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Positive effect of visual cuing in episodic memory and episodic future thinking in adolescents with autism spectrum disorder

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15 **Keywords:** autobiographical memory, episodic memory, visual cues, sensory details,
16 **autism**

17 **Abstract** (*words: 154/350*)

18 Cognitive studies generally report impaired autobiographical memory in individuals with
19 autism spectrum disorder (ASD), but mostly using verbal paradigms. In the present study, we
20 therefore investigated the properties of both past and future autobiographical productions

21 using visual cues in 16 boys with ASD and 16 typically developing (TD) participants aged
22 between 10-18 years. We focused on sensory properties, emotional properties, and
23 recollection, probing past and future productions for both near and distant time periods.
24 Results showed that the ASD group performed more poorly than controls on free recall for
25 recent periods, but performed like them when provided with visual cues. In addition, the ASD
26 group reported fewer sensory details than controls and exhibited difficulties in the experience
27 of recollection for the most remote events. These data suggest a combination of consolidation
28 and binding deficits. Finally, our findings reveal the relevance of using visual cues to probe
29 autobiographical memory, with possible perspectives for memory rehabilitation.

30

31 *Word count: 5877/12000*

32 *4 tables and 2 figures*

33 1 Introduction

34 Autism spectrum disorder (ASD) is a neurodevelopmental disorder, characterized by
35 deficits in social communication, with restricted and repetitive behaviors. There is growing
36 evidence that people with ASD have atypical memory functioning (Bowler, et al., 1997), even
37 if their language skills are intact. Difficulties include, among others, impairment of
38 autobiographical memory (AM). AM is a very long-term memory of personal knowledge and
39 events related to individuals' own lives that are accumulated from a very early age. AM
40 allows individuals to build an identity based on a feeling of continuity (Bon, et al., 2012;
41 Conway, 2005).

42 Current cognitive models of AM distinguish between a semantic component pertaining
43 to general personal knowledge or facts, and an episodic component relating to personal
44 events. This episodic component relies on the ability to remember past experiences (i.e.
45 episodic autobiographical memories) and to imagine possible future experiences (episodic
46 future thinking) (Tulving, 1985). Both episodic memories and projections involve auto-
47 noetic consciousness, namely the ability to project our states of self into the past, present or future to
48 maintain self-continuity. This mental time travel allows individuals to re- or pre-experience
49 personal events associated with their original context, giving individuals a feeling of (re)living
50 these events. To evoke episodic events, sufficient phenomenological details (i.e. feelings,
51 emotions, sensory details such as colors, sounds, smells, tactile feelings) must be stored in
52 memory, as they serve as retrieval cues. More specifically, episodic future thinking or
53 projection involves imagining oneself in the future to *pre-experience* a possible scenario
54 (Atance & O'Neill, 2005). This projection is supported in part by episodic memory oriented
55 toward the past (Suddendorf & Corballis, 1997; Wheeler, et al., 1997). Moreover,
56 remembered personal events and envisioned future plans have been found to share a common
57 brain network (D'Argembeau, 2015; Viard, et al., 2011). This network is thought to support

58 common constructive thought processes that allow for the retrieval and flexible combination
59 of stored information to reconstruct past experiences and construct novel future ones. Besides
60 constructive and executive processes, AM involves a broad range of cognitive processes,
61 ranging from perception (Hopkin, 2004) to more integrative processes. Some of these are
62 preferentially related to the self (self-concept: Howe & Courage, 1997; theory of mind: Perner
63 & Ruffman, 1995; Welch-Ross, 1997) and social events (Nelson, 1993), while others refer to
64 narrative abilities (Kleinknecht & Beike, 2004). Hence, the maturation of these cognitive
65 processes during childhood and adolescence supports AM development (Bauer, et al., 2007;
66 Nelson & Fivush, 2004; Picard, et al., 2009; Piolino, et al., 2007).

67 In ASD, both children and adults produce fewer specific memories and projections,
68 characterized by reduced specificity, elaboration and episodic coherence. The content of these
69 memories is also more semantic (e.g. general or repeated event) than episodic (Bon, et al.,
70 2012; Crane, et al., 2013; Crane, et al., 2012; Goddard, et al., 2014; McDonnell, Valentino, &
71 Diehl, 2017; Terrett, et al., 2013). Ciaramelli, et al. (2018) recently reported that providing a
72 series of standardized questions (e.g., “Where did this event take place”) does not seem to
73 increase performance, either for past recollection or for future thinking. Similarly, difficulty
74 retrieving specific memories is observed in children and adolescents with ASD, with poorer
75 access to the remote past (8- to 17-year-olds; Goddard, et al., 2014), and impaired episodic
76 future thinking (8- to 12-year-olds; Terrett, et al., 2013). Children with ASD also have greater
77 difficulty recalling their own activities than typically developing (TD) children (Millward, et
78 al., 2000). However, differences may be observed between children and adults with ASD. For
79 example, discourse analysis has shown that children with ASD aged 6-14 years produce fewer
80 past narrative details, as well as fewer emotional (e.g., *happy*, *scared*), cognitive (e.g.,
81 *thought*, *believed*) and sensory (e.g., *seen*, *heard*) terms than TD children (Brown, et al.,
82 2012). This difference is more pronounced for remote life events than for recent ones for

83 children aged 5-17 years (Brown, et al., 2012; Bruck, et al., 2007; Goddard, et al., 2014) or
84 future thinking (Terrett, et al., 2013). On the contrary, results obtained in adults show that
85 sensory references are more frequent in ASD than in TD for self-defining memories (Crane, et
86 al., 2010) and early childhood events (Zamoscik, et al., 2016). Hence, some sensory details
87 may be more salient than other features and contribute to the structure of AM in adulthood.
88 This heterogeneity highlights the importance of exploring changes between childhood and
89 adulthood, by focusing on the adolescence period.

90 The impairment of AM in ASD can be interpreted according to different cognitive
91 theories. First, the theory of mind deficit resulting in difficulty recognizing one's own
92 psychological states and understanding of the self (Williams, 2010) may impact the narration
93 of episodic events (Goldman, 2008; Kristen, Rossman, & Sodian, 2014; Losh & Capps, 2003;
94 McCabe, Hillier, & Shapiro, 2013). Second, a detail-focused perceptual style, which refers to
95 perception theory, or the *weak central coherence* evoked by Happé and Frith (2006), may also
96 have a significant impact on the properties of autobiographical memories. Temple Grandin, a
97 woman with high functioning ASD, reported in her 2006 book *Thinking in Pictures* that the
98 visual modality is ubiquitous in her daily life:

99 "I translate both spoken and written word into full-color movies, complete with sound,
100 which run like a VCR tape in my head... [I] see the words in pictures ... I have a
101 video library... When I recall something I have learned, I replay the video in my
102 imagination. The videos in my memory are always specific ... My imagination works
103 like the computer graphics programs ... When I do an equipment simulation in my
104 imagination or work on an engineering problem, it is like seeing it on a videotape in
105 my mind. I can view it from any angle, placing myself above or below the equipment
106 and rotating it at the same time... I create new images all the time by taking many
107 little parts of images I have in the video library in my imagination and piecing them

108 together... Unlike those of most people, my thoughts move from video-like, specific
109 images to generalization and concepts. For example, my concept of dogs is
110 inextricably linked to every dog I've ever known. It's as if I have a card catalog of
111 dogs I have seen, complete with pictures, which continually grows as I add more
112 examples to my video library.”

113 She describes her visual memory as a collection of personal *photographs* of her own
114 life, which has a direct impact on the formation of visual representations of semantic
115 concepts. Moreover, she is able to take different perspectives but, as suggested by her
116 testimony, these tend to be field perspectives with egocentric navigation. This was
117 experimentally corroborated by Ring, et al. in a recent paper published in 2018. Hence, visual
118 autobiographical memories may be very specific and detailed but more fixed than those of TD
119 people.

120 Third, the AM deficit in ASD may result from difficulty mentally assembling the
121 details that form the experience (e.g. *episodic simulation*; Schacter, et al., 2012) and
122 elaborating the context of this experience (e.g. *scene construction*; Hassabis & Maguire,
123 2007). Scene construction relies on visual imagery-which involves the mental generation and
124 maintenance of a single element-and the binding of all the properties of the event (e.g.,
125 objective and subjective details). Poorer scene construction is consistent with the impaired
126 binding processes observed in ASD (Bowler, et al., 2011; Lind, et al., 2014).

127 Most studies reporting difficulties with AM were conducted using verbal paradigms
128 that elicit narrative abilities (Crane & Goddard, 2008; Crane, et al., 2009; Crane, et al., 2012;
129 Goddard, et al., 2007). Since these narrative abilities are impaired in ASD, solely using
130 language to investigate AM may bias the assessment of memory properties. Most of the
131 studies that have reported an AM impairment in ASD used questionnaires or a fluency task.
132 However, individuals with ASD performed just as well as controls when other methodologies

133 were used. No differences were observed with the use of a sentence completion test that
134 indexes memory retrieval (Crane, Lind, & Bowler, 2013), or yes-no questions (Bruck, et al.,
135 2007), when the recall test was written rather than oral (Crane, et al., 2012) or when the cue
136 words were high in imageability (e.g., *letter vs. permission*) (Crane, et al., 2012). All these
137 tasks provide cues or support at retrieval. These observations are in line with the *task support*
138 *hypothesis* that emphasizes the role of retrieval support in improving AM productions
139 (Bowler, et al., 2004).

140 Hence, and as suggested by Temple Grandin's testimony, pictures could be a valuable
141 tool for studying AM, by providing a visual aid to overcome the language constraints
142 associated with the free recall paradigm. Therefore, pictures would constitute a more
143 appropriate mean of testing the properties of episodic memories in ASD. In addition, these
144 visual supports would provide an opportunity to test different kinds of properties, including
145 sensory details, and investigate the possible impact on AM of the impairments in sensory
146 processing observed in ASD (Stevenson, et al., 2014).

147 The main aim of the present study was to investigate the properties of episodic
148 memories and future thinking in high-functioning adolescents with ASD using visual cues.
149 We focused on the sensory and emotional properties and the quality of the experience of
150 recollection associated with autobiographical productions for four time periods: two in the
151 past (i.e. yesterday and last summer vacation) and two in the future (i.e. tomorrow and next
152 summer vacation). First, given the known retrieval deficit in ASD and possible difficulties in
153 scene construction, we predicted that free recall performance would be impaired, but
154 performance would normalize when visual cues were provided. We added a general
155 neuropsychological assessment focusing on cognitive functions involved in AM retrieval, i.e.
156 executive functions, short-term memory and verbal episodic memory, to discuss our results.
157 Based on the cognitive profile of ASD, we expected to find baseline differences in verbal

158 episodic memory, planning and short-term memory. Second, given the perceptual bias
159 reported in ASD (Mottron, et al., 2003) and the frequent references to sensory details reported
160 by adults with ASD (Crane, et al., 2010), we predicted that participants would exhibit an
161 atypical pattern of performance concerning sensory properties, with a probable focus on some
162 perceptual modalities to the detriment of others. Third, given the well-known difficulty with
163 emotion processing and reduced recollection capacity in ASD (Gaigg, 2012), we expected
164 participants to perform poorly on emotion and recollection assessment.

165 2 **Material and Methods**

166 2.1 **Participants**

167 Participants were 16 boys aged 10-18 years (mean = 13.4 years, $SD = 2.4$) (Table 1).
168 They were recruited through autism resource centers in Caen and Tours in France. The
169 recruitment started prior to the 2013 publication of DSM5, hence participants had all been
170 diagnosed with verbally and intellectually high-functioning autism or Asperger's syndrome
171 according to DSM-IV (American Psychiatric Association, 2000) criteria. The diagnosis was
172 established by experienced professionals using the Autism Diagnostic Interview-Revised
173 (ADI-R; Lord, et al., 1994) and/or Autism Diagnostic Observation Schedule (ADOS; Lord, et
174 al., 1989). The ADI-R is a detailed semi-structured interview of parents about their child's
175 developmental history and autism symptoms that yields ratings for reciprocal social
176 interaction, language and communication, and restricted repetitive behaviors. The ADOS is
177 also a semi-structured interview and is a standardized assessment of social interaction,
178 communication, play and imaginative use of materials. Participants with ASD were compared
179 with 16 TD controls matched for age, sex, and scores on the Perceptual Reasoning Index
180 (PRI) and Verbal Comprehension Index (VCI) of the fourth version of the Wechsler
181 Intelligence Scale for Children (WISC-IV; Wechsler, 2005). These two indices were

182 calculated according to performances on four WISC-IV subtests: Block Design and Matrices
183 for PRI, and Vocabulary and Similarities for VCI. They allowed us to ensure that participants
184 had no general impairment of language comprehension or perceptual abilities. TD adolescents
185 were recruited from several French schools. Brief interviews ensured that none of the
186 participants met the exclusion criteria: history of previous neurological disorders or
187 psychiatric illness (other than ASD in the ASD group), a first-degree relative with ASD in the
188 TD group, head trauma, current psychoactive medication, intellectual disability, and learning
189 disabilities. Families were given a comprehensive description of the research. The study was
190 approved by the relevant ethic committees, and written consent was obtained from all the
191 participants (or their parents, in the case of minors), in line with committee guidelines.

192 **2.2 General cognitive assessment**

193 Each child also underwent a neuropsychological assessment focusing on the cognitive
194 abilities involved in AM production (Picard, et al., 2009). This assessment included tests of
195 five executive and memory functions: inhibition (Stroop test; Albaret & Migliore, 1999),
196 planning (Tower of London; Lussier, et al., 1998), verbal short-term memory (forward digit
197 span, WISC), visuospatial short-term memory (Forward Corsi blocks; Pagulayan, et al.,
198 2006), and verbal episodic memory (story recall from Children's Memory Scale; Cohen,
199 2001). Picard, et al. (2009) found that these cognitive abilities were involved in the production
200 of autobiographical memories in childhood (6-11 years).

201 Finally, all participants underwent a brief investigation of personal semantic
202 knowledge, in order to exclude a possible major deficit that might interfere with the AM task.
203 This consisted of a questionnaire coupled with visual cues about general personal information
204 on three different topics, adapted from Piolino, et al. (2007)'s methodology. Questions

205 concerned acquaintances, school life, and personally relevant famous names (e.g. heroes,
206 stars, etc.). The maximum score was 6 for each of these categories.

207 2.3 From Past to Future Task

208 This task explored specific past personal events and future thinking for the day before
209 (recent past), last summer vacation (remote past), next day (near future) and forthcoming
210 summer vacation (distant future). For each period, visual cues were provided to support
211 production (Fig. 1). All responses were directly manually transcribed by the interviewer. The
212 interviewer had a grid for coding each personal event that was reported (free recall and cued
213 recall of personal event). All other responses were directly coded by the participants
214 themselves.

215 2.4 Visual Cues

216 Questions were illustrated with drawings that provided a timeline and visual cues for
217 detailing personal events, contents and perceptions (i.e. colors, smells, tactile feelings, sounds,
218 tastes). Contents could refer to temporal situations, spatial locations (e.g. home, school, beach,
219 etc.), modes of transport (e.g. car, plane, train, etc.), activities (e.g. video games, football,
220 musical instrument, etc.) and people present (e.g. parents, children, etc.). All the pictures were
221 drawn by a professional illustrator who ensured that each type of content was included. For
222 example, for the *who* content, there was a person of every age (i.e. children, adults and older
223 adults) and gender. In addition, five types of perceptions were illustrated with drawings. For
224 example, colors were associated with a color chart, while smells were indicated with a trash
225 can or a flower; sounds with a musical note or bell; tastes with a lemon or a sweet; and tactile
226 feelings with a finger placed on a pillow (mushy) or on ice (cold), (Fig. 1e). Each question
227 included explanations of the properties being tested (e.g., “Did you have tactile feelings? Did
228 you touch something soft like cotton wool, cold like ice, mushy like a pillow, hard like wood,

229 wet like water, or painful like a hedgehog?”). Participants repeated the property when they
230 selected the drawing that supported their autobiographical production (e.g. “I touched
231 something soft...”). This procedure was applied to all visual cues.

232 2.5 Procedure

233 Each participant was asked to produce descriptions of memories or projections with as
234 many details as possible, focusing on the past (i.e. one event that happened yesterday and one
235 last summer vacation) and the future (i.e. one event that could happen tomorrow and one next
236 summer vacation). These questions allowed us to manipulate orientation (past vs. future) and
237 temporal distance, either close (yesterday or tomorrow) or remote (last or next summer
238 vacation). For past events, participants were instructed to remember real events that had
239 happened to them (e.g., “Can you remember something that happened to you yesterday? I
240 want you to recall it with plenty of details, as if you were reliving this event, and your
241 description has to allow me to imagine this event too”). For future events, participants were
242 instructed to imagine an event that could happen in their lives or else was completely invented
243 (e.g., “Can you imagine what you might do tomorrow, either something planned or
244 completely new, but I want you to imagine what could happen with plenty of details, as if you
245 were living this event, and your description has to allow me to imagine this event”). If 1
246 minute went by without an answer, the interviewer gave the children an open-ended prompt
247 (e.g. “What else can you remember?”). If they were still not able to provide different contents
248 associated with an episodic event, after a further minute, they were helped with visual cues for
249 each of these components. Cues concerned activities (*what*), temporal situation (*when*), spatial
250 location (*where*), course of the event (*how*), and people present (*who*) (Figs. 1a and b).
251 Episodic free recall and cued recall (with visual cues) were each scored out of 5, with 1 point
252 per type of content: what (theme), when (e.g., beginning, middle or end of the month;
253 morning, afternoon or evening), where (which city and where in that city; e.g., home, garden,

254 beach), how (three different details; e.g., perception, feeling, activity, script), and who
255 (participants). Scoring was performed separately by the interviewer and a psychologist until a
256 consensus was reached (Table 2).

257 Next, we asked participants about the properties of each event. Participants rated their
258 own productions. First, we asked them to rate the emotional feeling associated with the event
259 on a 6-point Likert-like scale featuring smiley faces ranging from very sad to very happy
260 (e.g., “I was happy to do this, so I choose the fifth smiley”; Fig. 1c). They also rated the level
261 of emotional arousal on a triangular ruler, again with a 6-point Likert-like scale along each
262 side (e.g., “I was happy to do this, but not very, so I rate it 2 on the scale”; Fig. 1d). The
263 Likert-scale was used for all the following questions. Participants were then asked to provide
264 sensory details (i.e. colors, sounds, smells, tactile feelings, tastes; Fig. 1e), and indicate the
265 importance of each one in their memories or future thinking, using the same 6-point triangular
266 ruler (e.g., “Which colors do you remember being associated with your memories? What was
267 the intensity of each one?”). In the final part of the questionnaire, we collected other
268 information. One question concerned the perspective from which they had relived the event:
269 either their own (field perspective, scored 3/3), that of an observer (observer perspective,
270 scored 1/3), or alternating between the two (scored 2/3) (Fig. 1f). Another question assessed
271 the mental imagery associated with the personal event, asking participants whether they could
272 visualize the personal event in terms of the number of images (e.g., “When you think about
273 this event? How do you see it? Please rate it on a scale from 0 (*No image*) to 6 (*Lot of*
274 *distinctive images*)”; Fig. 1g) and accuracy (e.g., “Can you evaluate the accuracy or
275 distinctiveness of these images on a scale from 0 (*Completely blurry*) to 6 (*Very precise*)?”;
276 Fig. 1g). We also asked about the sense of subjective recollection (i.e., feeling of reliving):
277 “When you think about this event do you feel that you are reliving it with all the sensations
278 you had at the time? Are you able to provide many details? And is it so realistic that you feel

279 you are reliving the scene?” We used a film/video metaphor to highlight the nature of
280 recollection: “When you think about this event, imagine that you have rewound the film and
281 are reliving this event as a déjà-vu scene. How do you feel about reliving it with all the
282 sensations you had at the time? Can you rate your feeling of experiencing it on a scale from 0
283 (*No feeling of reliving*) to 6 (*Very intense feeling*)?” (Fig. 1h). Finally, we asked participants
284 about the memory’s personal relevance (e.g., “Was this event important to you? Please
285 indicate your answer on a scale of 0 (*Not at all*) to 6 (*Very important*)”), its frequency of
286 evocation (e.g., “How often do you remember or mention this event on a scale of 0 (*Not at*
287 *all*) to 6 (*Very often*)”) for past and future events. For future events only, we asked whether
288 they wished them to happen (e.g., “Would you like this event to happen? Please indicate your
289 answer on a scale of 0 (*Not at all*) to 6 (*Very much*)”), and the probability of occurrence (e.g.,
290 “Please rate the likelihood of this event happening on a scale of 0 (*Not at all*) to 6
291 (*Certainly*)”) (Table 2). To ensure that the adolescents made appropriate use of the criteria,
292 we asked them to reformulate the instructions. This procedure was adapted to each participant
293 and repeated until the experimenter was confident that the child understood the judgment
294 criteria.

295 **2.6 Statistical analyses**

296 Statistical analyses were performed using Statistica Version 10 software (StatSoft,
297 Tulsa, OK, USA). The reported values are means and standard deviations.

298 Due to the limited number of participants and some non-normally distributed variables
299 (K-S test $p < .05$ in one or both groups), we conducted non-parametric analyses (Friedman
300 ANOVAs and Wilcoxon for within comparisons and Mann-Whitney for between comparisons
301 with Z adjusted).

302 **3 Results**

303 **3.1 General cognitive assessment**

304 As expected, Mann-Whitney U Test revealed that the ASD group performed more poorly than
305 the TD group on verbal episodic memory (Immediate recall $z= 2.13$; $p=0.03$, $\eta^2= .14$;
306 Recognition $z=2.46$; $p=0.01$, $\eta^2=.18$), and planning (Tower of London, success at first
307 attempt $z= 2.11$; $p=0.03$, $\eta^2= .14$), but none of the other comparisons including working
308 memory, yielded significant differences (Table 1).

309 Semantic performance plateaued in both groups, (Table 1) confirming the absence of a
310 major deficit in personal semantic knowledge in ASD.

311 **3.2 Personal Event**

312 Mann-Whitney U Tests on free recall performance revealed significant differences for
313 two periods: recent past ($z=2.93$, $p=.004$, $\eta^2= .25$), near future ($z=2.41$, $p=.01$, $\eta^2= .18$) and a
314 marginally significant effect for the distant future ($z=1.95$, $p=.056$, $\eta^2= .11$). The ASD group
315 produced fewer event memories and projections than the TD group (see Fig. 2a).

316 Mann-Whitney U Tests on cued recall performance did not show any differences.
317 However, Friedman ANOVA revealed a significant period effect on performance in the
318 control group ($X^2=13.1$, $p=.004$, $\eta^2= .84$). The control group reported less details for the
319 distant future period compared to the recent past ($p = .03$) and near future periods ($p = .03$)
320 (see Fig. 2b).

321 **3.3 Emotional Feeling**

322 The analyses of emotion (i.e., valence and arousal) revealed no significant differences
323 between groups (Table 3). However, Friedman ANOVA revealed a significant period effect
324 on arousal in the TD group ($X^2=13.13$, $p=.004$, $\eta^2= 0.84$). The arousal associated to memories
325 for the recent past was lower compared to the remote past ($p=.02$) and distant future periods

326 ($p=.008$). Friedman ANOVA analyses conducted in the ASD group showed a period effect for
 327 valence ($X^2=7.72$, $p=.05$, $\eta^2=.39$). Memories associated with the remote past had a more
 328 positive valence than the recent past ($p=.01$).

329 3.4 Sensory Perceptual Details

330 Analyses on the total number of sensory details showed a significant reduction in the
 331 ASD group for the remote past ($z=2.74$, $p=.006$, $\eta^2=.23$). Analyses of each perceptual
 332 modality revealed significant differences between the ASD and control group on color for
 333 recent past (number $z=2.48$, $p=.01$, $\eta^2=.19$ and intensity $z=2.19$, $p=.03$, $\eta^2=.15$) and for
 334 remote past (number $z=2.78$, $p=.005$, $\eta^2=.24$). We also observed differences on smell for
 335 remote past period (number $z=2.61$, $p=.01$, $\eta^2=.19$ and intensity $z=2.00$, $p=.05$, $\eta^2=.12$), on
 336 sound (intensity for remote past $z=2.21$, $p=.03$, $\eta^2=.15$ and distant future $z=-2.05$, $p=.04$, $\eta^2=$
 337 $.13$) and tactile feeling for remote past (number $z=2.12$, $p=.04$, $\eta^2=.13$). Except for sounds for
 338 the distant future, the ASD group produced fewer information associated with less intensity
 339 than the TD group for all modalities and periods cited above (Table 3).

340 Friedman ANOVA analyses were conducted within each group on each category of
 341 sensory perceptual details. First and concerning the TD group, analyses showed a period
 342 effect on both the number and intensity of smell (respectively $X^2=12.05$, $p=.007$, $\eta^2=.75$ and
 343 $X^2=8.28$, $p=.04$, $\eta^2=.44$): both scores associated with the near future were reduced compared
 344 to the remote past (number $p=.02$, intensity $p=.01$) and distant future (number $p=.005$,
 345 intensity $p=.02$). Second and concerning the ASD group, analyses showed a period effect on
 346 the intensity of colors ($X^2=10.03$, $p=.02$, $\eta^2=.58$): the intensity of colors associated with the
 347 recent past was reduced compared to the remote past ($p=.01$). We also observed in this group
 348 a period effect on the intensity of sounds ($X^2=10.74$, $p=.01$, $\eta^2=.64$): sound intensity
 349 associated with the remote past was reduced compared to the distant future ($p=.02$).

350 3.5 **Recollection and Other Properties**

351 Mann-Whitney comparisons revealed no significant difference for the measures of
352 perspective, personal relevance, wish for it to happen, or probability of occurrence (Table 4).
353 However, the ASD group had lower scores than the TD group on several measures associated
354 to the remote past period: mental imagery (number, $z=2.17$; $p=.03$, $\eta^2=.14$), subjective
355 recollection ($z=1.98$, $p=.05$, $\eta^2=.12$) and frequency of evocation ($z=2.3$, $p=.02$, $\eta^2=.16$).
356 Friedman ANOVA analyses conducted in the TD group showed a period effect on mental
357 imagery (number: $X^2=8.01$, $p=.05$, $\eta^2=.39$ and accuracy: $X^2=12.24$, $p=.007$, $\eta^2=.39$). Number
358 of mental imagery associated with recent past was more important than near ($p=.05$) and
359 distant ($p=.008$) future periods. Accuracy of mental imagery associated with recent past was
360 better than for the remote past ($p=.008$) and distant future periods ($p=.008$) and accuracy of
361 mental imagery associated with near future was better than distant future period ($p=.05$).

362 **4 Discussion**

363 The aim of this study was to analyze the properties of past memories and future
364 thinking produced by adolescents with ASD, compared with their TD peers, using a visual
365 cues paradigm. As hypothesized, results revealed difficulty with free recall in the ASD group
366 that contrasted with typical performance on the visually cued task. We found differences
367 between the groups on the total number of sensory details provided only for the remote past
368 period. These differences also appeared when we considered each perceptual modality
369 separately, with the ASD group reporting fewer color, smell, sound and tactile feeling details
370 and intensity than the TD group. Finally, we did not observe any impairment on the measures
371 of emotion and quality of the experience of recollection, except for number of mental
372 imagery, subjective recollection and frequency of evocation for the remote past.

373 4.1 **Visual Cues in Autobiographical Memory Tasks**

374 Our results showed a significant benefit from visual cues in the production of both past
375 and future episodic autobiographical events. This enhanced performance is in line with the
376 task support hypothesis developed by Bowler, et al. (1997), which postulates that performance
377 is better when support is provided at retrieval. Hence, visual cues may be more effective for
378 learning/retrieval, as demonstrated by previous studies that used pictorial prompts for
379 teaching children with ASD (McClannahan & Krantz, 1997; Quill, 1997). AM may be used as
380 a support for social interaction in a social skill program and, for example, ASD participants
381 may use visual cues to share their personal memories.

382 The impaired performances of participants with ASD on the free recall task were in
383 accordance with their story recall performances (i.e., on the verbal episodic memory test), and
384 mirror previous findings in individuals with ASD (Brown, et al., 2012; Lind & Bowler, 2010;
385 Lind, Bowler, & Raber, 2014; Lind, Williams, Bowler, & Peel, 2014). Our data also
386 corroborate the findings of previous studies on future thinking (Ciamelli, et al., 2018; Terett,
387 et al., 2013). In addition, planning difficulties observed in the ASD participants may have
388 contributed to this result. We went beyond them by considering temporal distance and
389 showing impairments of both near that may extend to distant future projections. These
390 impairments may result from difficulty with scene construction, as suggested by Lind, et al.
391 (2014) and, more recently, by Ciamelli, et al. (2018). These authors reported the production
392 of fewer internal details (i.e. episodic), compared with TD controls, but similar numbers of
393 external details (i.e. semantic). Difficulty describing internal states leads to abnormalities in
394 binding experience directly to the self and establishing bonds between the self and others, and
395 consequently, giving coherent meaning to events (Fivush, 2009). Maister and Plaisted-Grant
396 (2011) also suggested that poorer temporal processing abilities in ASD are related to episodic
397 memory impairments. The difficulty accessing episodic AM seemed less pronounced for
398 memories related to the previous and forthcoming summer vacations. Compared with the

399 recent past (restricted to the previous or next day), the more extended vacation period offered
400 a range of possible autobiographical events, facilitating the retrieval of one specific and
401 especially salient moment. Moreover, in contrast to many other studies (Goddard, et al.,
402 2014), our task fixed the time period but not the topic, and consequently allowed participants
403 greater flexibility in choosing their personal events, which may have been more closely
404 related to their concerns.

405 4.2 **Sensory Properties**

406 Contrary to our prediction, the episodic memories provided by the participants with
407 ASD contained just as many sensory details as those produced by controls for three periods.
408 These results are in accordance with Crane and Goddard (2008), who did not observe any
409 difference in sensory or emotional information in adults with ASD. This may result, in part,
410 from the use of visual cues for each perceptual modality. However, a lack of details persists
411 for the remote past that may illustrate consolidation difficulties reported by Goddard, et al.
412 (2007) and Bon, et al. (2013). This reduction is relatively homogeneous and concerned all
413 modalities except taste. Rather surprisingly, however, the recent episodic memories also
414 lacked color details. The adolescents with ASD did mention colors, but fewer than controls.
415 This finding is in accordance with the accounts of some families, who report particular
416 interest in or aversion to some colors and lights in daily life. Some individuals with ASD may
417 have either an obsession with or phobia of colors, as described by Ludlow, et al. (2014) in a
418 case study. Hence, they may have an atypical perception of colors that affects the
419 formation/retrieval of memories, even when support is provided. Very few studies have used
420 colored material to study either working memory (see, for example, Vogan, et al., 2014) or
421 long-term memory (Massand & Bowler, 2015) in ASD. When Franklin, et al. (2008)
422 investigated color memory per se, they found impaired performance for colors compared with

423 shapes. Two years later, Franklin, et al. (2010) also reported a general reduction in chromatic
424 sensitivity. This atypical sensitivity to color may account for the present results.

425 **4.3 Recollection and Emotional Properties**

426 When our participants with ASD were prompted by visual cues, we did not find any
427 difference in the processing of either the valence or intensity of emotions: they produced
428 memories that were just as positive as those of controls. These results further justify the use of
429 visual cues at retrieval to compensate for the difficulty that individuals with ASD have
430 understanding verbally expressed emotions. Moreover, Maccari et al. (2014) demonstrated
431 that individuals with ASD are able to process positive emotional information embedded in
432 pictures just as well as controls. Our results indicate that this ability can be generalized to
433 familiar autobiographical scenes.

434 Concerning the other properties, we observed differences between the two groups only
435 for the remote past. The ASD group had reduced mental imagery, subjective recollection and
436 frequency of evocation. Participants with ASD produced memories lacking in details and
437 associated with reduced episodic properties, compared to controls. Once more, this result is in
438 accordance with abnormal forgetting previously reported in ASD. These data replicate those
439 of other experimental studies that used anterograde memory paradigms (Bowler, et al., 1997;
440 Cooper & Simons, 2018; Souchay, et al., 2013). Our participants' recollection difficulties may
441 reflect an additional deficit in relational processes, as demonstrated by Bowler, et al. (2014)
442 and Gaigg, et al. (2015). Individuals with ASD have difficulty binding together the different
443 features that make up an episodic event (Happé & Frith, 2006). Hence, the ASD group may
444 have been successful in recalling some episodic features separately, with the aid of visual
445 cues, but had difficulty binding them together to generate a feeling of reliving. This may be
446 due to weak central coherence, leading to construction, organization, and retrieval difficulties

447 (Bowler, et al., 2011; Happé & Frith, 2006), and possibly impacting other abilities such as
448 theory of mind, as suggested recently by Ciaramelli, et al. (2018).

449 Surprisingly, we did not observe the same pattern of performance for projections into
450 the future. Performance was poorer for future versus past periods in the control group for
451 number and accuracy of mental imagery, as previously demonstrated by Abram, et al. (2014),
452 thus reducing differences with the ASD group. Hence, the ASD group had an intact feeling of
453 pre-experiencing the future, supporting the notion that the feeling of reliving previous
454 experiences and the pre-experiencing of future events are subtended by partially distinct
455 mechanisms. The feeling of pre-experiencing may have been the product of reasoning based
456 on vividness, the visual perspective adopted during the questionnaire, and personal relevance,
457 as previously demonstrated by D'Argembeau and Van der Linden (2012). All these features
458 were preserved in our participants. The sense of self may be involved to a more limited extent
459 in the ability to elaborate a mental representation associated with future thinking than in the
460 remembering of past autobiographical events.

461 **5 Limitations and perspectives**

462 This work presents certain limits. First, the sample size is relatively small, preventing us from
463 generalizing to the ASD population. In addition, since we had the opportunity to include only
464 boys, inclusion of a group of girls would extend our conclusions to ASD as a whole. Second,
465 our groups do not differ in age but have a wide age range. Given the major influence of age
466 on cognitive development, it would be particularly interesting to investigate the relationship
467 between AM development and other cognitive abilities, such as theory of mind which is
468 impaired in ASD. Third, given the interaction between AM development and social
469 interactions, environment and lifestyle (e.g. family, therapies, activities, etc.), largely
470 neglected in previous studies, it is crucial to consider these factors in future research. Fourth,

471 each personal event was manually transcribed and scored according to a grid coding for five
472 components of episodic memory (i.e. what, where, when, how, who). Scoring was obtained
473 separately by the interviewer and a psychologist until a consensus was reached. In future
474 work, recording verbatim productions would refine the analysis in providing a more detailed
475 investigation of each component. Finally, the interviewer was one of the two coders and was
476 thus not blind to groups. It would be relevant to replicate our results with two coders blind to
477 the diagnoses and verify their inter-rater reliability.

478 **6 Conclusion**

479 Our study suggests that AM impairment may result from a combination of a
480 consolidation deficit for the most remote events associated with a binding deficit and
481 demonstrates the relevance of using visual cues to facilitate AM retrieval. These results are in
482 keeping with other studies and may be relevant to other cognitive abilities, as recently
483 suggested by Caramallli, et al. (2018). This may offer new methodological opportunities for
484 managing ASD. It also shows that some specific properties associated with episodic
485 memories, possibly colors, may be less important than they are to TD people. This raises the
486 issue of the impact of perception on AM, which requires further investigation. In addition, we
487 observed considerable variability, which we could not analyze because of the small size of our
488 sample. Hence, characterizing the different AM profiles should be the next step in studies of
489 cognition in ASD. This could open up new perspectives for cognitive rehabilitation, such as
490 working on AM as the key to social interactions.

491 **7 Conflict of Interest**

492 The authors declare that the research was conducted in the absence of any commercial
493 or financial relationships that could be construed as a potential conflict of interest.

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735 Table 1. Mean Ages and Cognitive Data for the ASD and TD Groups.

		ASD (<i>n</i> = 16)		TD (<i>n</i> = 16)		Group differences <i>p</i> value and effect size
		Mean	<i>SD</i>	Mean	<i>SD</i>	
Age (in years)		13.4	2.4	13.0	2.0	<i>p</i> =.54, η^2 =.01
PRI		101.3	17.7	109.4	16.3	<i>p</i> = .22, η^2 =.05
VCI		108.3	21.4	116.1	14.7	<i>p</i> =.13, η^2 =.07
<i>Short-term memory and executive functions</i>						
Tower of London	Success at first attempt	7.1	1.5	7.9	1.5	<i>p</i>=.03* , η^2 =.14
	Total number of trials	19.7	3.7	19.5	4.9	<i>p</i> =.18, η^2 =.06
Stroop		33.2	10.8	27.1	10.1	<i>p</i> =.24, η^2 =.08
Visuospatial span		6.1	1.7	5.9	1.2	<i>p</i> =.87, η^2 =.001
Verbal span		5.9	1.1	6.1	1.3	<i>p</i> =.61, η^2 =.009
<i>Episodic memory</i>						
Immediate recall		22.4	9.4	28.9	6.3	<i>p</i>=.03* , η^2 =.14
Delayed recall		21.2	9.3	26.8	6.1	<i>p</i> =.09, η^2 =.09
Recognition		11.6	2.4	13.4	0.9	<i>p</i>=.01* , η^2 =.18
<i>Personal semantic knowledge</i>						
Acquaintances		5.8	0.5	5.9	0.5	<i>nd</i>
School life		5.9	0.1	5.9	0.1	<i>nd</i>
Famous names		5.9	0.3	6.0	0.0	<i>nd</i>

736

737 *Note.* *nd* = not done owing to a ceiling effect; PRI: Perceptual Reasoning Index; VCI: Verbal
738 Comprehension Index; ASD: participants with autism spectrum disorder; TD: typically
739 developing participants.

740 * Significant differences observed between the ASD and TD groups.

741

742

743 Table 2. Episodic memory paradigm, variables and scoring.

Personal event*		
What, when, where, how, who	<i>Free recall</i>	/5
What, when, where, how, who	<i>Visual cued recall</i>	/5
Emotional feeling		
	<i>Valence</i>	/6
	<i>Arousal</i>	/6
Sensory details		
	<i>Details</i>	No.
Color	<i>Importance</i>	/6
	<i>Details</i>	No.
Sound	<i>Importance</i>	/6
	<i>Details</i>	No.
Smell	<i>Importance</i>	/6
	<i>Details</i>	No.
Touch	<i>Importance</i>	/6
	<i>Details</i>	No.
Taste	<i>Importance</i>	/6
Mental imagery		
	<i>Details</i>	/6
	<i>Accuracy</i>	/6
Perspective		
	<i>Field perspective</i>	1
	<i>or Field/Observer perspective</i>	2
	<i>or Observer perspective</i>	3
Subjective recollection		/6
Personal relevance		/6
Frequency of evocation		/6
Wish for it to happen[#]		/6
Probability of occurrence[#]		/6

744 *Note.* No. = number.745 * Coded by two persons: the interviewer and the psychologist. All other measures were
746 directly coded by participants.747 [#] Variables for future periods only.

Table 3. Mean (SD) Emotional Feeling and Sensory Details for Each Group and Each Period. Number of Details and Importance Are Reported.

			<i>Emotional feeling[#] (/6)</i>	<i>Color (/6)</i>	<i>Smell (/6)</i>	<i>Sound (/6)</i>	<i>Tactile feeling (/6)</i>	<i>Taste (/6)</i>	
ASD	Recent Past	ND	4.0 (1.5)	2.0 (2.0)^a	0.6 (0.7)	1.6 (1.0)	1.1 (0.9)	0.8 (1.3)	
		I	4.1 (1.5)	2.3 (1.8)^a	1.7 (2.2)	3.3 (1.6)	3.0 (2.0)	1.5 (2.2)	
	Remote Past	ND	4.9 (1.2)	1.9 (1.6)^a	0.4 (0.6)^a	1.6 (1.0)	0.9 (0.7)^a	0.5 (0.6)	
		I	4.7 (1.6)	3.7 (1.9)	1.4 (2.0)^a	2.8 (1.4)^a	2.7 (2.3)	1.5 (2.1)	
	Near Future	ND	4.0 (1.7)	2.2 (2.3)	0.4 (0.6)	1.4 (1.3)	1.0 (0.9)	0.5 (0.7)	
		I	4.6 (1.3)	2.9 (2.2)	1.3 (1.8)	3.4 (1.9)	3.2 (2.4)	1.6 (2.3)	
	Distant Future	ND	4.7 (1.2)	2.2 (2.3)	0.9 (1.3)	1.6 (1.0)	1.8 (1.8)	0.4 (0.5)	
		I	4.5 (1.3)	3.0 (2.2)	1.7 (2.0)	4.0 (1.6)^a	3.2 (1.9)	1.8 (2.6)	
	TD	Recent Past	ND	4.5 (1.4)	3.5 (1.8)	0.6 (0.5)	2.1 (1.4)	1.4 (0.9)	0.4 (0.6)
			I	3.1 (1.3)	3.8 (1.2)	1.6 (1.8)	3.3 (1.1)	3.1 (2.0)	0.9 (1.6)
		Remote Past	ND	5.0 (0.8)	3.6 (1.6)	1.2 (0.8)	2.5 (1.5)	1.8 (1.2)	0.6 (0.8)
			I	4.5 (1.2)	3.6 (1.1)	2.8 (1.8)	3.8 (1.4)	3.1 (1.7)	1.4 (1.8)
Near Future		ND	4.6 (1.1)	3.3 (2.2)	0.6 (1.0)	2.0 (1.2)	1.8 (1.9)	0.2 (0.4)	
		I	4.3 (1.5)	4.0 (1.7)	1.1 (1.7)	3.4 (1.4)	3.0 (2.0)	0.6 (1.5)	
Distant Future		ND	4.9 (1.2)	2.6 (1.9)	1.3 (1.3)	2.1 (2.1)	1.6 (1.7)	0.8 (0.9)	
		I	4.8 (1.1)	3.7 (1.8)	2.1 (1.7)	2.9 (1.6)	2.3 (2.0)	2.3 (2.2)	

Note. ND = Mean of number of details (SD); I = Mean of importance (SD). [#] *Importance* for emotions corresponds to arousal. ASD: participants with autism spectrum disorder, TD: typically developing participants. ^a Significant differences were observed between the ASD and TD groups (in bold), $p < 0.05$.

Table 4. Mean (SD) Properties of Personal Events According to Group

		Mental imagery		Perspective (/3)	Subjective recollection (/6)	Personal relevance (/6)	Frequency of evocation (/6)	Wish for it to happen [#] (/6)	Probability of occurrence [#] (/6)
		Number (/6)	Accuracy (/6)						
ASD	Recent Past	3.9 (1.7)	4.7 (1.4)	2.4 (0.9)	3.3 (2.0)	3.7 (2.2)	1.9 (1.9)	/	/
	Remote Past	3.1 (1.9)^a	3.9 (1.6)	2.3 (0.9)	2.6 (1.8)^a	3.8 (1.9)	2.1 (1.9)^a	/	/
	Near Future	3.5 (2.0)	3.5 (2.1)	2.2 (1.0)	3.7 (2.0)	3.5 (2.1)	1.9 (1.9)	3.4 (2.5)	4.8 (1.7)
	Distant Future	3.9 (1.8)	4.4 (1.6)	2.1 (1.0)	3.9 (1.7)	3.5 (1.7)	3.2 (2.0)	3.7 (2.3)	4.3 (2.1)
TD	Recent Past	4.6 (1.5)	4.9 (1.0)	2.8 (0.6)	4.3 (0.9)	3.8 (1.4)	2.8 (1.6)	/	/
	Remote Past	4.5 (1.5)	4.6 (1.0)	2.6 (0.8)	3.7 (1.5)	3.6 (1.5)	3.3 (1.3)	/	/
	Near Future	3.9 (1.6)	4.0 (1.5)	2.6 (0.8)	3.4 (1.2)	2.9 (1.5)	2.3 (1.7)	4.3 (1.7)	5.1 (1.3)
	Distant Future	3.3 (1.6)	3.8 (1.7)	2.4 (0.9)	3.2 (1.6)	3.3 (1.7)	2.7 (1.7)	4.6 (1.8)	5.5 (0.6)

Note. [#] For future events only. ASD: participants with autism spectrum disorder; TD: typically developing participants.

^a Significant differences were observed between the ASD and TD groups (in bold), $p < 0.05$.

Figure 1

From Past to Future Task.

This task explored specific past personal events that had occurred either the day before (recent past) or during the previous summer vacation (remote past), as well as projections to the next day (near future) or forthcoming summer vacation (distant future). First, participants were provided with a visual timeline and asked to point to the current day, to ensure that they were oriented in time (a). Second, participants were asked to describe a memory or future event for each period with as many details as possible. If, after 1 minute, any of the participants were not able to provide the different types of contents associate with an episodic event, they were helped with visual cues for each of the following components: what, how, when, where, who (b), emotions (c), 6-point Likert scale (d), perceptions (e.g., color; e), perspective (field or observer; f), mental imagery (g), and reliving (h).

Figure 2

Episodic score: mean performances and standard deviations on (a) free recall and (b) cued recall for each period according to group. * $p < 0.05$.

