happé & Frith, 2006]. Hence, the use of visual stimuli adds an additional layer of complexity in assessing episodic recognition in ASD, since access to the semantic memory system can vary across stimuli. Ameli, Courchesne, Lincoln, Kaufman, and Grillon [1988] first identified lower recognition for meaningless shapes contrasting with similar performance on meaningful pictures in adolescents and young adults with ASD, relative to participants without ASD, and concluded that the ASD participants used semantic information to aid their visual memory. However, these results were not replicated in two other studies [Salmanian, Tehrani-Doost, Ghanbari-Motlagh, & Shahrivar, 2012; Semino, Zanobini, & Usai, 2019]. Some studies evaluated episodic recognition abilities for visual items from different semantic categories. Blair [2002] identified increased memory difficulties when ASD participants were provided potential agents (i.e. living and non-living objects capable of self-propelled motion) compared to objects that do not have agency. By contrast, Molesworth, Bowler, and Hampton [2005] showed that children with ASD were as sensitive as TD peers to the prototype effect—the individual's tendency to display false recognition to an unstudied prototype of a category—which implies a similar level of integration of visual features. Similarly, Jiang, Palm, DeBolt, and Goh [2015] also report a high level of object category recognition and a high precision of recognition of specific exemplars in children with ASD, suggesting that their visual long-term memory was similarly structured to that of TD individuals. Other accounts, in line with the *enhanced perceptual functioning* account of ASD [Mottron & Burack, 2001; Mottron, Dawson, & Soulières, 2009; Mottron, Dawson, Soulières, Hubert, & Burack, 2006], have proposed that superior low-level processing interacts with locally oriented bias to produce enhanced visual or visuospatial episodic memory [Caron, Mottron, Berthiaume, & Dawson, 2006; Caron, Mottron, Rainville, & Chouinard, 2004]. Even though the episodic visual recall may be affected in Autism, recognition appears as a preserved cognitive domain in ASD adults, as evidenced by Lever and Geurts [2016] in a large cohort of adult and elderly participants showing that visual recognition abilities persist across adulthood in ASD, while reducing in TD with old age [see Ring, Gaigg, & Bowler, 2016].

This relative preservation of recognition, particularly in the visual modality, is, however, challenged by the observation of binding memory difficulties in ASD. Visual associative recognition paradigms have shown unexpected and contradictory results with regard to the *binding deficit hypothesis*, which argues for a specific impairment in hippocampally mediated associative and contextual memory, accompanied by intact item-specific and context-independent memory [Bowler, Gaigg, & Lind, 2011; Gaigg, Gardiner, & Bowler, 2008]. This account may explain memory difficulties in tasks involving an associative processing and also may constitute a possible explanation of the *complex information processing* theory [Williams, Goldstein, & Minshew, 2006], which suggests that difficulties arise when demand for integration of information increases [Bowler et al., 2014], and to the *weak central coherence* theory [Happé & Frith, 2006], giving rise to difficulties in associating together the elements of a scene into a coherent representation [Lind, Bowler, & Raber, 2014]. Some studies have confirmed the *binding deficit* account during visual recognition [Bowler et al., 2014; Cooper et al., 2015], while other studies did not [Lind et al., 2014; Semino et al., 2019], possibly due to differences in age participants or in paradigm. Rather, Solomon, McCauley, Iosif, Carter, and Ragland [2016] identified that adolescents with ASD performed similarly to TD peers for the associative recognition of picture pairs being interactively encoded, with similar recollection awareness, while performing lower at single-item recognition. Solomon et al.'s paradigm has further been tested with functional magnetic resonance imaging (fMRI) in a

large cohort of adolescents and young adults with and without ASD by Hogeveen et al. [2019], who identified similar item and associative recognition performance in both groups. During associative encoding, authors identified a diminished functional connectivity between the medial temporal lobes and the posterior medial network that are mainly involved in associative memory, and increased hippocampal recruitment that may offset this atypical connectivity to support preserved performance. These results extend those of Cooper et al. [2017], who identified a similar accuracy for relational visual information, associated with reduced hippocampal connectivity with the frontoparietal control network in adult participants with ASD relative to those without ASD. Together, these MRI studies suggest atypical information processing at the cerebral level, but are more limited to infer a cognitive significance.

Its high-temporal resolution makes electroencephalography (EEG) a key method in exploring the temporal profile of the cognitive processes implicated in memory recognition. A neurocognitive model of visual episodic recognition integrating the *dual-process* theory and ERP studies describes a sequence of three memory processes associated with three distinct kinds of representations (the *Type–Token model*) [Zimmer & Ecker, 2010]: perceptual priming, associated with the P2 potential, enables the sensory identification of a previously encountered object (*type trace*); familiarity is a graded signal that increases with the number of perceived intraitem features that match the specific object; then recollection enables the reinstatement of a high-level object representation that integrates item–context-associated information. The ERP signature of recognition in memory is referred as the old/new effect, that consists in a greater positivity for correctly recognized old as compared to correctly rejected new items. In this context, familiarity and recollection processes are associated with two successive and independent old/new effects, respectively located on the frontocentral and negative FN400 (300–500 msec) and *late positive component* or *late parietal component* (LPC; 500–800 msec) potentials [see Rugg & Curran, 2007; Wilding & Ranganath, 2012, for reviews]. Hence, the FN400 old/new effect can be elicited by the recognition of single items, as well as items unitized into a single-item representation [e.g., Rhodes & Donaldson, 2007]. This FN400 potential may reflect semantic processing during recognition testing [e.g., Voss & Federmeier, 2011], or be a specific marker of familiarity-based recognition [e.g., Bridger, Bader, Kriukova, Unger, & Mecklinger, 2012; Stróżak, Abedzadeh, & Curran, 2016], more recent paradigms leading to a mixed model [Leynes, Bruett, Krizan, & Veloso, 2017]. Consistently, the recollective nature of the LPC old/new effect has been confirmed during recollection awareness [e.g., Wynn, Daselaar, Kessels, & Schutter, 2019], source memory [e.g., Addante,

Ranganath, & Yonelinas, 2012], associative recognition [-e.g., Borst, Ghuman, & Anderson, 2016; Opitz & Cornell, 2006], and simultaneous EEG–fMRI recordings identified posterior hippocampal and parahippocampal generators—areas being related to the episodic memory system [Hoppstädter, Baeuchl, Diener, Flor, & Meyer, 2015]. Picture recognition and particularly nameable pictures recognition is associated to a more right-lateralized LPC old/new effect than for words [Ally & Budson, 2007; Küper & Zimmer, 2015], in accordance with fMRI study [Dalton, Hornberger, & Piguet, 2016] showing right perirhinal cortex and right hippocampus activations for episodic recognition of visual relative to verbal stimuli. Hence, exclusion paradigms, that require discrimination of identical "old" pairs among rearranged and new pairs, are suited to assess associative recognition and explore the ERP correlates of the *dual-process theory*. Studies using exclusion paradigms both with verbal or visual paired items have consistently shown old/new effect, and old/rearranged effects mainly for verbal stimuli, on both the FN400 and LPC potentials for unitized pairs, and on the LPC potential only for nonunitized pairs [e.g., Donaldson & Rugg, 1998; Kriukova, Bridger, & Mecklinger, 2013].

To date, only two studies have been conducted using ERPs to investigate episodic recognition in ASD. First, Massand, Bowler, Mottron, Hosein, and Jemel [2013] employed a single words recognition paradigm, and found a parietal rather than anterior early familiarity old/new effect in adults with ASD relative to non-ASD comparison participants. This was followed by parietal recollective process in both groups. To explain this lack of topographical difference in the ASD group, these authors hypothesized overlapping neural generators for the semantic and episodic memory systems, being possibly collapsed into a single-memory system. Massand and Bowler [2015] conducted another more elaborated study, also in adults, designed to further distinguish the semantic and episodic systems, using a single-picture recognition test followed by a recall phase—recall of the color of the studied items—that relied more on episodic memory. The authors described successive old/new effects with a posterior only topographical distribution in the ASD group and made similar arguments as Massand et al. [2013] in favor of a single nondifferentiated memory system. Together, these ERP studies do not argue in favor of the dual-process theory in ASD memory, suggesting instead a single-process recognition.

We conducted here an EEG study investigating the ERP correlates of visual associative recognition for semantically unrelated picture pairs in participants with and without ASD. This task is an adapted version of a paradigm developed in our lab in TD young adults [Desaunay et al., 2017], which contrasted the associative recognition for semantically related and unrelated picture pairs,

showing respectively a semantic and an episodic effect on the FN400 potential, followed by a recollective LPC old/new effect for both categories of stimuli, which supports the value of using picture pairs to assess the interaction of semantic and episodic processes in memory recognition in typical and atypical populations. In order for our sample to be representative of ASD individuals, participants with and without ASD were selected from late childhood to young adulthood, given the very moderate or even absent effect of age on this period in TD population, and the absence of age influence in memory difficulties in ASD [Desaunay et al., 2020]. Developmental studies show that memory for associations emerges early in TD population, with a pronounced increase until the age of 10, followed by a period of relative stability until adulthood [Guillery-Girard et al., 2013; Mastrogiuseppe, Bertelsen, Bedeschi, & Lee, 2019], with similar visual associative memory performance between late childhood and adulthood [Baadte & Meinhardt-Injac, 2019]. Congruent with these age-related differences, EEG studies have identified a greater reliance on recollection-based recognition during early childhood, shifting more toward a familiarity-based recognition from late childhood to adulthood [see Friedman, 2013; Friedman, de Chastelaine, Nessler, & Malcolm, 2010, for a review].

Our objective was to compare, in participants with and without ASD, the ERPs elicited by the associative recognition of paired nameable pictures, especially on the early P2 and FN400 potentials, respectively, indicative of perceptual priming, semantic and familiarity processing, then on the LPC potential, more associated with the recollection process and episodic memory.

Methods
Participants

Twenty-two participants (two females) with ASD without accompanying intellectual impairment (IQ > 70 on the Wechsler Intelligence Scale for Children-IV or the Wechsler Adult Intelligence Scale-IV), aged 10–25 years (mean: 16.5 ± 3.6), and 32 participants with typical development, matched on age, sex, and IQ took parts in the study (see Table 1).

Participants with ASD were recruited from two regional autism resource centers in the university hospitals of Caen and Amiens; clinical diagnoses were made according to the Diagnostic and Statistical Manual of Mental Disorders-5 (DSM-5) [American Psychiatric Association, 2013] criteria and using the Autism Diagnostic Interview-Revised [Rutter, Le Couteur, & Lord, 2003] and/or the Autism Diagnostic Observation Schedule [Lord et al., 2000]. All ASD diagnoses were specified without a known medical or genetic condition or environmental factor, and all ASD participants had no comorbid mental disorder, including attention deficit hyperactivity disorder, according to DSM-5.

All participants were right handed (assessed by the De Agostini and Dellatolas checklist [1988]) and reported normal or corrected normal vision. None had a history of head trauma with loss of consciousness, a recent use of alcohol or illicit drugs, or current medication likely to interfere with memory measures or EEG signal. A major deficit in associative memory was ruled out, using the immediate and delayed recall scores of the verbal paired associates subtest of the Wechsler Memory Scale-IV (2012; >5th percentile for all participants). Participants with typical development had no current or past mental disorder, and no neurological disorder (including seizures) or current medical condition.

This study was conducted in accordance with the Code of Ethics of the World Medical Association [Williams, 2008]. After detailed information on the aims and course of the study, all participants signed for consent, and their parents for minors. The protocol of the study was approved by the local ethics committee before it started (CPP Nord-Ouest, ID-RCB: 2014-A00481-46).

Table 1. Participant Characteristics and Independent Samples *t*-Test

	Autism spectrum disorders group (*n* = 22)		Typical development group (*n* = 32)		
	Mean	SD	Mean	SD	*P* value
Age (years)	16.51 (10.4–25.75)	3.56	17.95 (12.3–25.6)	3.97	0.178
FSIQ	101.4 (72–132)	14.65	106.22 (86–134)	12.38	0.199
VCI	106.72 (69–145)	17.32	110.06 (77–143)	17.11	0.487
PRI	105.68 (72–142)	18.22	104.40 (84–130)	12.51	0.761
VPA-IR	10.86 (5–18)	3.37	11.06 (5–16)	2.78	0.813
VPA-DR	10.4 (1–17)	3.59	10.46 (5–15)	2.43	0.942
AQ	34.42	8.57	12.28	6.45	<0.0001
ADOS[a]	10.11	4.83			

Abbreviations: AQ, autistic quotient (total); FSIQ, full-scale intelligence quotient; PRI, perceptual reasoning index; VCI, verbal comprehension index; VPA-IR/VPA-DR, verbal paired associates immediate recall/delayed recall.
[a]Nine participants with ASD received a diagnosis based on the ADOS.

Materials

Materials and methods were derived from the Desaunay et al. [2017] study. Three hundred and twenty simple, colored line drawings were used for this study. The items depicted were either objects or animals selected from 20 semantic categories (18 were selected from Marchal and Nicolas [2003] according to their imageability, a 19th category—jewels—and a 20th category—prepared food—were generated based on a Wikipedia search), selected for their distinctiveness. All stimuli were drawn at to the same size (not scaled) on a same-color background in 300×300 pixel squares.

Stimuli were used to create 120 semantically unrelated picture pairs that were presented during the learning phase. We avoided supra-categorical pairings (e.g., pairing "pets" and "wild mammals"), and functionally associated items pairings (e.g., nail-hammer), to avoid familiarity-based recognition at test [e.g., Rhodes & Donaldson, 2007; Tibon & Levy, 2014].

For the retrieval phase, 80 target pairs of pictures were the same as those seen in the learning phase (identical pairs), 40 pairs of pictures were rearranged in order to differentiate item memory and relational memory, and 40 new pairs were also presented to test the classic old/new effect. All picture pairs, including new pairs, were semantically unrelated. In order to control for a purely perceptual association between paired items and a relational association between items, the position of half

the identical and rearranged pairs was swapped during the test phase. New pairs were randomly distributed across identical and rearranged pairs. For all picture pairs, 4 lists were created and counterbalanced across participants (in both groups) for the learning and retrieval phases respectively.

Procedure

Stimulus presentation was controlled by Eprime Pro on a 17″ LCD screen with a 1280×1024 resolution. Participants were sitting comfortably 90–100 cm from the screen in a dimly lit room during the whole experiment and were asked to try and minimize blinking and moving during recording.

At both study and test phases (Figure 1), a trial started with a white fixation cross presented on a black background for a pseudorandom interval of 1500 ± 200 msec. A pair of pictures then appeared on the screen for 3000 msec, followed by a blank screen for 1000 msec. Pairs were presented in pseudorandom order. For the incidental learning phase, participants were given the following instructions: "for each pair of drawings, you have to imagine a situation or an image that associates the two drawings presented on the screen. You must then decide whether this situation is plausible (possible) in reality or not. If you think the situation is possible (plausible), press the left button. If it is not plausible, press the right button." These instructions aimed to enhance a deep,
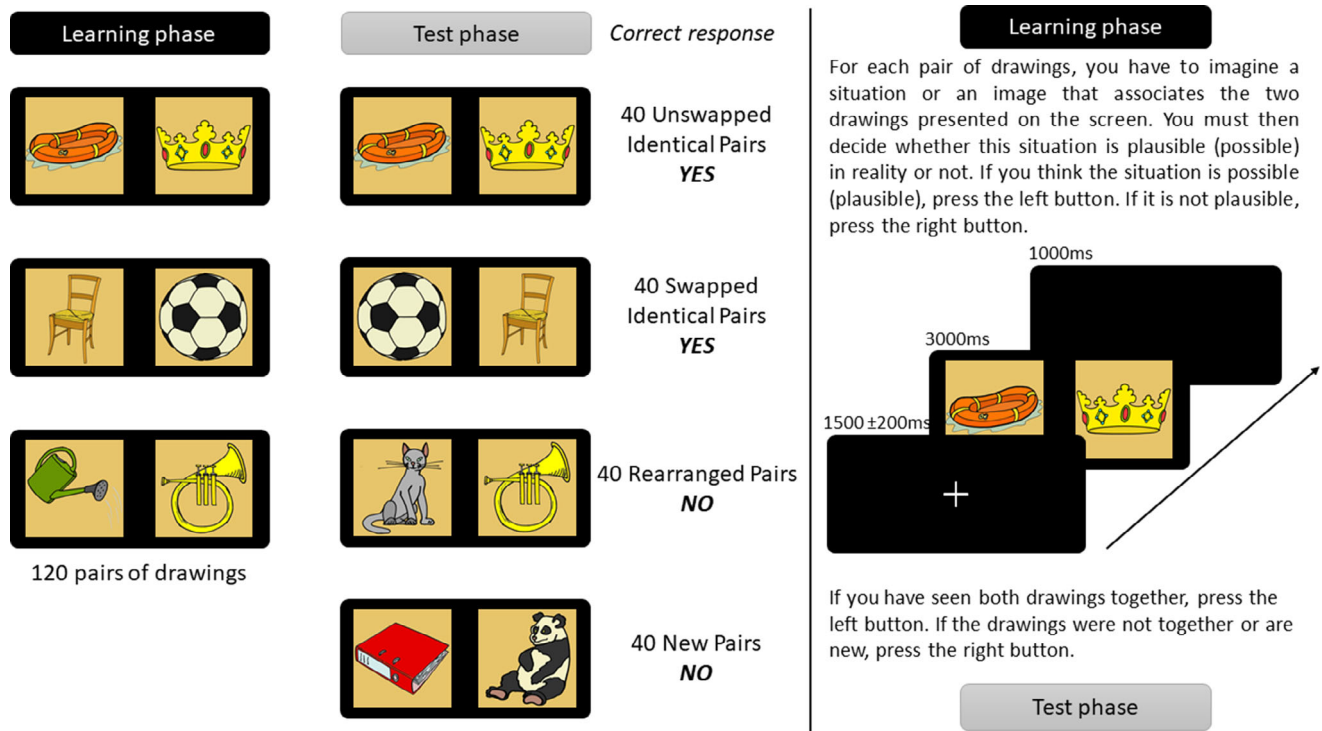
Figure 1. Materials (left panel) and procedure (right panel).

relational encoding. There was no mention that participants would later be tested on their memory for the pairs, so learning was incidental. In recognition phase, participants were instructed to indicate whether or not they had seen both pictures together during the learning phase, regardless of the position of the images on the screen. In both cases participants responded by pressing one of two keys on a response box. They were instructed to respond as quickly as possible, and responses were collected only if they were produced either during the presentation of the stimulus or during the following blank (3000-msec response interval). Both phases were preceded by a training phase using five mock items, which was repeated if necessary. An interval of 15 min separated the learning phase and the test phase, during which participants did not engage in any particular task while the experimenter checked the impedances of the electrodes.

EEG Acquisition

EEG activity was recorded continuously by GES 300 amplifier (Electrical Geodesics, Inc.) using an EGI Hydrocel Geodesic Sensor Net (HGSN-130) with dense array of 128 Ag/AgCl sensors [Tucker, 1993]. Impedances were kept under 100 kΩ [Ferree, Luu, Russell, & Tucker, 2001], and EEG channel was referenced to a vertex reference Cz and ground to CPPZ (fixed by the EGI system). The signal was sampled at 20 kHz frequency with a 24-bit A/D and was online (hardware) amplified and low pass filtered at 4 KHz. However, NetStation software cannot currently acquire at any rate faster than 1 KHz. Hence, the signal was filtered by a Butterworth low-pass finite impluse response (FIR) filter at 500 Hz and subsampled at 1 KHz. Electrooculogram was recorded using four electrodes placed vertically and horizontally around the eyes. Before exporting EEG data, given that we use our own EEG processing software developed in laboratory and since the amplifier are a DC-coupled amplifier, EEG data were processed offline using Netstation 4.4.2 (Electrical Geodesics Inc., Eugene, OR).

The signal was filtered using a 1 Hz Kaiser FIR first-order high-pass filter (which ensures a linear phase and no distortion in the bandwidth) in order to discard DC and very slow waves. Recordings were rereferenced offline to a common average reference [Bertrand, Perrin, & Pernier, 1985; Tucker, 1993] to minimize the effects of reference-site activity and accurately estimate the scalp topography of the measured electrical fields [Dien, 1998]. The artifact in EEG stimulus signal was excluded of the analysis by visual inspection. No other corrections and electrodes reconstructions were applied.

ERP waveforms were created by averaging the ERPs and the signal was segmented into stimuli-synchronized epochs, which were extracted at 250 msec before (baseline) and until 1000 msec post stimulus onset. Trials were discarded from subjects for whom every individual response conditionalized. ERP analyses were performed on trials associated to correct behavioral responses (hits and correct rejections) with a minimum of 15 artifact free trials per condition for each participant (number of trials for "identical pairs" ASD: 17–56, TD: 30–68; "rearranged pairs" ASD: 15–30, TD: 15–32; "new pairs" ASD: 15–34, TD: 18–39; Table A1 inAppendix). Finally, the evoked potential was then baseline-corrected.

Analyses

Behavioral analyses were conducted using SAS software (SAS Institute Inc., version 9.4). We measured accuracy (proportion of correct responses in each condition), and calculated two associative discrimination indexes (percentage of hits for identical pairs minus percentage of false alarms for new pairs [$Pr_{Hits-New}$] or for rearranged pairs [$Pr_{Hits-Rearranged}$]) [Snodgrass & Corwin, 1988]. We ran analyses of variance (ANOVAs) using a general linear model (GLM) procedure. Post hoc multiple comparisons were Tukey corrected. We also conducted Pearson correlations to test the absence of association between age and behavioral performance in both groups.

For EEG analyses, groups of electrodes were averaged together to form each region of interest (ROI) that increased signal/noise ratio and increased statistical power, with 4 to 8 electrodes per region [Kurikawa, Mizuseki, & Fukai, 2019; Ross et al., 2015]. We obtained 15 ROIs (Figure 2): LpF, left prefrontal; MpF, midline prefrontal; RpF, right prefrontal; LF, left frontal; MF, midline frontal; RF, right frontal; LT, left temporal; RT, right temporal; MC, midline central; LP, left parietal; MP, midline parietal; RP, right parietal; LO, left occipital; MO, midline occipital; RO, right occipital. Statistical analyses were only realized on ROIs where components (P2, FN400, LPC) were visible. Statistical analyses of quantitative electroencephalography (qEEG) parameters were also performed with SAS software. Differences in qEEG indices were analyzed by the means of a GLM with age as a covariate.

We used a priori defined latencies of interest according to the literature and confirmed by visual inspection of ERP grand average, resulting in three time windows for the ERP analysis. First, visual inspection of ERPs revealed an unexpected amplitude and shape differences between ASD and TD groups on the posterior P2 potential. Hence, we realized between-group analyses on two time windows, the former being 220–270 msec that correspond to measures reported in the literature [e.g. Wolff, Kemter, Schweinberger, & Wiese, 2014], and the latter being extended to 120–300 msec to ensure that the difference in amplitude is not confused with a difference in latencies. Second, visual inspection of ERPs also revealed an
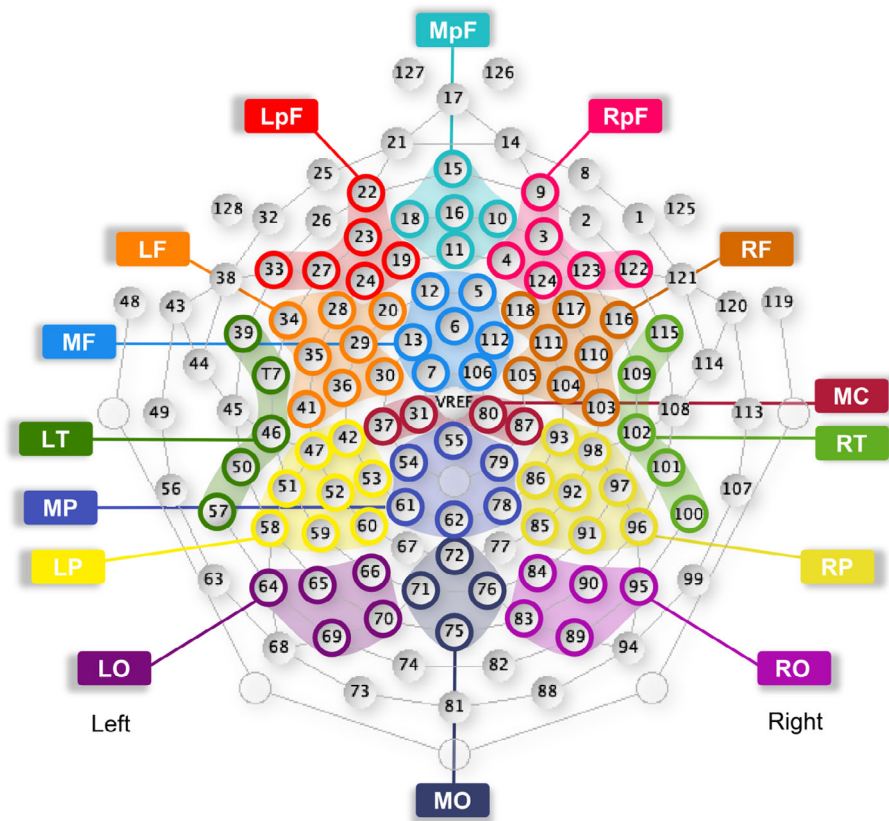
Figure 2. Electrode grouping and localizations. LpF, left prefrontal, MpF, midline prefrontal; RpF, right prefrontal; LF, left frontal, MF, midline frontal; RF, right frontal; LT, left temporal; RT, right temporal; MC, midline central; LP, left parietal; MP, midline parietal; RP, right parietal; LO, left occipital; MO, midline occipital; RO, right occipital.

unexpected amplitude difference between ASD and TD groups on the 350–470 msec time window, corresponding to the FN400 familiarity signal. Third, for the LPC, we begun analyses focusing on 600–700-msec time window. Studies usually report that the LPC lasts longer with verbal material [e.g., Friedman & Johnson, 2000; Johnson, Kreiter, Zhu, & Russo, 1998; Vilberg, Moosavi, & Rugg, 2006; Woodruff, Hayama, & Rugg, 2006], but shorter time windows lasting around 100 msec are more often reported with pictures, either for single or associative recognition [Ally & Budson, 2007; Desaunay et al., 2017; Tibon, Gronau, Scheuplein, Mecklinger, & Levy, 2014]. Besides, in order to better characterize the latencies of the LPC old/new effect in both groups, we run analyses on 50-msec intervals, from 500 to 800 msec. In order to focus on associative processes and to have a sufficient number of trials per condition, data for unswapped and swapped pairs were therefore collapsed across each type of trial. According to Speer and Curran [2007], varying the position of visual stimuli within a pair from one trial to the next has no effect on the FN400 and the LPC old/new effect.

For the P2 analysis, electrode sites for analysis included left occipital (electrodes PO7, O1, PPO9h, POO9h, P11),

right occipital (electrodes PO8, O2, PPO10h, POO10h, P12), and midline occipital (electrodes POO1, POz, Oz, POO2) ROIs. For the FN400 analysis, electrode sites for analysis included midline frontal (electrodes FFC1h, FFC2h, FCz, FCC3h, FCC4h, FCC1h, FCC2h) and midline central (electrodes CP1, CCP1h, CCP2h, CP2) ROIs. For the LPC analysis, electrode sites for analysis included midline parietal (electrodes CPz, CCP2h, CPP1h, P1, Pz, P2), right parietal (electrodes CP4, CP6, TP8, P6, PO4, P8, P4, P10), midline occipital (electrodes POO1, POz, Oz, POO2), and right occipital (electrodes O2, PO8, POO10h, PPO10h, P12) ROIs, based on previous data [Desaunay et al., 2017] and neuroimaging studies using visual stimuli [e.g., Achim & Lepage, 2005].

Results
Behavioral Results

Regarding to identical pairs, a 2 (group: ASD, TD) × 2 (condition: swapped, unswapped) ANOVA revealed a main effect of group only ($F_{(1,104)} = 15.34$, $P = 0.0002$; η_p^2

= 0.126), reflecting lower performance for participants with ASD when compared to TD, but there was no main
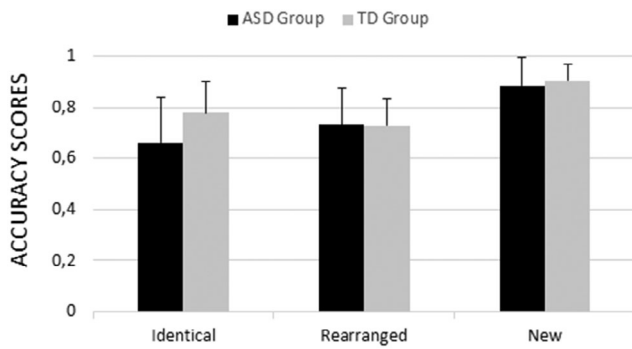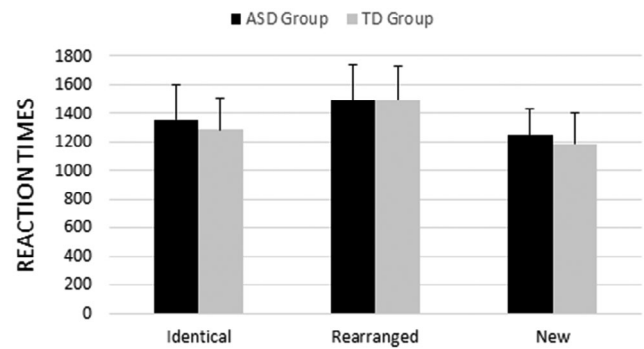
Figure 3. Accuracy scores per condition (means and SDs for identical, rearranged, and new pairs), in the ASD group and TD group. ASD, autism spectrum disorder; TD, typical development

Figure 4. Reaction times per condition (means and SDs for identical, rearranged, and new pairs), in the ASD group and TD group. ASD, autism spectrum disorder; TD, typical development

effect of condition ($F_{(1,104)}$ = 1.9, P = 0.17; η_p^2 = 0.016) nor group × condition interaction ($F_{(1,104)}$ = 0.22, P = 0.64; η_p^2 = 0.002). Hence, we collapsed these two conditions (as "identical pairs"). All accuracy results were significantly higher than chance level (0.50, all $P < 0.05$) (Figure 3). A 2 (group: ASD, TD) × 3 (condition: identical, rearranged, new pairs) ANOVA revealed a main effect of group ($F_{(2,156)}$ = 5.3, P = 0.022; η_p^2 = 0.099) and condition ($F_{(2,156)}$ = 33.94, $P < 0.0001$; η_p^2 = 0.59) on accuracy. The group × condition interaction was also significant ($F_{(2,156)}$ = 3.33 P = 0.038; η_p^2 = 0.12). Post hoc Tukey tests indicated that participants with ASD had lower scores than control participants on correctly identified identical pairs (P = 0.01), but groups did not differ on the correct rejection of rearranged and new pairs.

The associative discrimination index for identical pairs compared to new pairs ($Pr_{Hits-New}$) was 0.61 (SD = 0.26) in the ASD group, and 0.76 (SD = 0.17) in the TD group. A one-way ANOVA ($F_{(1,52)}$ = 6.49, P = 0.014; η_p^2 = 0.11) revealed this difference to be significant, in the sense of a lower discrimination index for participants with ASD relative to TD controls. The other associative discrimination index for identical pairs compared to rearranged pairs ($Pr_{Hits-Rearranged}$) was 0.44 (SD = 0.25) in the ASD group, and 0.57 (SD = 0.21) in the TD group, and a one-way ANOVA ($F_{(1,52)}$ = 3.87, P = 0.054; η_p^2 = 0.07) revealed this difference not to be significant.

There were no between-group differences in reaction times (Figure 4). There was also no significant correlation between age and both behavioral performance and reaction times in the TSA and TD groups (for identical pairs, unswapped and swapped separately or pooled, rearranged pairs, and new pairs: all $P > 0.05$).

There was also no significant between-group difference on the responses during study phase (for "yes" responses for plausible situations "no" responses for implausible situations, out of time or absence of response: all $P > 0.05$; see Table A2 in Appendix).

ERP Results

We conducted a series of ANOVAs on the P2, FN400, and LPC potentials, to evidence an old/new or an old/rearranged effect. *P2 potential.* To characterize the P2 potential on the 220–270-msec time window (Figure 5), we first conducted a 2 (group: ASD, TD) × 2 (condition: identical, new pairs) ANOVA which revealed a main effect of group, unexpectedly indicating that P2 amplitude was lower across conditions in the ASD compared to the TD group, in each of the three ROIs: left occipital ($F_{(1,104)}$ = 10.79, P = 0.0014; η_p^2 = 0.18), right occipital ($F_{(1,104)}$ = 5.44, P = 0.021; η_p^2 = 0.098), and midline occipital ($F_{(1,104)}$ = 11.36, P = 0.001; η_p^2 = 0.18). In line with the ERP literature on recognition identifying no old/new effect on early potentials, there was no significant effect of conditions in these three areas ($F_{(1,104)} < 1$) nor interaction ($F_{(1,104)} < 1$). We then conducted a 2 (group: ASD, TD) × 2 (condition: identical, rearranged pairs) ANOVA on the 220–270-msec time window, replicating the group effect with an amplitude decrement in the ASD group relative to TD group, in the same three ROIs: left occipital ($F_{(1,104)}$ = 9.64, P = 0.002; η_p^2 = 0.084), right occipital ($F_{(1,104)}$ = 5.07, P = 0.026; η_p^2 = 0.046), and midline occipital ($F_{(1,104)}$ = 12.09, $P < 0.001$; η_p^2 = 0.104), without effects of condition ($F_{(1,104)} < 1$) nor interaction ($F_{(1,104)} < 1$).

We then replicated these statistical analyses on the 120–300-msec time window. A 2 (group: ASD, TD) × 2 (condition: identical, new pairs) ANOVA confirmed the main effect of group, in the sense of a reduced amplitude for all pairs in the ASD relative to TD group, in left occipital ($F_{(1,104)}$ = 4.63, P = 0.033; η_p^2 = 0.042) and midline occipital ($F_{(1,104)}$ = 9.66, P = 0.002; η_p^2 = 0.085) ROIs, but
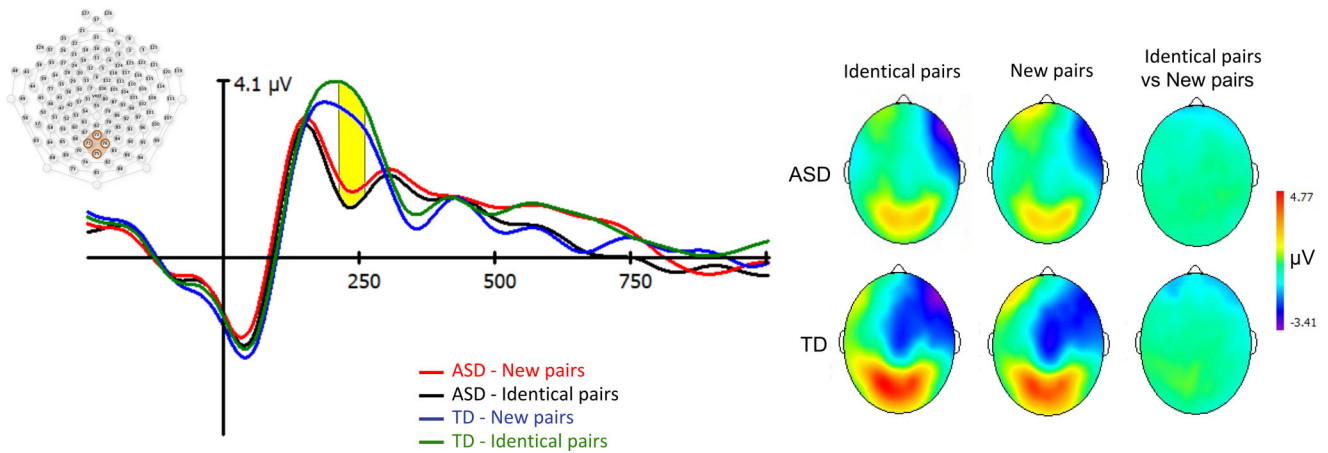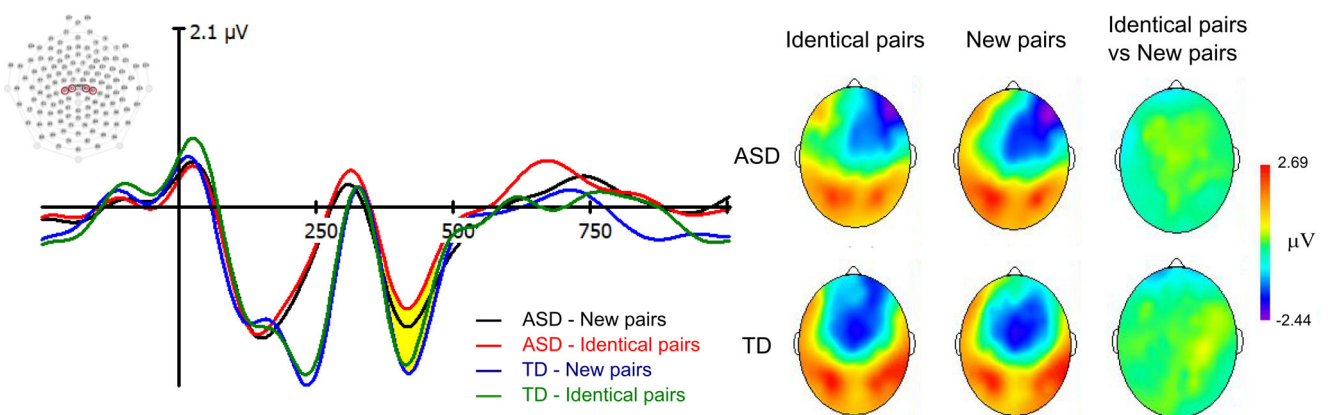
Figure 5. Event-Related Potentials and topographies for the P2 potential (signal in midline occipital area between 220 and 270 msec). Yellow shaded areas correspond to significant differences between ASD and TD waveforms. ASD, autism spectrum disorder; TD, typical development

we failed to replicate between-group difference on the right occipital ROI. There was also no significant condition effect of conditions in left occipital and midline occipital areas ($F_{(1,104)} < 1$) nor interaction ($F_{(1,104)} < 1$). Then, a 2 (group: ASD, TD) × 2 (condition: identical, rearranged pairs) ANOVA on the 120–300-msec time window also revealed a group effect on the left occipital ($F_{(1,104)} = 4.77$, $P = 0.031$; $\eta_p^2 = 0.043$) and midline occipital ($F_{(1,104)} = 7.14$, $P = 0.009$; $\eta_p^2 = 0.064$) ROIs only, being non significant on the right occipital ROI, without effects of condition ($F_{(1,104)} < 1$) nor interaction ($F_{(1,104)} < 1$) in these three areas.

FN400 potential. To characterize the familiarity FN400 potential on the 350–470-msec time window (Figure 6), we first conducted a 2 (group: ASD, TD) × 2 (condition: identical, new pairs) ANOVA, which also revealed a main

effect of group on the midline central ROI only ($F_{(1,104)} = 6.81$, $P = 0.01$; $\eta_p^2 = 0.061$), indexing a FN400 decrement across conditions in the ASD compared to the TD group. Congruently with the ERP literature on unrelated and nonunitized paired stimuli, there was no condition effect, that is, no old/new effect ($F_{(1,104)} < 1$) nor interaction ($F_{(1,104)} < 1$). There was no significant group, nor condition, nor interaction on the midline frontal ROI. Second, we conducted a 2 (group: ASD, TD) × 2 (condition: identical, rearranged pairs) ANOVA on the same time-window, replicating the group effect on the midline central ROI ($F_{(1,104)} = 4.99$, $P = 0.03$; $\eta_p^2 = 0.045$), in the sense of a reduced amplitude for all pairs in the ASD relative to TD group, without effect of conditions ($F_{(1,104)} < 1$) nor interaction ($F_{(1,104)} < 1$). There was also no significant group, nor condition, nor interaction on the midline frontal ROI.

Figure 6. Event-related potentials and topographies for the FN400 potential (signal in midline central area between 350 and 470 msec). Yellow shaded areas correspond to significant differences between ASD and TD waveforms. ASD, autism spectrum disorder; TD, typical development
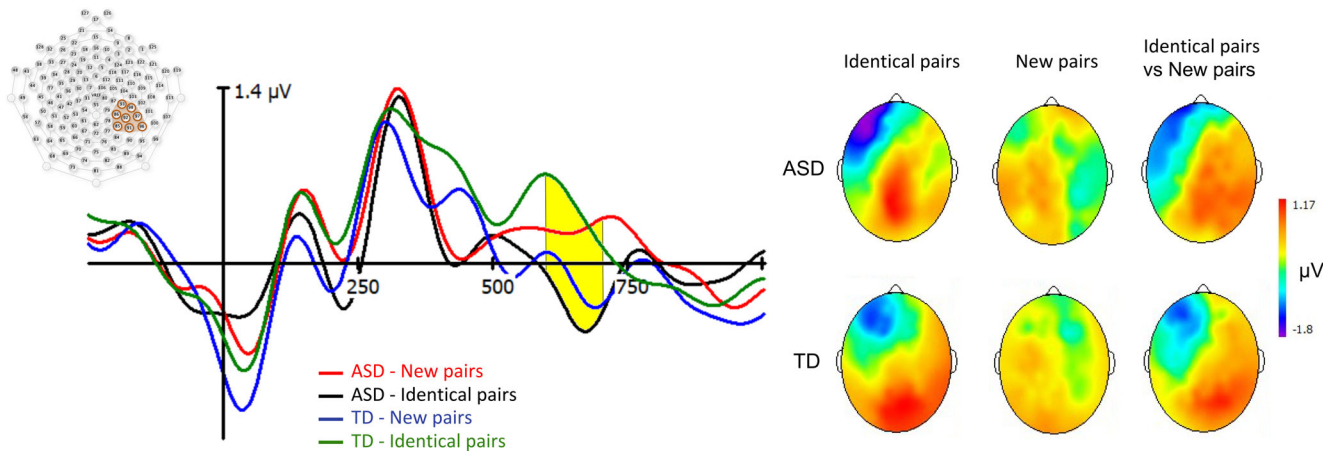
Figure 7. Event-Related Potentials and topographies for the LPC potential (signal in right parietal area between 500 and 600 msec). Yellow shaded areas correspond to significant differences between conditions, that is, old/new effect in ASD and TD groups. ASD, autism spectrum disorder; LPC, late positive component; TD, typical development

LPC potential. To characterize the recollection effect (Figure 7), we conducted a series of ANOVAs on the LPC potential.

First, to test the LPC old/new effect, we performed a 2 (group: ASD, TD) × 2 (condition: identical, new pairs) ANOVA on the 600–700-msec time window. A significant condition effect was identified in four ROIs: right parietal ($F_{(1,104)} = 23.63$, $P < 0.0001$; $\eta_p^2 = 0.181$), midline parietal ($F_{(1,104)} = 8.14$, $P = 0.005$; $\eta_p^2 = 0.069$), midline occipital ($F_{(1,104)} = 14.76$, $P = 0.0002$; $\eta_p^2 = 0.123$), and right occipital ($F_{(1,104)} = 12.68$, $P = 0.0006$; $\eta_p^2 = 0.104$). A significant group effect was also identified in midline parietal ROI ($F_{(1,104)} = 4.51$, $P = 0.036$; $\eta_p^2 = 0.038$), and a tendency in the right occipital ROI ($F_{(1,104)} = 3.58$, $P = 0.061$; $\eta_p^2 = 0.029$). There was no significant group × condition interaction. Then, old-new effects were estimated using post hoc Tukey corrected comparisons between "identical" and "new" conditions in each group separately. In the ASD group, we identified a significant LPC old/new effect on right parietal ($P = 0.006$) and midline parietal ($P = 0.05$) ROIs, being marginally significant on the midline occipital area ($P = 0.076$), and nonsignificant in the right occipital area ($P = 0.22$). In the TD group, we identified an LPC old/new effect on the right parietal ($P = 0.002$), midline occipital ($P = 0.014$), and right occipital ($P = 0.008$) ROIs, being nonsignificant in the midline parietal ROI ($P = 0.53$). There was no group × condition interaction (all $F_{(1,104)} < 1$).

Second, to better characterize latencies of the LPC old/new effects in both groups, we extended the statistical analyses on the 550–600- and 700–750-msec time window. From 550 to 600 msec, we found a significant condition effect on the right parietal ROI ($F_{(1,104)} = 5.07$, $P = 0.026$; $\eta_p^2 = 0.045$), and a trend on midline occipital ($F_{(1,104)} = 3.86$, $P = 0.052$; $\eta_p^2 = 0.035$) and right occipital ($F_{(1,104)} = 3.45$, $P = 0.066$; $\eta_p^2 = 0.031$) ROIs, without significant post hoc analyses, that is, no LPC old/new effects. On the 700–750-ms time window, a significant group effect was present on the right parietal ROI only ($F_{(1,104)} = 4.75$, $P = 0.031$; $\eta_p^2 = 0.042$), while only a trend on the right occipital ($F_{(1,104)} = 3.35$, $P = 0.07$; $\eta_p^2 = 0.031$) and midline occipital ($F_{(1,104)} = 32$, $P = 0.071$; $\eta_p^2 = 0.03$) ROIs, without significant post hoc analyses, that is, no LPC old/new effects as well.

Third, to test the LPC old/rearranged effect, we performed a 2 (group: ASD, TD) × 2 (condition: identical, rearranged pairs) ANOVA on the 600–700-ms time window. We only identified a group effect in the midline parietal ROI ($F_{(1,104)} = 6.57$, $P = 0.012$; $\eta_p^2 = 0.059$), without significant post hoc analyses. There was no effects of condition ($F_{(1,104)} < 1$) nor interaction ($F_{(1,104)} < 1$). To further characterize potentials, we also conducted a 2 (group: ASD, TD) × 2 (condition: identical, rearranged pairs) ANOVA on the 550–600 and 700–750-ms time windows, showing only a group effect on the right occipital ROI between 550 and 600 msec ($F_{(1,104)} = 4.46$, $P = 0.04$; $\eta_p^2 = 0.04$) then on the right parietal ROI between 700 and 750 ms ($F_{(1,104)} = 3.93$, $P = 0.05$; $\eta_p^2 = 0.036$), without significant post hoc analyses.

Discussion

Because of their dual perceptual and conceptual coding, picture stimuli allow investigating the successive

electrophysiological features associated with memory recognition. Here, picture pairs were used in an associative recognition paradigm that is a well-validated method to assess the ERP correlates of familiarity and recollection. Participants with ASD were less well able than matched TD comparison participants in correctly identifying identical "old" pairs, but were as accurate as TD comparison participants at rejecting rearranged and new pairs. We observed the same succession of ERP waveforms in both groups, and an old/new effect on the LPC potential only, demonstrating the same recollection-based retrieval of associative information in ASD participants as was observed in the TD controls. However, amplitudes for all ERP waveforms was reduced in P2 and FN400 potentials in the ASD relative to the TD group, and the topographical distribution of the LPC old/new effect was larger on parietal areas, possibly reflecting compensatory processes. We conclude that there is a reduced conceptual processing of visual stimuli in memory in ASD, and that the LPC old/new effect is in line with the *dual-process theory* in ASD as in TD participants.

Diminished Associative Recognition for Paired Pictures

Diminished associative recognition of identical pairs for ASD relative to TD participants is in line with the *relational binding account* [Bowler et al., 2011; Gaigg et al., 2008] that posits a specific impairment in relational memory accompanied by intact item-specific memory. However, cognitive and neuroimaging models of associative recognition suggest that item and associative information are stored as distinct memory representations [Buchler, Light, & Reder, 2008; Ranganath, 2010], hence memory for either a picture within a pair or for the association may be diminished. A recent meta-analysis of episodic memory in ASD [Desaunay et al., 2020] identified a medium deficit for visual material with a small deficit for verbal material in individuals with ASD, compared to TD controls. This observation contrasts with the *pictorial superiority effect* over words usually observed in TD populations [Nelson, Reed, & Walling, 1976; Snodgrass & Asiaghi, 1977; also see Baadte & Meinhardt-Injac, 2019, in associative memory]. We suggest that the dual coding of pictures interacts with *enhanced perceptual functioning* [Mottron & Burack, 2001] and *weak central coherence* [Happé & Frith, 2006] in ASD, resulting in visual memory being less conceptually driven relative to TD population. As a consequence, visual memory may be less supported by the semantic system and so less encoded into episodic memory as argued by hierarchical models of memory [SPI model (for Serial Parallel Independant) Tulving, 1995; MNESIS model (for Memory NEo-Structural Inter-Systemic model), Eustache, Viard, & Desgranges, 2016]. Taking these points together, we hypothesize that the use of pictorial stimuli in the current study may have reduced

memory for items within a pair, independently of memory for the association.

The contrast between our results and with those of Hogeveen et al. [2019], who found preserved visual associative recognition in ASD, may result from methodological differences. Their paradigm was composed of a study phase divided into 27 picture pairs requiring item-specific encoding and 27 others with relational encoding. All participants were given an item recognition phase, and only a subset of participants performed the associative recognition phase. First, participants in our study had to encode more picture pairs, hence those with ASD may have been disadvantaged by higher memory load, as noted in other memory domains [e.g., Desaunay et al., 2019]. Second, the item recognition phase in the Hogeveen et al.'s [2019] study may have reinforced item memory during the subsequent associative recognition phase, as previously demonstrated in elderly TD participants who show binding difficulties [Fine, Shing, & Naveh-Benjamin, 2018]. Third, only participants who did not show fatigue were tested on the associative recognition phase of Hogeveen et al.'s [2019] study, which may limit their conclusion that all participants showed preserved relational memory.

For rearranged pairs, we observed similar between-groups accuracy and reaction times. Although this difference was not significant, higher reaction time for rearranged compared to identical and new pairs in both groups suggests an additional "recall-to-reject" process of recollective detail. This memory process is a slower but more accurate strategy enabling more effective rejection of lures [see Xu & Malmberg, 2007, with unrelated picture pairs]. In addition, Cooper et al. [2015, 2017] suggested that this might also operate during visual associative recognition in ASD.

Reduced Early Processing of Semantically Related Visual Information

We found a reduced amplitude for all pairs (i.e., identical and new) on the occipital P2 and mid-frontal FN400 components, for ASD relative to TD participants. Electrophysiological studies show a leftward lateralization of functional connectivity in ASD compared to TD [see O'Reilly, Lewis, & Elsabbagh, 2017, for a review], leading to a reduced global/local integration of information due to hemispheric brain specialization (i.e., left and right hemispheres being specialized toward local–featural, and global–configural processing, respectively), which is suggested to participate to memory deficits in ASD in line with the greater right hemispheric dependence on visual memory [Fiebelkorn, Foxe, McCourt, Dumas, & Molholm, 2013]. Here, our results extend these findings, by suggesting a reduced processing of semantically-related visual information on the early stages of recognition.

The occipital P2 potential is thought to index an intermediate processing stage linking elementary perceptual processes with higher-level semantic processes [De Cesarei, Mastria, & Codispoti, 2013]. During picture categorization tasks, the P2 potential has been associated with the perception of shape [Lee, Huang, Federmeier, & Buxbaum, 2018; Schendan & Kutas, 2007a, 2007b], while higher-order between- and within-category information processing are associated with the later N300 and N400 potentials, respectively [Hamm, Johnson, & Kirk, 2002]. In visual episodic recognition, the P2 potential has been linked to the perceptual overlap between encoding and recognition of fragmented objects, corresponding to memory reactivation or priming [Schendan & Kutas, 2007a, 2007b], and to the processing of metric distances between facial features [Latinus & Taylor, 2006]. During short-term memory for meaningless shapes, Cepeda-Freyre, Garcia-Aguilar, Eguibar, and Cortes [2020] showed its amplitude to increase with stimulus complexity, reflecting a visual attentional process. Here, we suggest that attenuation of the P2 amplitude for all pairs in the ASD relative to the TD group may correspond to a reduced early processing of perceptual visual information of pictures within a pair. Consistent with this account, Fiebelkorn et al. [2013] identified during a visual-target detection task, an attenuation of ERP waveforms in children with ASD relative to without in a close time window (240–280 msec), suggesting diminished selective attention and reduction of early categorization processing. Atypical electrophysiology in ASD on the P2 potential has also been found in audiovisual speech integration with a reduced amplitude, leading to the same conclusion of a reduced early semantic integration of information [Magnée, de Gelder, van Engeland, & Kemner, 2011; Megnin et al., 2012].

No old/new effect was observed on the FN400 potential in either group—that is, no familiarity-based recognition—indicating that interactive encoding of picture pairs was not associated with unitization. Interestingly, we identified a reduced amplitude for all pairs in the ASD group relative to TD group. Given that the FN400 potential reflects both conceptual priming and familiarity during episodic recognition [see review and recent account in Leynes et al., 2017], this amplitude decrement in the ASD group may correspond to reduced semantic processing and familiarity signal elicited by pictures within a pair. Consistent with this account, Solomon et al. [2016] identified during the recognition of picture pairs after relational encoding a reduced level of familiarity awareness in their adolescent participants with ASD relative to those without ASD. In addition, Massand and Bowler [2015] showed that single-item recognition of line-drawings was associated with a reduced familiarity old/new effect (in the 300–650-msec time window) in adults with ASD relative to those without ASD.

Together, the sequence of amplitude decrement on the P2 then FN400 potentials suggests a reduced integration of low-level perceptual into high-level conceptual information of pictures in ASD participants, associated with a reduced familiarity-based memory. This conclusion fits with recent EEG results of atypical integration between low- and high-level information with visual stimuli [Ortiz-Mantilla, Cantiani, Shafer, & Benasich, 2019; Wang, Yang, Liu, Shao, & Jackson, 2017], and recent model of visual episodic memory being less supported by semantic knowledge than verbal memory in individuals with ASD relative to TD controls [Desaunay et al., 2020; Semino et al., 2019].

Similar Neurophysiological Process Associated With Recollection in ASD as in TD Individuals

In both groups, we identified an old/new effect on the LPC potential only, highlighting that associative recognition in ASD is supported by the recollection process, just as in TD individuals [Donaldson & Rugg, 1998; Rugg & Vilberg, 2013]. This finding may challenge previous ERP studies from Massand et al. [2013] and Massand and Bowler [2015], who suggested a single nondifferentiated memory system in ASD, contrary to the semantic/episodic distinction observed in TD individuals [Tulving, 1972]. In Massand et al.'s [2013] study, the FN400 and LPC potentials for the ASD group were located in overlapping parietal areas, preventing any clear distinction between these two potentials. In their following study, Massand and Bowler [2015] observed an attenuated familiarity old/new effect for the ASD group, but in a large time window (300–650 ms), less specfic to the FN400 potential [see Rugg & Curran, 2007 for a review]. These paradigms required single-item recognition, supported by the familiarity FN400 old/new effect, while the current paradigm was specifically designed to track the recollective LPC old/new effect, which may in part explain the different pattern of EEG results. Moreover, the LPC old/new effect identified in our study may instead suggest a distinctive recollective process, which supports the proposition of a relatively preserved *dual-process* account of recognition [Yonelinas, 2002] in ASD. This interpretation seems consistent with Cooper et al. [2017] fMRI study on visual recognition, which showed similar patterns of brain activity in ASD and TD individuals, reflecting the same processing of memory representations in the two groups. This argument may also help to resolve the apparent contradiction between existing EEG studies showing fewly qualitative differentiated familiarity and recollection processes [Massand et al., 2013; Massand & Bowler, 2015], and behavioral studies, which have shown that recollection and familiarity measures in ASD participants respond similarly to manipulations as do TD participants' responses [Bowler,

Gardiner, & Gaigg, 2007]. These last findings alongside those reported in the present study highlight that recollection can occur in ASD when the binding of information is required during episodic recognition.

Analysis of the LPC old/new effect showed similar latency and duration in both groups, with a spatial extension to Midline Parietal ROI in the ASD compared to TD group. First, this additional parietal recruitment may suggest a compensatory process, that is, effortful retrieval of associative information, in some similarly with Hogeveen et al. [2019] study showing a hippocampal hyper-recruitment due to lower memory strength for individual items—indexed by the reduced FN400 familiarity signal. Second, the pattern of electrophysiological processes—that is, reduced amplitude of the FN400 familiarity potential, while similar amplitude but parietal extension of the LPC recollective potential—may reflect an immature development of memory processes in ASD. Developmental EEG studies of verbal or visual recognition in TD individuals have consistently identified a greater reliance on the LPC recollective process than on the familiarity FN400 process in younger participants, with the opposite pattern occurring when age increases [e.g., Friedman et al., 2010; Sprondel, Kipp, & Mecklinger, 2011]. Hence, reduced familiarity but enhanced recollection EEG signals in ASD compared to non-ASD participants, beyond the associative nature of our paradigm, may reflect an earlier developmental stage, that is, a greater recollection-based recognition, as observed in younger TD individuals. This conclusion is supported by a behavioral study by Solomon et al. [2016] showing greater visual memory both for items and associations in ASD when supported by recollection than familiarity. By contrast, we identified in the TD group a right occipital extension of the LPC old/new effect, suggesting a greater representation of individual items as suggested by fMRI studies [Yonelinas, Hopfinger, Buonocore, Kroll, & Baynes, 2001], possibly resulting from the greater familiarity signal.

Electrophysiological Hypotheses on Visual Recognition in ASD

Our results, in conjunction with other ERP studies, may provide insights on the neural processes associated with the local/global imbalance during the early phases of visual recognition in ASD (i.e., *enhanced perceptual functioning* [Mottron & Burack, 2001], and *weak central coherence* [Happé & Frith, 2006]). In two recognition studies using faces, Gunji, Inagaki, Inoue, Takeshima, and Kaga [2009] and Churches, Damiano, Baron-Cohen, and Ring [2012], have identified a reduced amplitude of the early N170 potential, and of the N250 [Gunji et al., 2009] or P300 [Churches et al., 2012] potentials, in individuals with ASD, compared to TD ones, suggesting a lower early attention and structural processing of faces (indexed by the N170 potential decrement), leading to a reduced

ability to develop a new face representation—that is, semantic memory for faces (indexed by the N250 or P300 potentials decrement). Together, ERP results converge toward a reduced perceptual priming of a target item, possibly resulting from attentional bias and locally oriented perception, leading to a lower integration of intraitem features into a coherent representation (i.e., conceptual priming), and to a reduced match with its representation stored in long-term memory, that is, a lower familiarity effect. This account is borne out by a recent meta-analysis on episodic memory showing greater difficulties for visual than verbal material in ASD [Desaunay et al., 2020], and a behavioral study reporting that memory for semantically related pictures in ASD is enhanced by associating picture names to the pictures themselves, suggesting that words would foster item and inter-item conceptual processing, leading to better memory [Parra et al., 2016].

The pattern of ERP observed in our study, which associated a reduced FN400 amplitude with a parietal extension in the LPC potential in participants with ASD compared to controls, suggests that visual recognition relies more on the recollection process in ASD than in TD. This observation may also explain to some extent the EEG results from Massand et al. [2013] with words, and Massand and Bowler [2015] with pictures, since single-item recognition led to a reduced old/new effect on the FN400 potential while being preserved on the LPC potential, in ASD relative to TD participants in both studies. First, this lowered familiarity/recollection ratio may attest of a greater involvement of associative memory processes, due to a more featural representation of visual stimuli in ASD, which, however, may necessitate more cognitive resources as suggested by lower performance. Second, it may reflect an immature development of memory processes in ASD, as observed in TD children [Friedman et al., 2010; Sprondel et al., 2011], possibly resulting from atypical connectivity which remains relatively intact some cognitive processes subserved by more posterior brain areas [see Rane et al., 2015, for a review]. From this perspective, this greater recollection-based recognition may correspond, in some respects, to the absence or reduced developmental shift from reliance on detailed representations more associated with recollection, to greater global and conceptual gist-based strategies more associated with the familiarity process in individuals with ASD contrary to TD individuals across the lifespan [Miller et al., 2014], as highlighted by the *Fuzzy-Trace* theory [Reyna & Brainerd, 1995].

Together, ERP studies, although being scarce, suggest that early stages of visual episodic recognition in ASD are more perceptual and oriented toward features than in TD, which reduces the match with long-term memory representation. Given similarities with encoding [Cox & Criss, 2020], visual memories in ASD may appear as being

more perceptually detailed, hence more unique since being less associated with semantic knowledge. Compared to TD, visual episodic recognition in ASD at its later stages may require greater binding of perceptual features, and would thus appear as more relying on recollection awareness, thus implying more controlled and effortful cognitive processes in visual memory functioning.

Limits

Limitations of this study include absence of statistical old/rearranged effect on the LPC, in both ASD and TD groups. First, it may result from a lack of statistical power and the use of pictorial stimuli. In spite of a strong theoretical account linking associative recognition to the LPC old/rearranged effect, it must be noted that this effect is not constantly replicated with visual associations paradigms—that remain scarce—resulting in the LPC old/new effect being more regularly discussed [e.g. Tibon et al., 2014; Tsivilis, Otten, & Rugg, 2001]. A possible explanation is that the LPC time window is generally narrower for visual stimuli than for words, lasting around 100–200 msec, which reduces the statistical power. Second, it may also suggest that an additional memory process is necessary to fully distinguish identical and rearranged picture pairs, such a "recall-to-reject" process, in which participants actively remember the target pairs for excluding rearranged ones [Xu & Malmberg, 2007], and is thought to start with pictures on the LPC and continue to the late frontal potential [Ally & Budson, 2007; Morcom, 2015]. In that sense, previous ERP studies by Massand et al. [2013] and Massand & Bowler [2015] have evidenced, using, respectively, word and picture stimuli, the presence and effectiveness of this late frontal potential in ASD as in TD participants during episodic recognition.

Conclusions

To conclude, this ERP study provides insights into the time course of associative recognition with visual material in individuals with ASD. Memory difficulties may emerge from the visual nature of paired stimuli, but may be partially compensated by a greater reliance on the recollection process and binding. The same succession of potentials, in particular separable FN400 and LPC potentials in both groups, suggests that information processing during associative recognition in ASD is qualitatively similar to that seen in TD, extending the *dual-process* theory of recognition in ASD condition, but may however differ quantitatively. Overall, the present study challenges the possibility that recollective processes may function entirely atypically in ASD while having a largely common electrophysiological correlates.

Conflict of Interest

The authors declare no conflict of interest.

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APPENDIX

TABLE A1. Average Number of Trials Before, After Rejection, and Discarded in Each Condition of Interest (Mean, Minimum, Maximum, SD) in the Autism Spectrum Disorder (ASD) and Typical Development (TD) Groups

	Autism spectrum disorders group (*n* = 22)		Typical development group (*n* = 32)		
	Mean	SD	Mean	SD	*P* value
Before artifact rejection					
Identical pairs (/80)	53.09 (24–70)	14.27	62.75 (38–73)	9.89	0.0049
Rearranged pairs (/40)	29.23 (21–39)	5.70	29.19 (20–37)	4.15	0.976
New pairs (/40)	35.36 (21–40)	4.34	36.19 (29–40)	2.56	0.384
After artifact rejection					
Identical pairs (/80)	38.05 (17–56)	10.57	47 (30–68)	10.89	0.0041
Rearranged pairs (/40)	21.41 (15–30)	5.03	22.59 (15–32)	4.29	0.357
New pairs (/40)	25.32 (15–34)	4.88	27.97 (18–39)	6.16	0.098
Number of responses removed when rejecting artifacts (i.e., number of responses before artifact rejection minus number of responses after artifact rejection)					
Identical pairs (/80)	15.05 (2–37)	8.49	15.75 (3–39)	10.21	0.791
Rearranged pairs (/40)	7.82 (1–23)	4.81	6.59 (0–15)	4.03	0.315
New pairs (/40)	10.05 (4–23)	4.66	8.22 (0–19)	5.46	0.207

Note. We can observe that the difference between groups for identical pairs remains after artifact rejection. Otherwise, the total number of trials discarded in the ASD group did not differ from controls.

TABLE A2. Number of "Yes" Responses, "No" Responses, Or Error Responses (Out of Time or Absence of Response) During the Presentation of the 120 Picture Pairs at Study

	Autism spectrum disorders group (*n* = 22)		Typical development group (*n* = 32)		
	Mean	SD	Mean	SD	*P* value
"Yes" responses (plausible)	29.45 (4–55)	14.35	38.38 (1–87)	19.94	0.078
"No" responses (implausible)	75.27 (27–104)	19.74	68.63 (15–107)	25.08	0.303
Errors	15.27 (0–68)	20.27	12.97 (0–68)	16.71	0.650