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The distinctive pattern of declarative memories in Autism Spectrum Disorder: Further evidence of episodic memory constraints.

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Abstract

This study examines declarative memory retrieval in ASD depending on the availability and access to stored conceptual knowledge. Fifteen autistic participants and a matched control group of 18 typically-developed (TD) volunteers completed a Remember-Know paradigm manipulated by encoding-type (categorical, perceptual) and item-typicality (high-typical, low-typical). The autistic group showed worse and slower recognition and less recollection but equivalent familiarity-based memories compared to TDs. Notably, low-typical items did not improve their memories, as they did for TDs, likely due to difficulties in matching low-fit information to the stored schema. Results suggest that memory decline in ASD may derive from the episodic system and its dynamics with the semantic system. These findings may inform interventional strategies for enhancing learning abilities in ASD.

Key-words: declarative memories; recognition; recollection; familiarity; autism spectrum disorder

The distinctive pattern of declarative memories in Autism Spectrum Disorder: Further evidence of episodic memory constraints.

Declarative memories include clearly defined long-term memory types that reflect our capability to store and retrieve different types of conscious memories. Episodic memory entails representations directly dependent on experiences or context, allocated to the Medial Temporal Lobe, namely the hippocampus (Tulving, 1972; 1985; Yonelinas, 2002; Yonelinas et al., 2010). Semantic memory comprises abstract representations (context-free) that are cortically supported (Tulving, 2000; Yonelinas et al., 2010). Recent accounts of memory consolidation (Nadel & Moscovitch, 1997; Winocur et al., 2010; Winocur & Moscovitch, 2011; Sekeres et al., 2018) are more dynamic and argue in favor of the transformation of contextually-based traits (hippocampus-dependent) into more schematic representations that are supported by neocortical regions and become progressively independent from the hippocampal regions. In other words, semantic memories are formed from the transformation of episodic traits into context-free traits. Episodic memories, however, remain supported by the hippocampus as long as they maintain their contextual details (Harand et al., 2012; Winocur & Moscovitch, 2011). According to this approach, the episodic system seems crucial in processing information that brings novelty or unexpectedness (see Bonasia et al., 2018; Dudai et al., 2015; Yonelinas et al., 2010). The hippocampus acts in binding such novel inputs (received from other brain regions) in a complex, relational manner (Yonelinas et al., 2010; 2019). However, when the new information fits prior stored conceptual knowledge (i.e., schema), the involvement of the episodic system in processing and integrating new, unexpected incoming information is circumvented or even suppressed (see Dudai et al., 2015).

People in the Autism Spectrum (Autism Spectrum Disorder, ASD) tend to present a characteristic pattern for long-term declarative memories, namely a decline in episodic memory of self-based recollection experiences (Boucher & Bowler, 2008; Bowler et al., 2011; Joseph et al., 2005; see also Bowler et al., 2011; Cooper & Simons, 2018 for reviews). However, it has also been argued that this particular episodic memory profile can be subtle or absent in the spectrum depending on the sample characteristics, type of measures, and task modalities (see Boucher et al., 2012 and Griffin et al., 2021 for reviews; see also Bennetto et al., 1996; Justus et al., 2021; Souchay et al., 2013). In contrast, semantic memory remains preserved across several tasks and stimuli types (e.g., Bowler et al., 2000; Carmo et al., 2016; 2017; 2020; Gaigg et al., 2013; 2015; Joseph et al., 2005; Meyer et al., 2014; Souchay et al., 2013; Souza et al., 2016; Toichi & Kamio, 2003).

The Remember-Know (R-K) paradigm is a classic memory retrieval task that enables a contrast between episodic and semantic memory performance. In this paradigm, after a study phase, participants are invited to retrieve the information (overall recognition) and subsequently to evaluate whether they remember, know or tried to guess their retrieval experience with the item ("phenomenological judgments"; see Tulving, 1985). Remember responses are episodic-like memories associated with vivid recollective experiences sustained by the hippocampus (Tulving, 2000; Yonelinas, 2010), while Know and Guess responses are driven by familiarity processes related to cortical engagement (Gardiner, 1988; Tulving, 1985; Yonelinas, 2010). In studies using the R-K paradigm, participants in the autistic spectrum have consistently shown diminished recollection together with a preserved or even enhanced, familiarity-based processing, regardless of stimulus type (e.g., Bowler et al., 2000; Gaigg et al., 2013; 2015; Meyer et al., 2014; Souchay et al., 2013). Gaigg et al. (2015) examined the selective retrieval mechanisms engaged by these two distinct memory-related processes as a function of the influence of relational encoding (i.e., associative learning of items and their semantic context) in autism. The results provided evidence of disparities in encoding episodic memories in ASD, with less engagement of the hippocampus and greater activation of Prefrontal Cortex (PFC) regions involved in relational demands for successfully encoded items. Moreover, individuals in the autism spectrum presented diminished recollection, associated with an absence of signal differentiation between recollection-based and familiarity-based trials in large PFC areas (middle and inferior frontal gyri), observed in their comparison group. This unusual PFC activity was attributed to a compensatory and more effortful memory encoding to overcome the reduced hippocampal binding strategies in autistic people.

Moreover, despite their preserved general semantic memory-related processes (Bowler et al., 2000; Carmo et al., 2016; 2017; Gaigg et al., 2013; 2015; Souza et al., 2016; Toichi & Kamio, 2003), autistic participants seem to present difficulties in semantic categorization (Carmo et al., 2016; Carmo et al., 2021 Gastgeb et al., 2006, but see Molesworth et al., 2005), namely in processing items that do not entirely fit the category-defining features (i.e., atypical items[1]). Autistic individuals also showed longer response times for processing atypical information (but not for typical) in categorization tasks than their comparison groups (Carmo et al., 2020; Gastgeb et al., 2006; Gastgeb & Strauss, 2012). These studies support the idea of semantic categorization decline in autistic participants that seems to be related to faulty encoding strategies during the relational binding of novel or atypical information with stored conceptual knowledge (such as category schemas).

The presence of complex associative conceptual knowledge, known as schemas, has been argued to assist and accelerate memory consolidation processes and improve retrieval of declarative memories for adaptative purposes (Tse et al., 2007 van Kesteren et al., 2013;

[1] Typicality refers to a semantic organization process reflecting how good an item is in representing its category. Typical items share the prototypical features of their categories (e.g., an apple in the Fruit category); atypical items present less fit with their categorical prototype (e.g., a dolphin is atypical in Mammals) (see Medin et al., 2007; Murphy & Medin, 1985; Rosch, 1978).

2014). However, recent studies with non-autistic participants have shown that the schema advantage seems to be selective for semantic memories (Mäntylä, 1997; Souza et al., 2021a). For example, Souza et al. (2021a) tested declarative memories of typically-developed (TD) participants using the R-K paradigm manipulated by encoding type (categorical vs. perceptual) and item-typicality (typical vs. atypical) in a visual recognition task. While schemas are generic representations, typicality reflects the likelihood of an item fitting its categorical prototype. Therefore, an atypical item activates the category prototype but does not entirely conform with it since it has more distinctive features. Their results showed that a categorical schematic encoding did not improve overall recognition and remember responses, while perceptual encoding did. Likewise, atypical items increased recollection-based memories, particularly in categorical encoding. These results are consistent with the idea of an engagement of the episodic system in case of novelty or when the item is inconsistent with the available prototype (see also Bonasia et al., 2016; Dudai et al., 2015; Yonelinas et al., 2010).

The current work is based on the assumption that the distinctive pattern of declarative memories in ASD rests on flaws in the episodic memory system, likely due to altered hippocampal functioning (Gaigg et al., 2015) and its interaction with cortical regions. Therefore, our primary goal was to explore the characteristic profile of declarative memories in ASD, seeking evidence of reduced episodic memory and their impact on semantic processing. Using the R-K paradigm manipulated by encoding type (categorical vs. perceptual) and item-typicality (high vs. low typical), we examined the influence of different types of conceptual knowledge (i.e., categorical schema activation and prototype activation) in recognition and related memory processes (Recollection vs. Familiarity). We expected to find an overall reduction of episodic memory in ASD participants compared to typically developing participants, reflected in lower accuracy and slower responses in overall recognition and recollective experience (Remember responses) but not in familiarity-based responses. Furthermore, we expected that such alleged differences in the episodic system would also impact the processing of item-typicality in ASD, namely by impairing the normal processing of atypical information (that has less fit with the categorical prototype), which has been shown to enhance overall recognition and recollection-based memories in non-autistic participants (Souza et al., 2021a; see also Dudai et al., 2015).

Methods

Participants

Fifteen male adults diagnosed with ASD (scoring > 70 points on the verbal subscale of Weschler Adult Intelligence Scale - WAIS) were matched with eighteen typically developed male participants in terms of age, education, and non-verbal general cognitive ability (see Table 1). The sample size was based on a prior neurocognitive study using the same paradigm and a similar sample (13 autistic and 13 typically developed participants; Gaigg et al., 2015). This study reported significant group differences across phenomenological judgments, $F(2,46) = 6.10$, $p < .001$, $\eta^2_p = .21$), namely lower remember judgments in ASD.

(INSERT TABLE 1 HERE)

Autistic participants were recruited with the collaboration of a specialized center for neurodevelopmental disorders. These participants had a clinical diagnosis provided by expert clinicians based on DSM-IV criteria (APA, 1994) and confirmed with a specific autism scale (ASDS-ASD; Myles et al., 2001).

Materials and procedures

The study was approved by the Ethics Committee of [Host], guided by the Declaration of Helsinki and other relevant documents in European legislation. All participants and their legal representatives were carefully informed of the participation conditions and signed the informed consent. The experiment was conducted in individual sessions at the laboratory of the [Host].

The task consisted of a R-K paradigm with visual stimuli (500 X 500 pixels images depicting common objects), manipulated by encoding type (categorical vs. perceptive) and item-typicality (typical vs. atypical) (see Souza et al., 2021a). The encoding phase included two different tasks, requiring more perceptive (complexity rating task) or more abstract (categorical sorting task) encoding. In the visual complexity rating task (in which perceptual details of the image are more relevant during encoding), participants were asked to rate, on a 4-point scale, how complex the image was. In the categories sorting task (in which categorical schematic knowledge is more relevant during encoding), participants had to indicate the best category to describe the item, using a 4-option forced-response corresponding to four different categories (e.g., vehicles, mammals). A brief pause (about 5min) was introduced between the rating and sorting blocks to avoid fatigue. During encoding, 160 images of common objects from eight different categories (i.e., birds, fruits, mammals, vegetables, vehicles, furniture, kitchen utensils, musical instruments, clothes) were presented. These images were selected based on previous ratings for typicality[2] (low: M = 4.75, SD = 0.01; high: M = 6.39, SD = 0.03, $t(158) = -16.14$, $p < .001$, $d_z = -1.280$, CI 90% [1.10, 1.45] see Figure 1 for examples) and controlled for relevant dimensions in common objects' processing such as arousal, valence, aesthetical appeal and visual complexity (all p's > .10; see Souza et al., 2020; 2021b). Each encoding task comprised 80 unrepeated items

[2] The items were selected from normative studies of concepts and their related pictures conducted with Portuguese samples (Santi et al., 2015; Souza et al, 2021b). The typicality ratings were obtained for items (displayed in a picture) representing specific basic concepts (e.g., penguin as less typical and cardinal as typical) within a specific superordinate category (e.g., birds).

equally distributed into four categories (counterbalanced across tasks). These items were equally distributed in two counterbalanced blocks across the two encoding conditions. The encoding conditions were counterbalanced across participants.

After a 20min retention interval, participants performed the retrieval phase. This phase consisted of a yes-no recognition task and subsequent phenomenological judgments. All encoded images (160 old items) were presented again together with 106 new images of common objects matched in the same criteria applied at encoding ($p > .10$). Participants saw an image (old or new item) and performed a recognition task (“did you see the item?” Yes/No). Whenever a “yes” response was given, participants were asked to provide a phenomenological judgment, indicating if they Remember (a recollective retrieval, based on vivid details about the experience), Know (based on a sense of familiarity), or Guess (an uncertainty feeling of having seen the item based on familiarity) the item, in a forced-choice response option (e.g., Gaigg et al., 2015; Mäntylä, 1997). At the end of the task, participants were thanked and debriefed.

Data analysis

Statistical analyses were conducted using mixed-effects regression models with R Version 4.0.2 (R Core Team, 2019), and the reported results are based on the best converging non-singular models. To favor the analysis’ generalizability, a model with a maximal random effects structure based on the design (see Barr et al., 2013 for further details) was used. If the “maximal” model failed to converge or was found to be overfitted, we simplified the random effects structure by removing random effects that were causing convergence or singular fit problems. The conceptual knowledge modulation on memory was subject to separate mixed-effects logistic regression models that considered overall recognition (correct vs. incorrect responses) and conscious retrieval judgments (recollection vs. familiarity responses) as dependent variables. Group (ASD vs. TD), encoding type (categorical vs. perceptive), item-typicality (typical vs. atypical), and their interaction were the main predictors. Holm-Bonferroni corrections were used as adjustment for multiple tests. Participants and items were considered as random effects. When appropriate, follow-up analyses were conducted to obtain simple effects. Additionally, a linear mixed-effects regression model (see Horchak & Garrido, 2020a; 2020b) used the same fixed and random effects for response times (RT) during overall recognition and conscious judgments. Outliers were trimmed based on participants' responses in the relevant condition for each group separately. First, trials shorter than 300ms or longer than 3000ms were removed. Second, trials with RTs 2.5 SDs or higher from the relevant condition means were discarded.

Results

Response time during Encoding

The mixed-effects model result for RTs (both perceptive and categorical conditions) and Accuracy (only in the categorical condition) during encoding showed that the only significant result was a main effect of group, ACC: estimate = −0.39, SE = 0.20, z = −1.97, p = .049, 95% CI [−0.78, 0.00]; RT: estimate = 91.17, SE = 25.55, t = 3.57, p = .002, 95% CI [41.08, 141.26], suggesting that autistic individuals were less accurate in their categorical appraisal (ASD: M = 0.90, SD = 0.30; TD: M = 0.95, SD = 0.21) and much slower in their overall responses (ASD: M = 915ms, SD = 529ms; TD: M = 729ms, SD = 418ms) than their controls. No other effects were significant (p> .600).

Overall Recognition Accuracy and Response Times

The overall recognition accuracy results of the mixed-effects logistic regression model showed a significant effect of group (*estimate* = −0.32, *SE* = 0.13, *z* = −2.40, *p* = .016, 95% CI [−0.58, −0.06]), with ASD group (*M* = 0.78, *SD* = 0.41) being less accurate than TD group (*M* = 0.85, *SD* = 0.35). As expected, the main effects of encoding type (perceptual: *M* = 0.87,

$SD = 0.33$; categorical: $M = 0.77$, $SD = 0.42$, $estimate = 0.44$, $SE = 0.07$, $z = 5.98$, $p < .001$, 95% CI [0.30, 0.59]) and item-typicality (low-typical: $M = 0.84$, $SD = 0.36$; high-typical: $M = 0.80$, $SD = 0.40$; $estimate = 0.17$, $SE = 0.07$, $z = 2.54$, $p = .011$, 95% CI [0.04, 0.31]) were significant. Finally, there was also a significant interaction between encoding type and item-typicality ($estimate = -0.12$, $SE = 0.04$, $z = -2.98$, $p = .003$, 95% CI [−0.20, −0.04]), as well as a trending interaction between item typicality and group ($estimate = -0.07$, $SE = 0.04$, $z = -1.81$, $p = .070$, 95% CI [−0.15, 0.01]). All other effects were not significant ($ps > .20$).

Follow-up analyses showed that the encoding type*item-typicality interaction was motivated by the higher accuracy for low-typical items (low-typical: $M = 0.81$, $SD = 0.39$; high-typical: $M = 0.73$, $SD = 0.45$; $estimate = 0.29$, $SE = 0.07$, z = 3.92, $p < .001$, 95% CI [0.15, 0.44]) during categorical encoding. However, no statistically significant difference was observed in perceptual encoding depending on item-typicality (high-typical: $M = 0.87$, $SD = 0.34$; low-typical: $M = 0.88$, $SD = 0.33$; $estimate = 0.04$, $SE = 0.08$, $z = 0.46$, $p = .646$, 95% CI [− 0.12, 0.20]). Follow-up analysis on the group*item-typicality interaction, showed that low-typical items ($M = 0.88$, $SD = 0.32$) were better recognized than high-typical items ($M = 0.83$, $SD = 0.38$) by TD participants ($estimate = 0.25$, SE = 0.08, z = 3.18, $p = .003$, 95% CI [0.10, 0.41]); an advantage that was not observed in the ASD group (low-typical: $M = 0.80$, $SD = 0.40$; high-typical: $M = 0.76$, $SD = 0.43$; $estimate = 0.13$, $SE = 0.08$, $z = 1.64$, $p = .101$, *95% CI* [−0.02, 0.28]) The results of major interest are presented in Figure 1 (a).

(INSERT FIGURE 1 HERE)

Because our omnibus analysis was performed considering both encoding conditions, we run a mixed-effects logistic regression model considering the categorical encoding condition only with item-typicality and group as predictors and Accuracy as a dependent variable. With this model, we look forward to disentangling the influence of item-typicality in categorical encoding from the influence of perceptual one (which would make sense since item-typicality are explicitly related to the categorical encoding) to further inspect the item-typicality effect at the group-level. Our outputs showed a significant effect of item-typicality (estimate = 0.29, SE = 0.07, z = 3.95, $p < .001$, 95% CI [0.15, 0.44]), reflecting the fact that low-typical items were recognized more accurately than high-typical items for both groups. Furthermore, there was a trending main effect of group (estimate = −0.26, SE = 0.15, z = −1.82, p = .069, 95% CI [−0.55, 0.02]), suggesting that autistic participants were less accurate than TD participants. Although the main effects emerged in the same direction presented in our robust model, there was no evidence for an interaction between typicality and group as well (estimate = −0.03, SE = 0.05, z = −0.55, p = .583, 95% CI [−0.13, 0.07]). So, no group-level differences were detected for recognition performance of categorically-encoded in function of the item-typicality. Therefore, in despite of showing decreased recognition over all conditions, the advantage of low-typicality was observed in autistic individuals as well.

The RTs results of the mixed-effects linear regression model showed a significant effect of group (*estimate* = 100.55, SE = 27.97, t = 3.60, $p < .001$, 95% CI [45.73, 155.37]), with autistic participants being much slower (M = 746, SD = 474) in their recognition responses than TD participants (M = 566, SD = 334). In addition, there was a main effect of encoding type (perceptual: M = 625, SD = 391; categorical: M = 673, SD = 436; *estimate* = − 29.53, SE = 10.22, t = − 2.89, p = .007, 95% CI [−49.56, −9.50]) and a trending main effect of item-typicality (low-typical: M = 635, SD = 411; high-typical: M = 661, SD = 415; *estimate* = − 13.88, SE = 7.46, t = − 1.86, p = .064, 95% CI [− 28.49, 0.73]). Finally, there was a significant interaction between encoding type and item-typicality (*estimate* = 15.41, SE = 7.07, t = 2.18, p = .030, 95% CI [1.54, 29.27]), as well as between encoding type and group (*estimate* = −26.24, SE = 10.22, t = −2.57, p = .016, 95% CI [−46.27, −6.22]). Other effects were not significant (ps > .20).

For a better understanding of those interactions, we performed follow-up analyses. As shown in Figure 1 (b), the encoding type*item-typicality interaction was motivated by the faster processing associated to correctly recognized low-typical items (*M* = 643, *SD* = 421) comparatively to high-typical items (*M* = 706, *SD* = 448) during categorical encoding (*estimate* = − 30.49, *SE* = 10.43, *t* = − 2.92, *p* = .007, 95% CI [−50.94, −10.05]). In contrast, no difference was observed for perceptual encoding (high-typical: *M* = 623, *SD* = 380; low-typical: *M* = 627, *SD* = 402; *estimate* = 1.21, *SE* = 10.04, *t* = 0.120, *p* = .904, 95% CI [−18.48, 20.90]). With regards to the group factor, autistic individuals were faster in correctly recognizing items during perceptual encoding (*M* = 700, *SD* = 436), as compared to categorical (*M* = 797, *SD* = 508; *estimate* = − 55.63, *SE* = 15.14, *t* = − 3.67, *p* = .001, 95% CI [−85.30, −25.95]). However, no significant differences were found for TD participants (perceptual: *M* = 560, *SD* = 335; categorical: *M* = 571, *SD* = 333; *estimate* = − 2.78, *SE* = 13.87, *t* = − 0.20, *p* = .841, 95% CI [−29.95, 24.40]).

Conscious Retrieval judgments (probability and RTs)

The models for conscious retrieval judgments were run with the same fixed and random factors used for overall accuracy. Results did not reveal any significant differences between groups (*p* > .400) for the probability of providing a Recollection-based judgment (vs. Familiarity). However, visual inspection of the data (see Figure 2) suggested relevant group differences. Further examination revealed that the performance of autistic individuals was variable, and thereby could have contributed to mask the effects. Using the same fixed effects and random intercept for items only, the simplified model showed a main effect of group (*estimate* = −0.22, *SE* = 0.03, *z* = −6.43, *p* < .001, 95% CI [−0.28, −0.15]) in that the autistic participants provided significantly less Recollection-based judgments (64%) than TD participants (73%). Furthermore, there were significant main effects of encoding type (perceptual: 73%; categorical: 64%; *estimate* = 0.20, *SE* = 0.03, *z* = 5.95, *p* < .001, 95% CI

[0.13, 0.27]) and item-typicality conditions (low-typical: 73%; high-typical: 64%; *estimate* = 0.23, *SE* = 0.04, *z* = 5.35, *p* < .001, 95% CI [0.14, 0.31]), influencing Recollection-based judgments in the same direction as reported for overall recognition. Finally, there was a significant interaction between encoding type and item typicality (*estimate* = −0.08, *SE* = 0.03, *z* = −2.23, *p* = .026, 95% CI [−0.14, −0.01]). Follow-up analyses showed that the interaction effect was motivated by the influence of perceptual encoding in increasing the probability of "Recollection" in both low-typical (perceptual: 75%; categorical: 71%; *estimate* = 0.15, *SE* = 0.07, *z* = 2.14, *p* = .003, 95% CI [0.01, 0.29]) and high-typical items (perceptual: 70%; categorical: 57%; *estimate* = 0.34, *SE* = 0.07, *z* = 4.93, *p* < .001, 95% CI [0.21, 0.48]). No other interaction effects were significant (ps > .200).

(INSERT FIGURE 2 HERE)

Two separated models were run for RTs in Recollection-based judgments (Remember responses) and Familiarity responses (Know and Guess). For these analyses, RTs faster than 150ms and RTs slower than 3 SDs from the relevant condition means in each group were discarded. The results of the best converging mixed-effects regression model for "Recollection" showed that there was a trending main effect of group, indicating that ASD group provided slower recollective-based judgments than their comparison group (ASD: *M* = 718, *SD* = 465; TD: *M* = 571, *SD* = 357; *estimate* = 93.47, *SE* = 51.61, *t* = 1.81, *p* = .080, 95% CI [−7.68, 194.61]). No other effects were significant. With regards to "Familiarity", the only significant effect was a 3-way interaction between encoding type, item-typicality, and group (*estimate* = −28.18, *SE* = 12.71, *t* = −2.22, *p* = .027, 95% CI [−53.09, −3.26]). To get sense of this interaction, we tested the significance of a 2-way interaction between encoding type and item typicality at each level of group factor. The results showed a marginally significant interaction between encoding type and item typicality for ASD (*estimate* =

−32.89, *SE* = 17.71, $t = -1.86$, $p = .064$, 95% CI [−67.60, −1.83]), but not for TD (*estimate* = 23.47, *SE* = 18.24, $t = 1.29$, $p = .198$, 95% CI [−12.28, −59.21]). However, follow-up analyses did not reveal any significant results (all *p's* > .180).

False alarms rates

The analysis of the false alarms (New items considered Old) inspected their overall occurrence as well as their incidence according to recollection-based judgments by comparing ASD and TD samples. The RTs were not considered for analysis since participants´ high performance in the task limited the number of false alarms necessary for further interpretations. The results showed that the overall incidence of false alarms was small and similar in both groups (M_{ASD}= 6.58%, SE_{ASD}= .99; M_{TD}= 6.55%, SE_{TD}= 1.1; $t(31)$= .021, p= .983). The further inspection of incidence of false alarms in recollection-based judgments using mixed-effects models showed no main effect of group (estimate = −1.80, SE = 0.52, $z = 0.17$, $p = .869$, *95% CI* [−0.84, 0.99]). These results indicate no significant differences between the groups in false alarm responses when providing more Familiarity than Recollection judgments.

Discussion

While impaired episodic memory performance has often been observed in ASD, it remains debatable whether this decline also affects semantic memory and its processes (Carmo et al., 2016; Gastgeb et al., 2006; Souza et al., 2016; Toichi, 2008; Toichi & Kamio, 2002; 2003, but see Carmo et al., 2017; Molesworth et al., 2005). As recently demonstrated, episodic and semantic memory systems continue to interact despite becoming structurally and functionally dissociated with time and accumulated experience (de Mendonça et al., 2021; Nadel & Moscovitch, 1997; Winocur et al., 2010; Winocur & Moscovitch, 2011). Therefore, impairments in the episodic memory system in ASD are likely to affect the learning, processing, and retrieval of semantic-like memories.

The current study explored this hypothesis by inspecting performance patterns in autistic individuals and their TD comparison group with regard to both declarative memory types within a Remember-Know paradigm. We hypothesized that autistic people would present a decline in overall recognition together with a decline in recollection-based memories but not for familiarity-based memories when compared to TD participants. We also inspected the role of stored conceptual knowledge availability at encoding in predicting memory retrieval. Since the episodic memory system is likely disrupted in autism, we expected to find no gains in episodic memory performance (recollection-based "remember responses") for perceptually encoded items in autistic individuals. Likewise, we did not expect autistic individuals to benefit from low-typical information to improve overall recognition and recollective-based memories (see Souza et al., 2021a), given the potential contribution of the episodic memory system and its interaction with the semantic system for the processing of unfitted information (see Bonasia et al., 2016; Dudai et al., 2015).

Overall, the main effects of encoding type and item-typicality as well as of the encoding type*item-typicality interaction replicated previous results (Souza et al., 2021a). Specifically, the observed gains in recognizing low-typical items only in categorical encoding reflect the enhancement of episodic memories in case of violation/novelty conditions (see Dudai et al., 2015; Souza et al., 2021a).

Regarding group differences, our results showed, as expected, that overall recognition in ASD was less accurate and slower than that of TD controls, thus replicating previous reports of moderate episodic memory decline in ASD (e.g., Gaigg et al., 2015; Meyer et al., 2014). Moreover, we found a lower production of recollective-based memories in ASD, while familiarity-based memories were preserved. These results indicate that when memories are dissociated from the contextual traits by which they were formed (context-free or abstract memories), retrieval seems to be preserved in ASD. Previous studies had already shown that, in the autism spectrum, people do not have the distinct neural patterns for Recollection compared to Familiarity memories described in their comparison subjects (Gaigg et al., 2015). Together with the worse overall recognition observed in autistic participants, the pattern of reduced recollection memories and preserved familiarity memories suggests that the episodic memory system might be responsible for the flaws observed in declarative memory retrieval. False alarm results were also congruent with the episodic memory constraints of such a clinical group (see Bowler et al., 2011; Gaigg et al., 2015), but further studies should be designed to address specific measures of false alarms. Likewise, the preserved general semantic memory functioning is compatible with previous studies (e.g., Bowler et al., 2000; Gaigg et al., 2013; 2015; Toichi & Kamio, 2003), indicating that this clinical group has access to stored semantic information during learning (Carmo et al., 2016; Gaigg et al., 2015).

Interestingly, and contrary to our expectations, autistic participants showed an advantage of perceptual encoding during recognition and conscious recollection as observed in TDs, despite their reduced performance in episodic memory. Although not consistent with the anticipated fully compromised episodic memory system, also documented in previous studies, this finding suggests that the autistic group has at least some access to their episodic system that is required to process contextually rich perceptual details (Sekeres et al., 2018).

Regarding item-typicality processing, autistic participants were, as expected, less competent in using low-typical information to enhance recognition, as TDs did (as in Alves & Raposo, 2015; Carmo et al., 2016; Gastgeb et al., 2006; Souza et al., 2021a). Low-fit information violates the stored prototypical representation activated and is likely to recruit more episodic and semantic memory systems interaction in processing novelty or inconsistencies with prior knowledge (see Bonasia et al., 2018; Dudai et al., 2015; Yonelinas et al., 2010). The improved recognition of atypical information appears to rest on an increased engagement of hippocampal structures and its connectivity with cortical regions (Nadel & Moscovitch, 1997; Sekeres et al., 2018; Yonelinas et al., 2010, 2019), a process that may be less efficient in ASD (see Gaigg et al., 2015). Nevertheless, the further inspection of item-typicality modulation in categorical encoding only raises the possibility that the atypical information (as part of semantic organization inherent to categorical learning processing; see Medin et al., 2007) exert a selective influence in the explicit coding of categorical knowledge. Or, it could be plausible that the overall deficitary episodic memory is playing a crucial role in masking item-typicality effect at the autistic sample at the whole data. Anyways, it appears that the putative disturbances in the episodic memory system in ASD are interfering in the process of binding novel incoming information that does not entirely fit the previously available stored concepts (see Sekeres et al., 2018), thus diminishing the probability of their successful recognition. According to the Schema Modification Theory (SMT), previous schemas can interact with newly acquired traits to accelerate episodic learning and facilitate future retrieval (Tse et al., 2007; Van Kesteren et al., 2013; 2014). Such relational encoding has been shown to be disturbed in ASD by Gaigg and colleagues (2015). They also found that autistic people recruit compensatory neural resources (specifically, regions in the inferior prefrontal cortex) to overcome their neurodiverse episodic memory system (as reflected in attenuated hippocampal engagement).

Contrary to what we expected, we did not find relevant group differences regarding an effect on RTs of possible interactions between item-typicality and encoding type. In contrast, prior studies observed a distinctive organization of typicality information in ASD (see also Carmo et al., 2016; Gastgeb et al., 2006), namely a more effortful encoding strategy for low-typical items (Gastgeb et al., 2006). Nonetheless, those discrepant findings may reflect differences in task demands between our and other studies using different tasks (Carmo et al., 2020; Gastgeb et al., 2006; Gastgeb & Strauss, 2012).

Overall, the current findings indicate a reduced performance in recognition and, notably, a different pattern of self-related and vivid recollective memories but not in familiarity-based (context-free) conscious memory in ASD. Such dissociation between Recollection and Familiarity memory processes suggests that the atypical pattern of overall recognition observed in autistic individuals might arise from differences in episodic memory processes. Notably, the (partial) absence of item-typicality advantage for recognition in the clinical sample is attributed to their inability to engage the episodic memory system during specific semantic processing. This finding converges with the interdependence between declarative memory systems and confirms the involvement of episodic memory systems in specific semantic memory processes (see Souza et al., 2021a). These findings also suggest inefficient processing of the semantic system in ASD (at least in the perceptual encoding) for information that does not fit the available schematic knowledge (Dudai et al., 2015; Sekeres et al., 2018). Therefore, episodic memory systems in autistic persons seem to be compromised in a manner that affects the processing of conceptual information that does not fit with prior knowledge, reflecting the complex declarative memories dynamics (see also Dudai et al., 2015; Sekeres et al., 2018). This pattern is likely to rest on an anomalous interaction between a preserved semantic system and/or a fragile and dysfunctional episodic memory system.

Research focusing on episodic recollection in autism has increased recently, although the diversity of methodologies and approaches still represents an obstacle for substantial consistency across findings (see Cooper & Simons, 2018). The present work used a classic and well-explored task applied in prior relevant memory studies in autism (e.g., Bowler et al., 2000; Gaigg et al., 2015). However, the dependence between Remember and Know judgments associated with the disparate number of trials by condition characteristic of this task (higher Remember responses) might mask the expected interaction effects. To surpass this issue, we used robust statistical analyses and the combination of Know-Guess responses to compose the Familiarity condition. This combination was motivated by the familiarity-based nature of both judgments (see Gardiner et al., 1998) as well as by the similar pattern of results observed between them. Future studies who want to balance the number of remember and know judgments and reduce their dependency should try to circumvent this issue by, for example, increasing the retention interval up to 24h, since this appears to decrease recollection-based memories (Gardiner & Java, 1991; Meier et al., 2013). Another possibility is to use an adaptation of the Remember-Know task that allows disentangling familiarity and recollection judgments (e.g., requesting them alternately or in blocks) without losing its dual-process perspective (see Yonelinas 2002; Yonelinas et al., 2010). Given the potentially challenging introspective nature of this task (particularly for ASD participants), we tried to ensure the quality of these judgments (i.e., actually reflecting recollective vs. familiarity processes) by providing explanations and examples of the type of judgment required in each category during the instructions and training phases. While the percentage of correct responses provides a good indicator that participants (in both groups) were able to complete the task, a qualitative measure would be desirable to confirm the quality of these judgments (see Gardiner, 1998). However, the number of trials used in the current paradigm would render this task unfeasible (i.e., length, tiredness), particularly for the participants in the clinical sample.

Another potential concern of the current study is the reduced sample size. While small sample sizes are common in studying underrepresented clinical samples (see Bowler et al., 2000; Gaigg et al., 2015; Molesworth et al., 2005 for some examples in samples diagnosed with ASD), they might lead to underpowered studies, particularly when considering the variability expected in ASD (Geurts et al., 2008). In the current study, we tried to circumvent this issue by adopting a mixed-effects model analysis on unaggregated data in an attempt to enhance the statistical power and reduce the Type 1 error (Barr et al., 2013).

Additionally, our sample included male participants only. While the prevalence of diagnosed cases is much higher in males than females (Giarelli et al., 2010), there seems to be a male bias in diagnosis criteria and assessment measures. Consequently, the number of females within the autism spectrum may be underrepresented. Moreover, there are reasons to believe that, at least to some extent, they might differ from males in their cognitive, social, and adaptative skills (Frazier et al., 2014; Zwaigenbaum et al., 2012). These differences may also be manifested in memory abilities. Our sample composition does not uncover such potential differences that should be addressed in future studies.

Despite these limitations, the current findings confirm that the characteristic profile of declarative memory in ASD derives from episodic memory constraints, which likely motivate flaws in semantic retrieval in specific circumstances. The current findings are also relevant for better understanding the interdependency between declarative memory systems, particularly the characteristic memory profile found in Autism. Further studies are needed to better explore the neural correlates of these two memory systems and their interaction in TD and ASD group samples. In particular, it is important to confirm the fundamental role of the hippocampus-dependent system and its connectivity with other regions in the formation and retrieval of long-term memories. Finally, the present findings showed that information less compatible with stored knowledge proved to be helpful in enhancing and likely re-instantiating memories, depending on their nature, for further actualization or modification purposes (see also Nadel, 2020). These findings may usefully inform clinical interventions and the implementation of enhancing learning contexts where schematic information is currently emphasized as a strategy for better outcomes.

Supporting information

The data files and supplementary modeling information is available at Open Science Framework (OSF) through the link <https://osf.io/w349g/?view_only=ea93784f295f49959e671caab6fa0154>.

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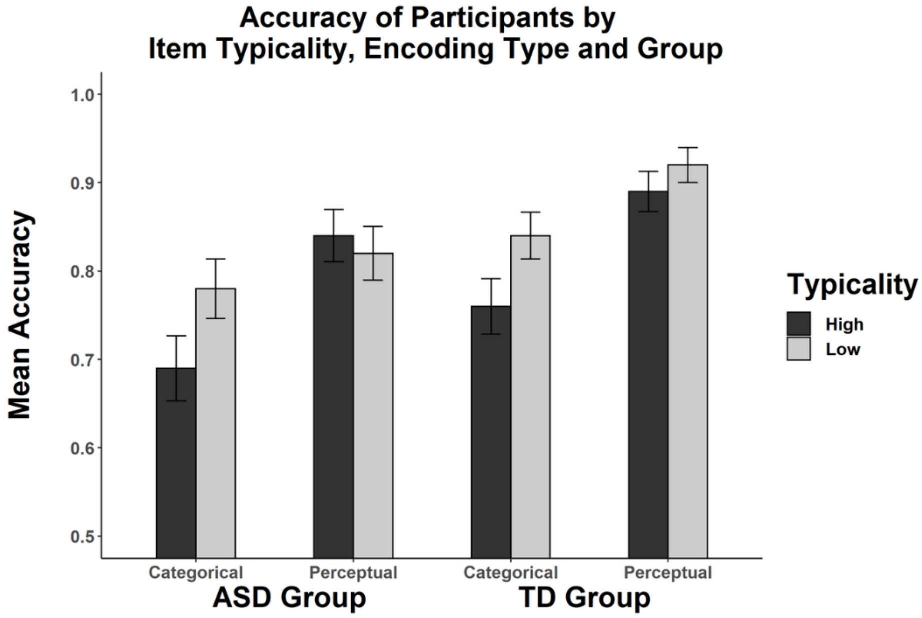
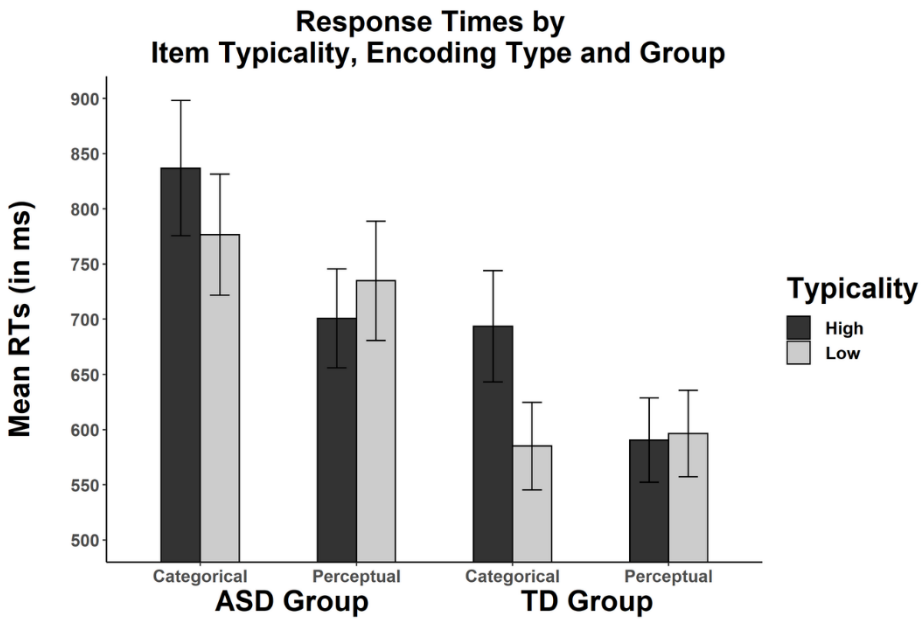
Figures

Figure 1 Participants' mean accuracy (a) and RTs (b) as a function of group, encoding type, and item-typicality

(a)

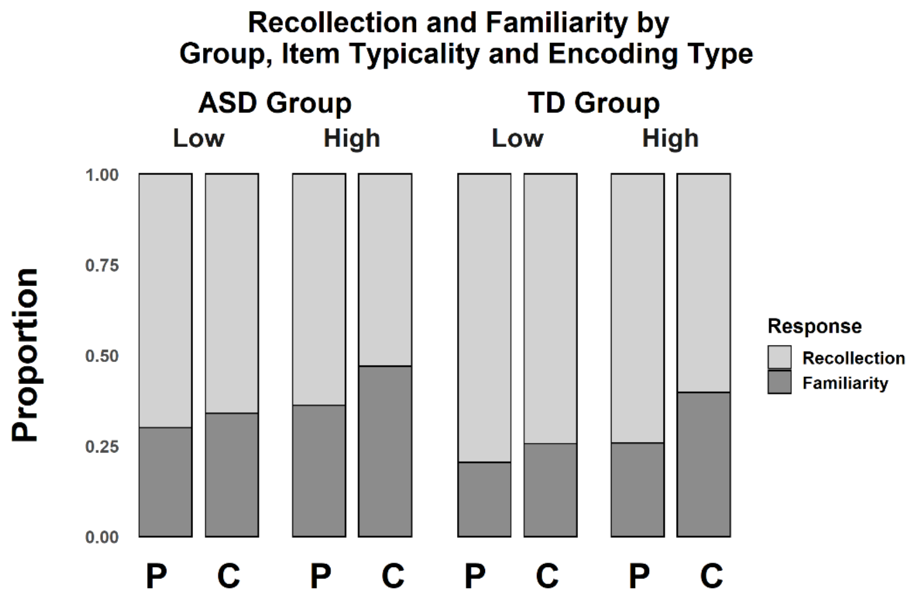


(b)



Note: Low (typicality) High (typicality); P (perceptual encoding); C (categorical encoding); Columns refer to means and error-bars to standard errors.

Figure 2 Proportion of judgment based on recollection and familiarity in ASD and TD groups as a function of encoding type and item-typicality



Note: Low (typicality) High (typicality); P (perceptual encoding); C (categorical encoding); Columns refer to mean proportions.

Tables

Table 1 Sample characteristics

		ASD	***TD***	*Group differences*
	N	15	18	
Age (in years)	*M*	29.93	33.94	*t*(31) = -1.373
	SD	5.98	9.90	*p* = .180
Schooling (in years)	*M*	14.4	15.17	*t*(31) = -.990
	SD	2.38	2.07	*p* = .330
Non-verbal intelligence (RAVEN raw score)*	*M*	50.33	51.78	*t*(31)=-.620
	SD	8.28	4.97	*p* = .540
Verbal IQ	*M*	105.95		
(WAIS quotient)	*SD*	13.87		
Diagnostic	*M*	101.51		
(ASDS-ASD score)	*SD*	9.71		

Note: ASD – refers to the group of participants within the Autism Spectrum Disorder; TD – indicates the non-clinical typically developed participants; IQ – Intelligence Quotient; RAVEN – Raven´s Progressive matrices; WAIS - Wechsler Adult Intelligence Scale (WAIS-IV); ASDS-ASD - Asperger Syndrome Diagnostic Scale.

**Standard raw score for RAVEN range: 0-60 correct responses; standards for high education (>12 years) and age 30-39 years-old: M= 47.91; SD= +/- 8.99 (Queiroz-Garcia et al., 2021).*