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How preadolescents and adults remember and experience virtual reality: the role of avatar incarnation, emotion, and sense of presence

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1. Introduction

Embodied cognition has given the body a central role in cognitive processes (e.g., memory, attention, emotion, action). More specifically, Barsalou [1] proposed that the state of the body, the situation of the action, and the modality of the simulation govern cognition. Evidence of embodied cognition has been demonstrated in children too, with empirical studies demonstrating that cognition emerges from sensorimotor interactions of the child with the environment [2–4].

In a virtual reality (VR) context, it is possible to create a fully virtual sensorimotor environment that the user can explore, and in which he or she has the possibility of embodying an avatar (i.e., a virtual body). It is critical for research on the child and adolescent population to understand the effect of embodying an avatar due to their early exposure to multiple virtual representations of themselves in different medias (e.g., picture on mobile phone, digital camera, handheld game console [5]), despite the ongoing development of the self. VR is a specific media that allows users to embody virtual avatars and to evolve in a virtual environment in the first-person view, especially with a head-mounted display (HMD), allowing visuomotor synchronicity. Research on adults has shown that VR is indeed an effective device to create feelings of embodiment [6] or to explore the embodied nature of memory [7]. However, only a few studies have investigated this point in preadolescents (i.e. middle school pupils, e.g., [8,9]). Thus, in order to ensure respectful use of VR in this population whose access to this media will potentially grow in the coming years, more studies are necessary to explore the effects of embodying an avatar in VR on cognition. The purpose of the present study is to compare adult and preadolescents, middle school pupils (MSP) with regard to the effects of embodying a virtual avatar during a VR experience on different aspects of cognition assumed to be linked to self-representation: memory, emotion, and sense of presence.

52 **1.1. Avatar: effects on memory and presence**

53 Presence is defined as the perception of *being there* in a physical or virtual environment
54 [10]. On one hand, research on adults has revealed that the incarnation of a virtual body (i.e.,
55 an avatar) can enhance presence [11], and memory [7]. On the other hand, some studies on
56 preadolescents MSP have shown the same positive impact of avatar incarnation on presence
57 [8,9]. Some studies have investigated this in adults (e.g., [12–14]), however concerning younger
58 populations research on avatar incarnation has predominantly focused on children or
59 adolescents with neurodevelopment disorders (e.g., autism disorder [15]).

60 First, concerning the relationship between presence and embodiment in an avatar, for
61 MSP, development could have a critical role. In fact, research on adults has, at least partially,
62 attributed the state of presence to the virtual implication of the self [16]. Bailey and Bailenson
63 [5] discussed the development of the self by pointing out that, even if a child is able to recognize
64 themselves in a mirror (mirror task) at the age of 3-4 years, it does not mean that the self is fully
65 mature. In fact, Suddendorf and Butler [17] argued that children who succeeded in the mirror
66 task were not always able to recognize themselves in a video. With older children (6-7 years),
67 Segovia and Bailenson [18] found that when children saw a virtual version of themselves
68 swimming with orcas, they confused it with reality, and later recalled that it had happened in
69 real life. However, Calvert et al. [19] have shown that preadolescent's behavior (mean age of
70 10 years and 11 month) was not affected by incarnating an avatar having the opposite sex that
71 their own sex. Thus, the self is a complex mechanism allowing us to recognize ourselves in the
72 present, but also at different points of time and space. Attention was drawn on the fact that VR
73 is a peculiar context that could be challenging for the self, even for adults [5]. In VR contexts,
74 the virtual self can diverge from the user's self in terms of looks and attitudes. Thus, because
75 of the different levels of maturation of the self, embodying an avatar in VR could have different
76 impacts on emotion or on sense of presence in MSP than in adults.

77 Second, concerning the link between embodiment and memory, studies have shown
78 positive effects of virtual embodiment on episodic memory performance in young adults (see
79 for review, [20]). A possible explanation can be found in neurodevelopmental observations that
80 functional episodic memory is linked to the development of locomotion, and the alignment of
81 hippocampal place cells and grid cells with the environment [21]. Moreover, the enactment
82 effect has already demonstrated that a possible action of the body on an object, even imaginary,
83 can impact the memory of this object. As an example, Dutriaux and Gyselinck [22] showed that
84 better memory performances for a list of manipulatable objects were obtained when the
85 participants' hands were free during encoding, compared to when they had to keep their hands
86 crossed behind their back. In a VR context, it is possible that embodying an avatar in the first-
87 person view (with full-body functioning), compared to seeing nothing, enhances possible
88 actions on the virtual environment, and thus enhances the memory thereof. Ratan [16]
89 mentioned that the effects of embodying a virtual body on cognitive functions could depend on
90 the level of self-presence, in other words, how much the user feels connected to their virtual
91 self-representation on different levels (body, emotion, identity). Moreover, it has been pointed
92 out for many years that self-reference could positively influence encoding and retrieval in
93 memory processes [23]. So, it is possible that this effect is stronger in adults than in MSP, in
94 view of the still-maturing body schema and self in the latter population. In order to explore such
95 a possibility, in this study, we manipulated the embodiment by exposing participants to virtual
96 environments through an avatar seen in the first-person view, or through a non-body condition,
97 where the participant could only see the two VR controllers.

98

99 **1.2. Emotional nature of the virtual environment: effects on memory and presence**

100 Research on adults found that presence can be impacted by emotion [24–26]. Some
101 empirical findings support that emotion can enhance presence in child populations too [27,28].

102 However, because emotional responses and regulation are still developing during childhood
103 and adolescence [29], it is possible that the strength of the link and the relationship between
104 emotion and presence is not the same for preadolescents and adults. In order to explore these
105 relationships, we manipulated emotion systematically by presenting positive, negative, and
106 neutral stimuli in the virtual environment. In order to measure emotional responses precisely,
107 we used self-assessed questionnaires (Self-assessment Manikin, [30]) administered
108 immediately after exposure to the virtual environment, which we coupled with physiological
109 measures during exposure, as previous studies did in their VR protocols [25,31].

110 The enhancing impact of emotion on memory is a well-known phenomenon in the
111 literature on adult [32] and child populations [29–31], but in the context of virtual reality, more
112 studies are necessary to describe the respective effects of emotion and presence on memory
113 performances. Makowski et al. suggested that the impact of emotion on memory depends on
114 presence [33]. In their study, with young adults population, they measured emotion and memory
115 in relation to scenes from a movie. Thus, the emotion was not methodically manipulated, and
116 did not depend exclusively on the nature of the stimulus recalled later. To our knowledge there
117 is no study that investigated effect of emotion on memory in VR with preadolescents. Thus, in
118 our study, we asked participants to recall as many stimuli as possible, and the emotional
119 stimulation during our protocol mostly stemmed from the stimuli themselves. In addition, the
120 narrative point of view during the film (third-person view) did not allow participants to develop
121 presence in the same way that a first-person view could. Riva et al. [34] described three levels
122 of presence: *proto presence*, or the capacity to set perception and movements together and
123 discern the internal and the external environment; *core presence*, the capacity to focus sensorial
124 processes on the current task; *extended presence*, the capacity to select previous experiences as
125 relevant for the self. In view of this proposition, a first-person view, especially with a full-body
126 avatar, provides the best conditions for enhancing presence.

127 In our study, we should be able to explore the combined effects of the emotional nature
128 of the virtual environment and the embodiment of an avatar, not only on memory, but on sense
129 of presence, and emotional subjective and physiological responses.

130

131 **1.3. Aim of the study**

132 To summarize, the first goal of this study is to explore the respective roles of three
133 factors (i.e., avatar embodiment, emotional responses, and sense of presence) on memory
134 performances in preadolescents, and to compare these results to adults' ones. To do so, we used
135 two conditions of embodiment: a full-body avatar in the first-person view *versus* only the view
136 of the two controllers at their actual location (i.e., avatar *versus* no-avatar). We hypothesized
137 that emotional enhancement of memory (EEM) would be stronger in preadolescents than in
138 adults, and that embodying an avatar would enhance this effect, especially in preadolescents.
139 The secondary objective of this study is to investigate the impact of avatar embodiment, age,
140 and the emotional nature of the virtual experience on sense of presence and emotional responses
141 (subjective, behavioral, and physiological). To achieve this secondary objective, we used
142 different measures provided by the HMD (head position and rotation), and additional material
143 (collecting heart rate and pupillary dilation during the task). We predicted that visiting a place
144 with emotional stimuli through an avatar would elicit a more heightened sense of presence,
145 emotional responses, and memory performances than visiting it with no avatar. We also
146 expected these same effects of avatar for the places with neutral stimuli, but these effects would
147 be decreased compared to the environments with emotional stimuli.

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2. Method

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2.1. Participants

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Seventy-two participants divided into two age-groups took part in the experiment: thirty-two preadolescent MSP ($M_{\text{age}} = 12.1$ years, range = 10-14 years; 19 girls and 13 boys) and forty young adults, students at Lyon 2 University ($M_{\text{age}} = 20.39$ years, range = 18-28 years; 20 women and 20 men). There were four experimental groups: preadolescents with avatars in the virtual environment (N=16), preadolescents with no avatar (N=16), young adults with avatars (N=20), and young adults with no avatar (N=20). All preadolescents were pupils attending middle school in Lyon and Clohars-Carnoët. All participants (and/or their legal representatives) gave their written informed consent in accordance with the Helsinki declaration, and had declared having good hearing and vision. The research was approved by Ethics Committee (Comité de Protection des Personnes, Ile de France, Nr. 2018 A01669-46). Our target sample size was determined using an *a-priori* power analysis (G*Power [35]), using η^2_p from previous studies investigating memory and sense of presence for virtual reality environments. For example, previous studies [36,37] found that η^2_p ranged from .038 to .219 for memory and from .038 to .538 for sense of presence. Using a $\eta^2_p = .16$, our study design with two between-participants factors (age and avatar condition) and one repeated factor (valence), could achieve 80% power with 16 young adults and 16 preadolescent participants per group. To achieve larger power we have planned to include 20 participants per group but we succeed in doing so only for young adults groups.

Before the experiment, all participants answered questionnaires about anxiety and depression - HADS [38], mood - PANAS [39], and immersive tendencies - QIT [40]. A one-way ANOVA was conducted to compare anxiety (HADS-A), depression (HADS-D), positive and negative affect (PANAS-PA and PANAS-NA respectively), and immersive tendencies (IT)

174 between the four experimental groups. No significant difference was found for all of the
175 questionnaires. Moreover, children obtained scores within normal performances in two subtests
176 (Matrix Reasoning and Similarities) of the Weschler Intelligence Scale for preadolescents:
177 WISC V, French version.

178

179 **2.2. Materials and stimuli**

180 **2.2.1. Apparatus**

181 We used the HTC Vive headset (first generation) with a spatial resolution of 1080 x
182 1200 pixels per eye, and 90 Hz refresh rate. To run the experiment, the PC we used had the
183 following specifications: an Intel® Core™ i8-7700HQ CPU with 2 x 3.60GHz, DDR 4 2 x 32
184 GB RAM, and a Geforce® GTX 1080, running Microsoft Windows 10. We used the cross-
185 platform game engine Unity to create the experiment, and sounds were played through the HTC
186 Vive headphones. We implemented the Pupil Labs add-on for eye tracking to our HTC Vive
187 headset in order to measure pupillary dilation. The HTC Vive HMD features an accelerometer,
188 a gyroscope, and laser position sensor, making it possible to track head and controller rotation
189 and position (see *Supplementary Material* for detailed description of recording and processing
190 of these data). We also used an Arduino system to measure heart rate with an ear clip pulse
191 sensor.

192

193 **2.2.2. Stimuli**

194 The stimuli used in the experiment were fifty-eight 3D assets (i.e., 3D models of objects
195 or animals, animated or not, with or without sound) from a larger set of 110 assets, previously
196 pre-tested for valence and arousal by 31 students from Lyon 2 University (see supplementary
197 material and Cadet & Chainay [36] for more detailed information concerning the stimuli) .

198 These assets were split into 12 sets of stimuli. Half of these sets were displayed in a virtual
199 Island environment (in one of the following places : a forest, a beach or a desert), with 3 sets of
200 negative stimuli with high arousal (2 sets of 5, and 1 set of 4), and 3 sets of neutral stimuli (2
201 sets of 5, and 1 set of 4). The other half was included in a virtual City environment (in places
202 representing different coffee shop terraces, 2 sets of 5 negative stimuli with medium arousal, 2
203 sets of 5 neutral stimuli, and 2 sets of 5 positive stimuli with medium arousal). We have chosen
204 these two environments and the six places in each environment to be able to coherently present
205 each set of the stimuli (i.e., each set in one of the 6 specific places in Island and the same in
206 City environment). The sets of stimuli were created such that the sets including the stimuli of
207 the same valence (i.e., negative, positive or neutral) are of a similar level of valence and arousal.
208 The mean scores, ranges and standard deviation for valence and arousal for each set are
209 available in the supplementary material in Table 1.

210
211

212 ***2.2.3. Procedure***

213 Participants were seated in an armchair. After setting up the VR HMD, the headphones,
214 and ear clip pulse sensor, the participants were asked to give the signal when they were ready
215 to start the experiment. We first proceeded with eye-tracking calibration. After this calibration,
216 the experiment settings menu appeared, and a computer-synthesized voice explained the aim of
217 the experiment, then the participants were asked to stay still and calm for one minute in order
218 to calculate their resting heart rate. Following this, and before starting to visit the environments,
219 for the Avatar condition, participants were asked to choose the color of their futuristic suit by
220 pointing it through the controller's raycast and pressing the controller's trigger. As previously
221 reported [41], this personalization was supposed to help the illusion of virtual body ownership.
222 A mirror was placed in front of them for 30s before the selection of the Island or the City
223 environment and they had to move their arms and head in order to see their avatar moving with

224 them. The mirror appeared also for 5 s before visiting each place. The arms and body of the
225 avatar in the first-person view (i.e., like a person could see his/her own body in real life) was
226 visible for the participants throughout the experiment, hand tracking was carried out by the two
227 controllers, but there was no leg tracking (participants were asked to move their legs as little as
228 possible). For the no-Avatar condition, participants were able to see the controllers instead of
229 their hands in the virtual experience. They started to visit environments straight after recording
230 the resting heart rate.

231 Irrespective of the Avatar condition, participants were asked to complete a visit of two
232 environments: City and Island, each containing six places. The order in which the environments
233 and places within each environment were visited was selected by the participants. When the
234 participants had selected an environment, they had to visit the six places of the currently
235 explored environment before visiting the second one (see Figure 1). In each place, stimuli were
236 presented one by one during 5s each and with 7s of interval between stimuli, in random order,
237 and always within 180° of the space in front of them. The total time of presentation per place
238 was 60s except 2 places in Island environment (48s). A spatialized sound was played before the
239 stimulus in order to help participants to locate it, and they were asked to point out each
240 stimulus before it disappeared.

241

242 Insert Figure 1 here

243 At the end of the visit of each place, the participants answered questions displayed in
244 the HMD and played using synthesized speech. First, they rated, on a 9-point illustrated scale,
245 the level of valence (from “very unpleasant” to “very pleasant”), and arousal (from “weakly
246 arousing” to “very arousing”) (SAM test, [30]) in respect of the visited place. Then, they
247 answered the following questions, on a 7-point scale (from “not at all” to “absolutely”): How
248 present did you feel in the environment? (general sense of presence); How much of an

249 impression did you have of being able to visit the environment? (sense of presence relative to
250 their ability to visit the place); How much capable did you feel of touching things? (sense of
251 presence relative to the ability to touch things); How focused did you feel on the task that you
252 were asked to do? (attentional focus), and; How motivated did you feel to do the task that you
253 were asked to do? (motivation). These five questions were selected because they fit with the
254 subscales usually included in extended questionnaires measuring presence (e.g., ITC-SOPI,
255 [42]). For the Avatar condition, the mirror appeared briefly (5s) after the questionnaire, and
256 before selecting a new place to visit; for the no-Avatar condition, nothing occurred during these
257 5s. To select environments, places and answers in the questionnaires, the controller's raycast
258 pointing accompanied with trigger pression was used for both avatar and no-Avatar conditions.

259 Once the participant had visited the six places of the first environment, the HMD was
260 removed and they were asked to respond to a French version of the ITC-SOPI questionnaire
261 (composed by four factors: spatial presence, engagement, ecological validity / naturalness,
262 negative effects), and then to recall all stimuli that they had seen in the places just seen ((in
263 Island (28 stimuli) or City (30 stimuli) environment depending on the order of visit that
264 participant has chosen)). Responses were written by the investigator. At the end of the recall,
265 the investigator could ask for details about an ambiguous response; if the participant's answers
266 did not allow the item recalled to be identified, it was counted as an incorrect response. Then,
267 the same procedure was repeated for the remaining environment.

268

269 **2.2.4. Statistical analysis**

270 Separate statistical analyses of ANOVA for the Island and City environments were
271 conducted. We performed the 2 x 2 x 2 ANOVAs for Island and 3 x 2 x 2 ANOVAs
272 ((Emotion)x(Avatar)x(Age)) with Emotion (for Island – negative vs. neutral; for City - positive
273 vs. negative vs. neutral) as within-subject factor, and Avatar (avatar vs. no-avatar) and Age

274 (Adults vs. Preadolescents) as between-subject factors. If necessary, to better understand the
275 significant effects, planned comparisons were performed. These analysis were conducted on
276 scores of correct free recalls (item memory for virtual stimuli), on the mean sense of presence
277 (score based on the responses to five questions for each place), and emotional valence and
278 arousal (SAM test). Each mean was obtained using scores for places presenting stimuli of the
279 same emotional valence (Island – negative and neutral; City – positive, negative, and neutral).

280 In addition, an ANOVA was conducted on the four ITC-SOPI factors with Environment
281 (Island vs. City) as within-subject factor, Avatar (avatar vs no-avatar), and Age (Adults vs
282 Preadolescents) as between-subject factors.

283 Preliminary analyses were performed to check for sphericity (Mauchly’s test), and
284 homogeneity of variances (Levene’s test). If a violation was found, corrected scores
285 (Greenhouse-Geisser) were used.

286 The correlation and regression analyses were also performed to determine which of the
287 subjective and objective measures of emotion and presence are linked to the recall performance
288 and could explain this performance.

289 The results are presented in the following order: (1) recall performance, (2) self-reported
290 measures for sense of presence, arousal, and valence, and (3) correlations and regression
291 analysis.

292

293

3. Results

294 First, we resume in Table 1 the results of the ANOVAs analysis in the Island and City
295 environment with Emotion as within-subject factor, and with Age and Avatar as between-
296 subject factors.

297

Insert Table 1 here

298

299 **3.1. Recall performances**

300 **3.1.1. Island**

301 A significant effect of Emotion ($F(1, 68) = 87.13, p < .001, \text{partial } \eta^2 = 0.56$) was
302 observed with higher recall of negative stimuli ($M = 8.71, SE = 0.25$) than of neutral stimuli
303 ($M = 6.18, SE = 0.18$). The effect of Age was also significant ($F(1, 68) = 11.54, p < .001, \text{partial}$
304 $\eta^2 = 0.15$), with higher recall for adults ($M = 8.04, SE = 0.23$) than for preadolescents ($M =$
305 $6.86, SE = 0.26$). Interaction between Age, and Avatar was significant ($F(1, 68) = 7.46, p =$
306 $.008, \text{partial } \eta^2 = 0.10$) (see Figure 2). The planned comparison revealed that for the no-avatar
307 condition, the recall was higher for adults ($M = 8.38, SE = 0.34$) than preadolescents ($M = 6.25,$
308 $SE = 0.36$), but in the avatar condition, the difference between adults ($M = 7.70, SE = 0.33$) and
309 preadolescents ($M = 7.46, SE = 0.37$) was not significant. There were no other significant
310 effects.

311 Insert Figure 2 here

312 **3.1.2. City**

313 A significant effect of Emotion ($F(2, 136) = 27.02, p < .001, \text{partial } \eta^2 = 0.28$) was
314 observed, with higher recall of negative stimuli ($M = 5.42, SE = 0.19$) and positive stimuli (M
315 $= 5.44, SE = 0.21$) than of neutral stimuli ($M = 3.80, SE = 0.20$; respectively $t(136) = 6.32, p <$
316 $.001$ and $t(136) = 6.40, p < .001$); no difference was observed between the positive and the
317 negative stimuli. The effect of Age was also significant ($F(1, 68) = 12.33, p < .001, \text{partial } \eta^2$
318 $= 0.15$), with higher recall for adults ($M = 5.36, SE = 0.18$) than for preadolescents ($M = 4.42,$
319 $SE = 0.20$). There were no other significant effects.

320

321 **3.2. Self-reported sense of presence – SoP evaluation of places**

322 **3.2.1. Island**

323 No significant effects were found.

324 **3.2.2. City**

325 Only the effect of Age was significant ($F(1, 68) = 4.87, p = .031, partial \eta^2 = 0.07$), with
326 preadolescents ($M = 22.20, SE = 0.76$) reporting feeling more present in the places than adults
327 ($M = 19.80, SE = 0.73$).

328

329 **3.3. Self-reported sense of presence – ITC-SOPI – evaluation of environments**

330 Significant effects of Age were found, independently of the environment, for the Spatial
331 Presence ($F(1, 68) = 7.57, p = .008, partial \eta^2 = 0.10$), Engagement ($F(1, 68) = 8.11, p = .006,$
332 $partial \eta^2 = 0.11$), and Naturalness factors ($F(1, 68) = 4.53, p = .037, partial \eta^2 = 0.06$), with
333 higher scores for preadolescents (spatial presence: $M = 72.3, SE = 2.18$; engagement: $M = 59.1,$
334 $SE = 1.22$; Naturalness: $M = 18, SE = 0.74$) than adults (spatial presence: $M = 63.8, SE = 2.18$;
335 engagement: $M = 54.2, SE = 1.22$; Naturalness: $M = 15.8, SE = 0.74$). For the Negative Effects
336 factors, no significant effect was found.

337

338 **3.4. Self-reported arousal**

339 **3.4.1. Island**

340 Only the effect of Age was almost significant ($F(1, 68) = 3.41, p = .069, partial \eta^2 =$
341 0.05), with preadolescents ($M = 5.68, SE = 0.27$) rating the places as more arousing than adults
342 ($M = 5.03, SE = 0.24$).

368 ($F(1, 68) = 28.99, p < .001, partial \eta^2 = 0.30$), with preadolescents rating places as more positive
369 ($M = 1.63, SE = 0.22$) than adults ($M = 0.04, SE = 0.20$). No other significant effects were
370 observed.

371 **3.5.2. City**

372 A significant effect of Emotion ($F(1.51, 102.69) = 62.68, p < .001, partial \eta^2 = 0.48$)
373 was observed, with places with positive stimuli ($M = 2.37, SE = 0.17$) being rated as more
374 positive than those with neutral ($M = 1.53, SE = 0.17$), and negative stimuli ($M = -0.02, SE =$
375 0.22 ; respectively $t(136) = 3.85, p < .001$, and $t(136) = 11.03, p < .001$), and places with neutral
376 stimuli being rated as more positive than those with negative stimuli ($t(136) = 7.18, p < .001$).
377 The effect of Age was significant ($F(1, 68) = 16.03, p < .001, partial \eta^2 = 0.19$), with
378 preadolescents ($M = 1.86, SE = 0.21$) rating places as more positive than adults ($M = 0.73, SE$
379 $= 0.19$). The interaction between Emotion and Age was also significant ($F(1.51, 102.69) =$
380 $15.90, p < .001, partial \eta^2 = 0.19$) (see Figure 4). The planned comparison revealed that adults
381 rated places with positive stimuli ($M = 2.38, SE = 0.22$) and those with neutral stimuli ($M =$
382 $1.04, SE = 0.22$) as more positive than those with negative stimuli ($M = -1.23, SE = 0.30$;
383 respectively $t(136) = 12.48, p < .001$, and $t(136) = 7.84, p < .001$), and places with positive
384 stimuli as more positive than those with neutral stimuli ($t(136) = 4.64, p < .001$). Preadolescents
385 rated places with positive stimuli ($M = 2.36, SE = 0.25$) as more positive than those with
386 negative stimuli ($M = 1.19, SE = 0.33; t(136) = 3.63, p = .006$), but there was no difference
387 between places with positive and neutral stimuli ($M = 2.03, SE = 0.25$) or between negative and
388 neutral for preadolescents. Moreover, preadolescents only rated places with negative stimuli as
389 more positive than adults ($t(136) = 6.40, p < .001$).

390 Insert Figure 4 here

391

392 **3.6. Correlations and regression analysis**

393 **3.6.1. Correlations**

394 Correlation analyses for all groups, then separately for adults and preadolescents, were
395 performed between the percentage of correct recall and the mean scores of self-reported arousal,
396 valence, sense of presence (SoP) per VE, and the mean per VE of different measures of head
397 movements (standard deviation of the head position on the x-, y-, and z-axis, standard deviation
398 of the head rotation on the x-, y- and z-axis, respectively, pitch, yaw and roll), pupillary dilation.
399 For the record, a higher standard deviation of the head position of rotation means more
400 movements.

401 **3.6.1.1. Island**

402 Independently of the age-group, Pearson's test showed a significant correlation between
403 recall performance and the valence rating ($r = -.134, p = .002$), and the standard deviation of
404 the head position on the y-axis ($r = .083, p = .039$). For the adult group, Pearson's test also
405 showed significant correlation between recall performance and the standard deviation of the
406 head position on the y-axis ($r = .148, p = .011$), and the z-axis ($r = .131, p = .021$). For
407 preadolescents, there were no significant correlations.

408 **3.6.1.2. City**

409 Independently of the age-group, Pearson's test showed a significant correlation between
410 recall performance and the valence score ($r = -.131, p = .003$), and the standard deviation of the
411 head position on the x-axis ($r = -.083, p = .040$). For the adult group, Pearson's test showed a
412 significant correlation between recall performance and the arousal score ($r = .115, p = .038$),
413 the valence score ($r = -.191, p = .002$), the standard deviation of the head position on the y-axis
414 ($r = -.125, p = .027$), and the BPM ($r = .123, p = .029$). For preadolescents, there were no
415 significant correlations.

416

417 **3.6.2. Regression analysis**

418 First, we report the correlations between different predictors (Arousal and Valence
419 ratings, sense of presence, standard deviation of the head position on the x-, y-, and z-axis,
420 standard deviation of pitch, yaw, and roll, pupillary dilation, heart rate (BPM), and heart rate
421 acceleration (Acc_BPM)), and, second, the regression analysis.

422 Insert Table 2 here

423 **3.6.2.1. Regression analysis**

424 The stepwise regression analysis was performed separately for the Island and City
425 environments (see Table 3). For each environment, we first included data for all participants,
426 and, second, we analyzed data for each group (adults and preadolescents) separately. The
427 percentage of correct Recall per VE was entered in the models as a dependent variable, and the
428 scores in respect of Arousal and Valence ratings, sense of presence, standard deviation of head
429 position on the x-, y-, and z-axis, standard deviation of pitch, yaw, and roll, pupillary dilation,
430 heart rate (BPM), and heart rate acceleration (Acc_BPM) as predictors.

431 Insert Table 3 here

432 **4. Discussion**

433 In the present study we aimed, first of all, to investigate the respective roles of avatar
434 incarnation, emotional responses, and sense of presence in preadolescents' and adults' memory.
435 In addition, we aimed to examine the possible effects of an avatar incarnation, the emotional
436 nature of the VR environment, and age on emotional responses and sense of presence. To
437 interpret and discuss the effects of the above-mentioned factors on memory performances more
438 easily, we will first discuss our results regarding our second objective.

439

440 **4.1. Modulation of sense of presence: effects of avatar and age**

441 Presence was assessed by means of a short questionnaire answered after each place
442 visited in both environments (City and Island), and by means of a global questionnaire - ITC-
443 SOPI [42], assessed after the visit to each environment. Contrary to our hypothesis, sense of
444 presence was not impacted by the incarnation of an avatar either in adults or preadolescents.
445 Interestingly, Tuena et al. [20] compared three conditions of embodiment in terms of sense of
446 presence, and showed that full embodiment (full-body avatar fully controlled by the
447 participant), and medium embodiment (full-body avatar with body movements controlled by
448 the participant, and navigation executed by the investigator) created more presence than low
449 embodiment (no avatar, and navigation controlled by the investigator). No difference was
450 observed between full and medium embodiment. The authors explained this last result by
451 pointing out the crucial role of motor control in presence. In these two conditions, body
452 movements were controlled by the participant, allowing them to have a stable action-intention
453 continuum. These results are in accordance with the theoretical model of Triberti and Riva [43]
454 that emphasizes a close relationship between presence, intention, and interaction in VR. In our
455 study, in the no-avatar condition, the two visible controllers in their current position were used
456 to select responses in emotional and presence questionnaires at the end of each visit. Thus, it is
457 possible that it provided sufficient motor control, and interaction with the virtual environment,
458 and thus generated a stable and predictable action-intention continuum. Our findings complete
459 the research by Tuena et al.[20], and Triberti and Riva [43], by confirming the critical role of
460 action in presence among adults, but also among preadolescents even without an avatar
461 embodiment.

462 With regard to the impact of age on presence, globally, preadolescents reported a more
463 heightened sense of presence than adults. More specifically, on the global measurement (ITC-

464 SOPI), this applied to spatial presence and engagement dimensions. These results are, at least
465 partially, in line with the results of Baumgartner et al. [27] showing a more heightened sense of
466 spatial presence in children and preadolescents than older adolescents during a realistic roller-
467 coaster ride projected on a wall. According to the authors, this could be due to ongoing
468 maturation of the prefrontal cortex in children, who are, consequently, less able to control and
469 monitor spatial sense of presence. Contrary to Sharar et al. [44] results, the preadolescents in
470 our study rated the realness of the virtual environment at the same level as adults. These authors
471 suggested that participants aged less than 18 years old rated VR environments as more real,
472 because they are more exposed to video games or other virtual experiences than older adults.
473 In our study, adults group aged between 18 and 28 years, thus is it possible that our population
474 of adults was equally exposed to video games than our preadolescents group. Concerning the
475 negative effects, no differences were observed between adults and preadolescents ratings. Our
476 data are consistent with a recent study by Tychsen and Foeller [45] on children (4 to 10 years),
477 showing good tolerance of 3D virtual reality games, without negative effects, in terms of visuo-
478 motor function, postural stability, or motion sickness. Our study points out that all dimensions
479 of presence might not be affected to the same extent by age, but more studies are necessary to
480 explore each of these dimensions specifically.

481 Interestingly, and somewhat surprisingly, on more fractionated measurements (assessed
482 after visiting each place), the effect of age on sense of presence was observed only for one of
483 the two environments: the City. This might be explained by the multiple differences between
484 the Island and the City environments, such as, familiarity with the environment, level of arousal
485 and valence of the presented stimuli, the fact that the stimuli were animated or/and
486 manufactured or not. For example, authors [46] demonstrated that young adults placed in a
487 realistic and more familiar virtual classroom felt more present than those placed in a non-
488 realistic and less familiar classroom. Emotional content of the VR is known to enhance presence

489 [24,26]; however, younger people might respond differently to emotional stimuli than adults,
490 especially to positive valence [47–50]. So, even if we did not observe a direct impact of emotion
491 on presence, it is possible that the differences in the emotional nature of the stimuli presented
492 in the City (less arousing stimuli, inclusion of positive stimuli) and Island environments might
493 partly explain the fact that the effect of age on presence was observed only for the City
494 environment. According to Detenber et al. [51], animation of the stimulus increases arousal.
495 Thus, as the stimuli presented in the City environment was mostly non-animated, altogether,
496 our results could suggest that the effect of age on sense of presence might depend on the level
497 of arousal of the VR environment. In sum, these different patterns of results between the City
498 and Island environments suggest that the effects of age on sense of presence might depend on
499 several factors (e.g., familiarity or animation), but further studies manipulating these factors
500 specifically are necessary to confirm this suggestion.

501 Globally, our results suggest a crucial role of sensorimotor interaction in sense of
502 presence in VR, as we did not observe an increased sense of presence with the avatar incarnation
503 compared to the no-avatar condition, which also allowed the participants to interact with the
504 virtual environment on a sensorimotor level. In addition, our results suggest that the impact of
505 age on sense of presence might depend on several factors, as we observed that preadolescents
506 experienced more heightened presence than adults only under certain circumstances, especially
507 in more familiar and less arousing environments.

508

509 **4.2. Emotional responses: effects of age and emotional nature of the stimuli**

510 Emotional responses were assessed with two questions of the SAM [30] assessing
511 arousal and valence after each place visited. Globally, we observed that places were rated
512 consistently with the emotional nature of the stimuli presented in it. We did not demonstrate

513 any impact of the avatar incarnation on emotional evaluations, probably due to the suggestion
514 mentioned above that sensorimotor inclusion matters more than incarnating a body.

515 We observed an effect of age on valence and arousal ratings. As regards valence, in the
516 Island environment, regardless of the valence (negative or neutral) of the stimuli presented,
517 preadolescents rated places as more positive than adults. Surprisingly, in the City environment,
518 this tendency was observed only for places with negative stimuli. The opposite results were
519 described by Cordon et al. [47], with no difference in terms of valence rating between children
520 and adults for negative stimuli, and children rating positive and neutral pictures more positively
521 than adults. It is possible that, in our study on VR, preadolescents confused the emotion
522 triggered by the virtual environment with the enjoyment of being in a virtual environment, and
523 of using an HMD. Visch et al. [52] described this as artefact emotions. Thus, it is probable that
524 the question concerning valence was particularly confusing for children. They might have
525 overestimated the positivity of places with negative stimuli, because of the peculiar sensation
526 of being near dangerous or disgusting things without any risk. It could be interesting to
527 introduce an additional question about artefact emotion in further studies to investigate this
528 hypothesis more specifically.

529 As regards the arousal rating, in general, preadolescents rated places as more arousing
530 than adults, except places with negative stimuli in the City environment. This result is consistent
531 with Cordon et al. [47], but other authors did not demonstrate this effect [53,54]. Cordon et al.
532 [47] obtained the same findings on arousal ratings of images. Surprisingly, unlike adults, in the
533 City environment, preadolescents rated places with positive, neutral, and negative stimuli as
534 equally arousing. It is possible that, in this environment, where the stimuli were less arousing
535 than in the Island environment in general, preadolescents had more difficulties estimating the
536 level of arousal that they experienced. Leventon et al. [53] suggested that between the 5th-7th
537 year of life, maturation is not complete, and emotional processes are still developing. Thus, one

538 of the consequences might be that emotional experience is less refined in children, and fine
539 evaluation in terms of arousal is rather difficult for young people even in preadolescents, as
540 observed in our study. Moreover, one limitation of this study is that, for technical reasons, we
541 did not pre-tested arousal and valence for each virtual place (e.g., the desert) as we did for each
542 stimulus. Thus, it is possible that the places themselves along with the presented stimuli could
543 have some influence on the participants' evaluation of valence and arousal.

544 Taken together, our results suggest that in VR, preadolescents are more sensitive to
545 emotional content than adults, probably because of their emotional system is still maturing. The
546 avatar incarnation did not interfere with emotional evaluation, probably because it did not differ
547 enough from our no-avatar condition in terms of sensorimotor interactions.

548

549 **4.3. Memory performances in VR**

550 ***4.3.1. Avatar incarnation could enhance EEM in preadolescents***

551 We hypothesized that EEM would be modulated by the avatar incarnation, leading to
552 greater recall of emotional stimuli than non-emotional stimuli in the avatar condition, especially
553 for preadolescents. In general, recall was less effective in preadolescents than adults, but, more
554 importantly, in both groups, we observed better recall for emotional than neutral stimuli in the
555 Island and City environments. These results confirm previous studies that showed EEM in
556 children, preadolescents, and adolescents [53–55]. Partially in accordance with our hypothesis,
557 though only in the Island environment where we observed an interaction between Avatar and
558 Age, we observed that embodying an avatar allowed preadolescents to perform at the same
559 level as adults. This interaction might be explained by the fact that at the descriptive level avatar
560 embodiment seemed to improve, on average, preadolescents' but not adult's memory, although,
561 as shown previously [20] no significant differences were observed neither for adults nor

562 preadolescents between avatar and no-avatar conditions in planned comparisons. Thus, the
563 preadolescents memory performance in our study was somehow more sensitive to embodiment
564 of avatar than that of young adults, but surprisingly only in one environment, the Island. This
565 difference is difficult to explain, because the statistical analysis (ITC-SOPI) and the inspection
566 of descriptive data (SoP, valence and arousal) for the different measures we used in our study
567 do not indicate that these two environments had clearly different impact on our participants.
568 However, it is possible that some other factors that we did not control and measure have
569 differentially modulated the impact of avatar on memory performance in Island and City
570 environment, such as familiarity, that is otherwise known to have an impact on memory [56,57].
571 Globally, we demonstrated that incarnation of an avatar during the encoding of stimuli could
572 impact memory differently in adults and preadolescents, but more studies are necessary to
573 explore this effect further.

574

575 ***4.3.2. Predicting memory in VR in adults and preadolescents***

576 Regression analysis were performed to investigate which variables could explain
577 memory performances in VR. Our variables of interest were self-reported measures of sense of
578 presence, arousal, and valence, and physiological measurements of pupillary dilation, heart rate,
579 heart rate acceleration, and movements of the head (standard deviation of position and rotation
580 on the three spatial axes).

581 The regression analysis revealed valence as a predictor of memory performances for the
582 analysis including all participants, in both environments, Island and City. These results seem to
583 be somehow inconsistent with previous studies on adults [58] and children [59], which
584 attributed memory performances more to arousal than valence. However, the analysis of
585 correlations between predictors showed that, in our study, the arousal and valence ratings of
586 each place were strongly correlated with each other. Moreover, valence explained less than 2%

587 of the data variance for the analysis including all participants. So, although our results suggest
588 that valence of the VR environment is a predictor of memory performance in preadolescents
589 and adults, this suggestion needs further investigations.

590 The separate analysis according to group, showed that for adults, valence was still a
591 predictor of memory performance, along with SD of head roll in the City environment, but only
592 SD of head position was a predictor in the Island environment. As regards these two measures,
593 they are supposed to reflect the exploration of a virtual environment [60,61]. Thus, it is possible
594 that, by changing their point of view frequently, young adults increased their exploration of the
595 stimulus, leading to richer visual encoding, and indeed better recall performances. For
596 preadolescents, no variables were predictors of memory performance. It is possible that the
597 reduced number of participants in the separate analysis prevented from significant effects from
598 being observed in both environments for preadolescents. In addition, in the case of
599 preadolescents, it has been suggested that there is considerable variability in EEM results due
600 to different methodological aspects [59]. So, it is possible that, along with the reduced number
601 of participants, the fact that we did not find any predictor for memory performance in
602 preadolescents has multifactorial causes. For example, as discussed previously in section 4.2,
603 the self-evaluation of places in respect of valence and arousal was probably affected by the fact
604 that preadolescents probably misunderstood these evaluations. In addition, the correlation
605 analysis between predictors shows that physiological and self-reported emotional measures
606 were not consistent for preadolescents. Indeed, there were only a few correlations between self-
607 evaluated arousal or valence in respect of places and physiological measures (as an example,
608 heart rate, heart rate acceleration, SD of the yaw were correlated with arousal in the Island
609 environment, but not in the City environment – see *supplementary material*).

610 To summarize, even if our study suggests that valence is a predictor of memory
611 performance in both preadolescents and adults, and that, in adults, other factors reflecting

612 environment exploration might also contribute to memory performance. In fact, the part of the
613 data variance which is explained by each of our models (global and separate analysis) is less
614 than 6.5%. For reference, Falk and Miller [62], state that a model regarding human data should
615 strive for a minimum of 10%. Moreover, our interpretation has to be treated with caution, as
616 we observed many correlations between our different predictors. Interestingly, these
617 correlations are consistent with the literature. For example, valence, arousal, and presence
618 correlated with one another, as previously reported by several other studies [24,33,63,64]. The
619 standard deviation (SD) of pitch was significantly correlated with self-evaluated arousal (only
620 in the Island), valence, and presence, and the SD of yaw was correlated with arousal. Similar
621 correlations were observed by Li et al. [60]. The mean heart rate was correlated with arousal,
622 and the mean acceleration with arousal, and sense of presence in the Island environment, which
623 is consistent with the Rose and Chen [65] study.

624

625 **5. Conclusion**

626 In the present study, we showed that EEM can occur in VR in both adults and
627 preadolescents. Interestingly, incarnating an avatar permitted preadolescents to have the similar
628 memory performances than adults. We found that self-evaluated valence in respect of virtual
629 places predicted memory performance, probably more consistently in adults than
630 preadolescents, and that head movements were also involved in adults. This could have
631 practical applications in the field of professional training or learning, by including these
632 measures in protocols. Interestingly these conclusions are not applicable to preadolescents,
633 further studies would be necessary to explore the factors that could predict memory
634 performances in VR for younger population. This study draws particular attention to the fact
635 that results on an adult population are not necessarily extendable to preadolescents.

636 We also found that valence, arousal, and sense of presence ratings were impacted by
637 age, with more positive and higher ratings of arousal and certain aspects of presence among
638 preadolescents than in adults. So, our results draw attention to the susceptibility young
639 population, even preadolescents, to feeling aroused and present in virtual environments.
640 Regarding the variability of results on presence evaluations, studies on preadolescents and
641 children should particularly be careful in their choices of questionnaires. Surprisingly, the
642 avatar condition had no effect on these measures, leading us to hypothesize that the ability to
643 interact and be included at a sensorimotor level is more important than the incarnation of a
644 body.

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657

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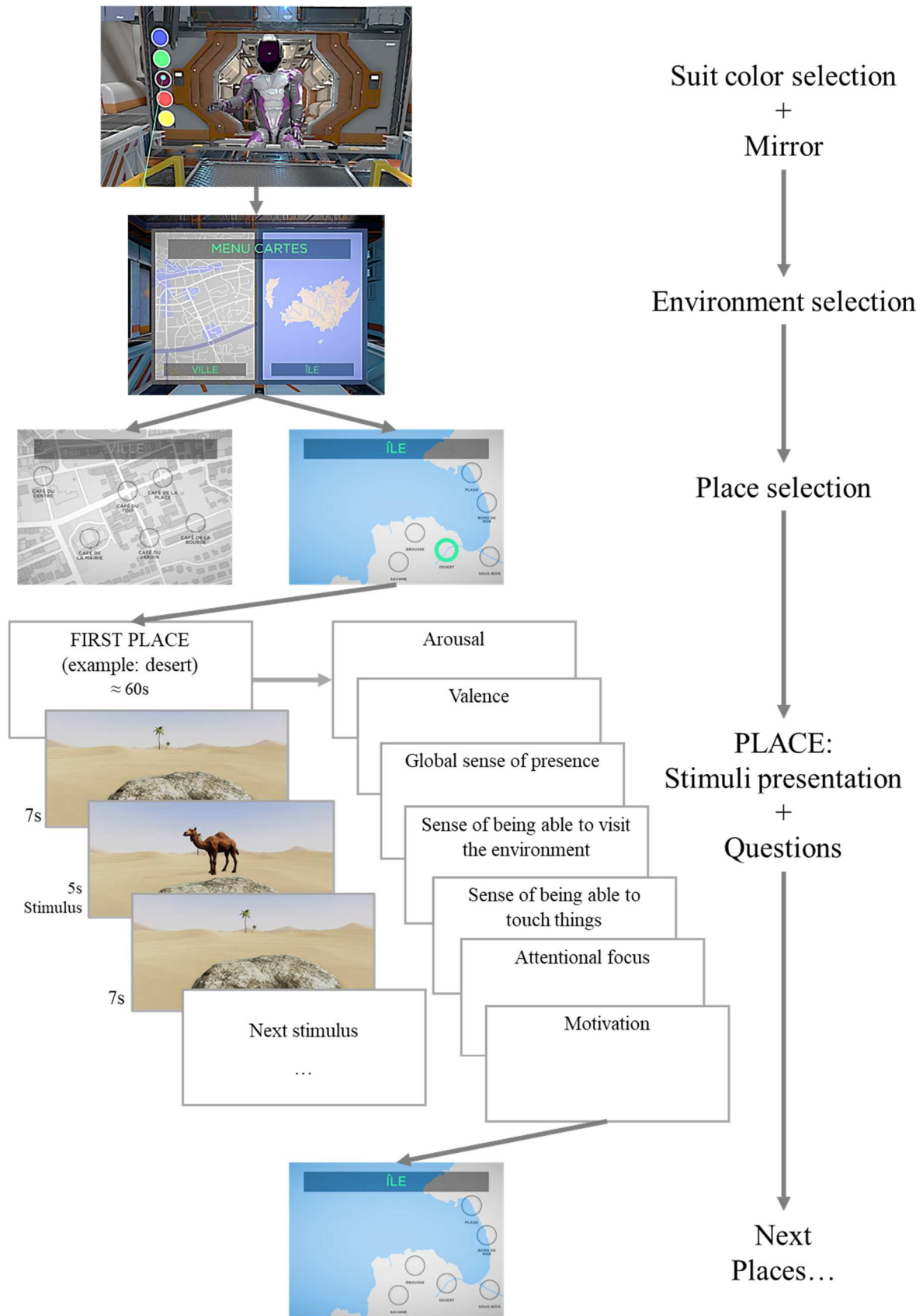


Figure 1. Presentation protocol of the two virtual environments (city and island), and of the six different places in each environment.

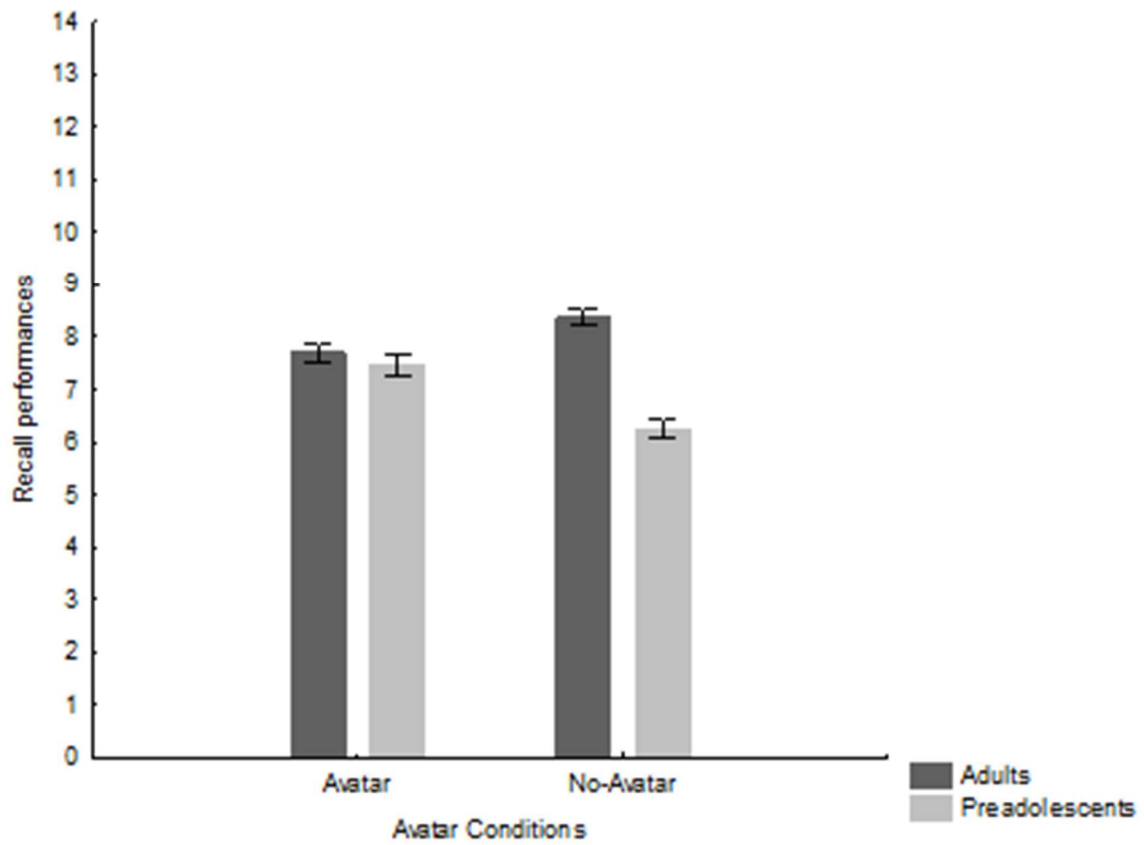


Figure 1. Mean score of Recall performance for the Island environment (min = 0, max = 14), according to Age (adults and preadolescents), and Avatar condition (avatar and no-avatar).

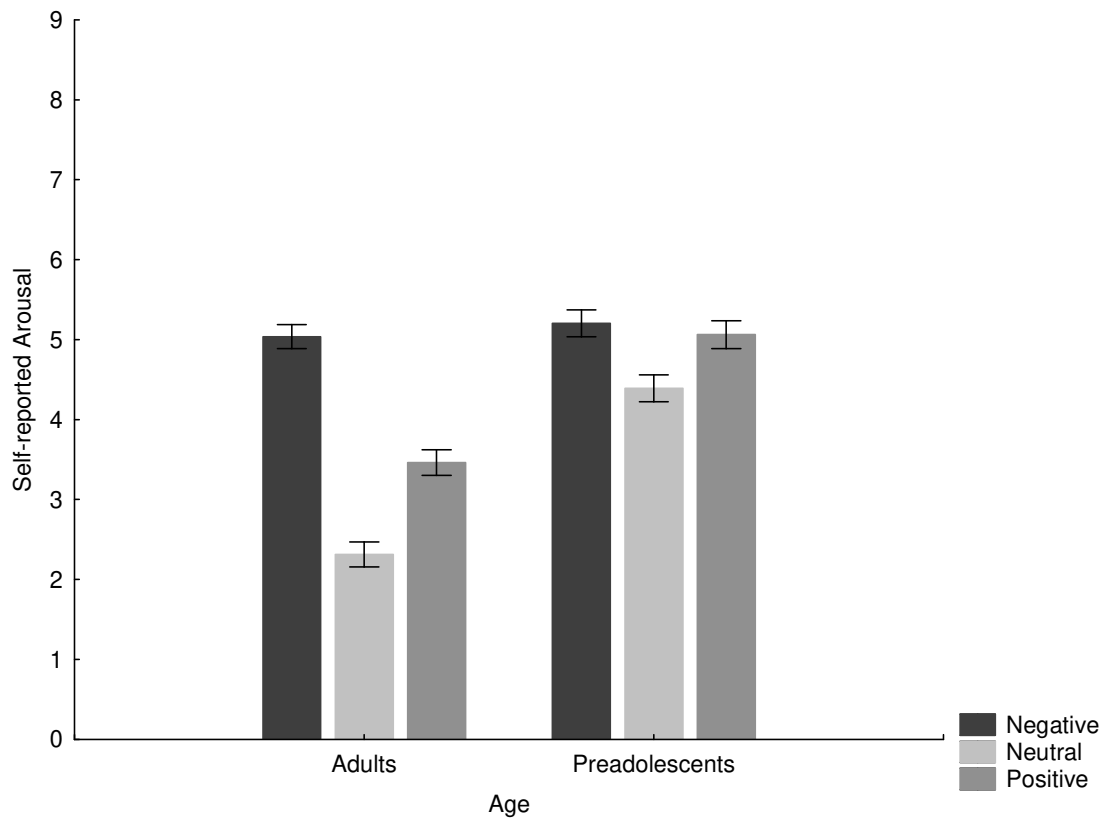


Figure 1. Mean score of Self-reported arousal for the City environment (min = 0 – weakly arousing, max = 9 – very arousing), according to Age (adults and preadolescents), and Emotion (negative and neutral).

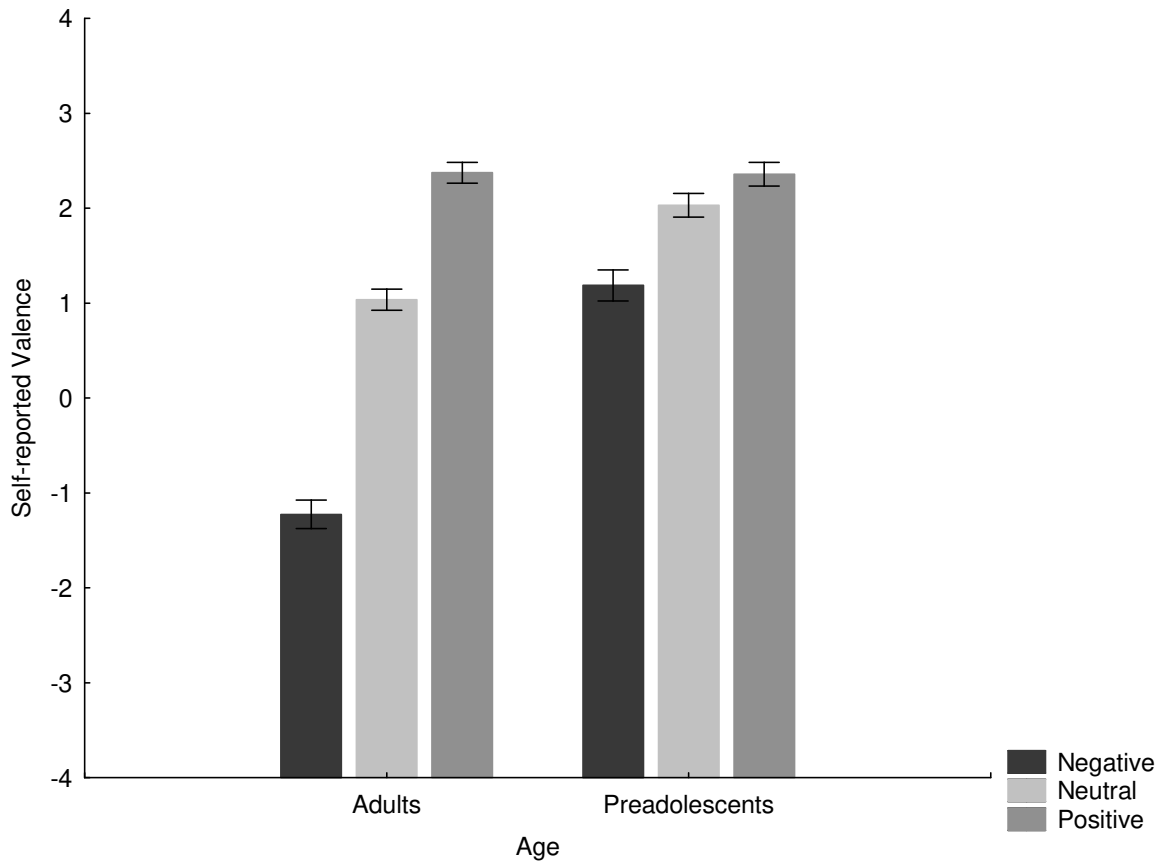


Figure 1. Mean score of Self-reported valence for the City environment (min = -4 – very unpleasant, max = 4 – very pleasant), according to Age (adults and preadolescents), and Emotion (negative and neutral).

Table 1. Resume of the results of the ANOVAs analysis in the Island and City environment with Emotion (Island – negative vs. neutral; City - positive vs. negative vs. neutral) as within-subject factor and Age (Adults vs. Preadolescents), and Avatar (Avatar vs. No-Avatar) as between-subject factors.

VD	Effects	df	F	p	partial η^2
ISLAND					
Recall performances	Emotion	68	87.13	< .001	0.56
	Age	68	11.54	< .001	0.15
	Age * Avatar	68	7.46	.008	0.10
Sense of Presence	NS				
Arousal	Age	68	3.41	.069	0.05
Valence	Emotion	68	18.44	< .001	0.21
	Age	68	28.99	< .001	0.30
CITY					
Recall performances	Emotion	136	27.02	< .001	0.28
	Age	68	12.33	< .001	0.15
Sense of Presence	Age	68	4.87	.031	0.07
Arousal	Emotion	112.06	25.67	< .001	0.27
	Age	68	12.39	< .001	0.15
	Emotion * Age	112.06	8.13	.001	0.11
Valence	Emotion	102.69	62.68	< .001	0.48
	Age	68	16.03	< .001	0.19
	Emotion * Age	102.69	15.90	< .001	0.19

Table 2. Results of the analysis of correlations between predictors in the Island and City environments for all groups taken together. Only significant correlations are reported.

	Arousal rating	Valence rating	SoP	SD head position x	SD head position y	SD head position z	SD Pitch	SD Yaw	SD Roll	Pupillary dilation	BPM	Acc_BPM
ISLAND												
Arousal rating												
Valence rating	$r = -.113$ $p = .016$											
SoP	$r = .420$ $p < .001$	$r = .171$ $p < .001$										
SD head position x	<i>ns</i>	$r = .219$ $p < .001$	<i>ns</i>									
SD head position y	<i>ns</i>	$r = .120$ $p = .010$	<i>ms</i>	$r = .500$ $p < .001$								
SD head position z	<i>ns</i>	$r = .150$ $p = .001$	$r = .123$ $p = .009$	$r = .589$ $p < .001$	$r = .629$ $p < .001$							
SD Pitch	$r = .120$ $p = .010$	$r = .169$ $p < .001$	$r = .173$ $p < .001$	$r = .151$ $p = .001$	$r = .201$ $p < .001$	$r = .179$ $p < .001$						
SD Yaw	$r = .095$ $p = .044$	<i>ns</i>	<i>ns</i>	$r = .322$ $p < .001$	$r = .208$ $p < .001$	$r = .132$ $p = .005$	$r = .220$ $p < .001$					
SD Roll	<i>ns</i>	$r = .181$ $p < .001$	$r = .120$ $p = .011$	$r = .196$ $p < .001$	$r = .200$ $p < .001$	$r = .155$ $p = .001$	<i>ns</i>	<i>ns</i>				
Pupillary dilation	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	$r = .110$ $p = .019$			
BPM	$r = .098$ $p = .038$	<i>ns</i>	<i>ns</i>	<i>ns</i>	$r = .139$ $p = .003$	$r = .145$ $p = .002$	<i>ns</i>	<i>ns</i>	$r = .138$ $p = .003$	<i>ns</i>		
Acc_BPM	$r = .121$ $p = .010$	<i>ns</i>	$r = -.128$ $p = .003$	<i>ns</i>	<i>ns</i>	$r = .103$ $p = .028$	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	$r = .540$ $p < .001$	
CITY												
Arousal rating												
Valence rating	$r = .108$ $p = .021$											
SoP	$r = .372$ $p < .001$	$r = .321$ $p < .001$										
SD head position x	<i>ns</i>	<i>ns</i>	<i>ns</i>									
SD head position y	<i>ns</i>	<i>ns</i>	<i>ns</i>	$r = .608$ $p < .001$								
SD head position z	<i>ns</i>	$r = .146$ $p = .002$	$r = .128$ $p = .006$	$r = .652$ $p < .001$	$r = .787$ $p < .001$							
SD Pitch	<i>ns</i>	$r = .153$ $p = .001$	$r = .113$ $p = .016$	$r = .119$ $p = .011$	$r = .210$ $p < .001$	$r = .213$ $p < .001$						
SD Yaw	$r = .095$ $p = .022$	<i>ns</i>	<i>ns</i>	$r = .260$ $p < .001$	$r = .198$ $p < .001$	$r = .156$ $p < .001$	$r = .283$ $p < .001$					
SD Roll	<i>ns</i>	<i>ns</i>	<i>ns</i>	$r = .303$ $p < .001$	$r = .286$ $p < .001$	$r = .289$ $p < .001$	$r = .092$ $p = .049$	$r = .234$ $p < .001$				
Pupillary dilation	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>			
BPM	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	$r = .100$ $p = .033$	<i>ns</i>		
Acc_BPM	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	$r = .100$ $p = .033$	<i>ns</i>	<i>ns</i>	<i>ns</i>	$r = .528$ $p < .001$	

Table 3. Results of stepwise regressions for all device conditions, adults, and preadolescents for the recall task (only significant regressions are reported).

Variables	Model	Predictors	β, (p)	R² adjusted
ISLAND				
Global				
Percentage Recall	1	Valence	-0.134, (.005)	.016
ADULTS				
Percentage Recall	1	SD Head Position y	0.148, (.022)	.022
PREADOLESCENTS				
Percentage Recall		NS		
CITY				
Global				
Percentage Recall	1	Valence	- 0.131 (.005)	.017
ADULTS				
Percentage Recall	1	Valence	- 0.191 (.003)	.037
Percentage Recall	2	Valence	- 0.220 (.001)	.063
		SD Roll	0.165 (.011)	
PREADOLESCENTS				
Percentage Recall		NS		

Note. Probability of F at .05 for entry, and at .10 for removal. The significance of β values is given in brackets in the tables.