

# Positive correlations between social hierarchy and memory in weaning mice and young children

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## Article

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1 **Positive correlations between social hierarchy and memory in weaning mice and young children**

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14

15 **Abstract**

16 Social hierarchy is associated with various phenotypes. Although memory is known to be  
17 important for hierarchy formation, the difference between dominant and subordinate individuals in  
18 memory abilities remains not well investigated. In this study, we examined memory performance  
19 in weanling mice with different social ranks and found better memory abilities in dominant mice, along

20 with higher memory-related gene expressions and greater long-term potentiation in the hippocampus  
21 than the subordinates. To validate this correlation across species, through inventory, behavioral and  
22 event-related potential studies, we further identified better memory abilities in preschool children with  
23 higher social dominance. Better memory potentially helped children in processing dominance facial  
24 cues and learning social strategies to acquire higher social positions. Our study shows a remarkable  
25 similarity between humans and mice in the association between memory and social hierarchy and  
26 provides a new perspective on the social interaction in young with potential implications for preschool  
27 education.

28

## 29 **Introduction**

30 The dominance hierarchy is a common social structure in several animal species. Under a stable  
31 hierarchical relationship, dominant animals would have priority in the choice of resources such as  
32 territory, food, and mating partners, whereas subordinate individuals would receive fewer resources  
33 but would be subjected to less conflict and peril<sup>1</sup>. Hierarchical ranking, therefore, greatly influences  
34 different behaviors, especially social behaviors such as mating and aggression<sup>2</sup>, as well as  
35 physiological components, such as stress hormones, cardiovascular function and the immune system<sup>3</sup>.  
36 The causality or cross-talk between social rankings and different phenotypes is extremely complicated  
37 and remains to be explored thoroughly.

38 The conceptual framework of social hierarchy has been applied to human interactions and has

39 uncovered recognizable dominance hierarchies, even in preschool-aged children<sup>4-7</sup>. Observational  
40 studies have indicated that children with more aggressive behaviors are usually recognized as higher  
41 ranking in their group and gain more positive peer regard than subordinate children<sup>8-11</sup>. In addition to  
42 the tendency to be coercive, young children's adoption of and change in social strategies to reach their  
43 dominance goals are also the focus of child development research<sup>9,12,13</sup>. Those who can gradually  
44 change from using coercive strategies to using prosocial strategies or dual strategies to control  
45 resources are more likely to achieve higher status for a long time<sup>9,12,13</sup>. Cognitive-oriented studies in  
46 recent years have further indicated that human children first be aware of social dominance cues in early  
47 infancy<sup>14</sup>. Young children aged 3 to 4 years old are able to use multiple physical and social cues to  
48 detect the social dominance status of others (e.g., facial expressions, body size or body postures, and  
49 the interaction of characters in the experimental films)<sup>15-17</sup>. At approximately 5 or 6 years of age, some  
50 children can even determine the relationships of dominance based only on static photos<sup>15</sup>. Surprisingly,  
51 in the face of children's amazing learning ability concerning social dominance, research on factors  
52 related to social dominance has mostly focused on environmental factors, such as interaction  
53 experience, parenting style, moral education, and cultural background<sup>9,12,18-20</sup>. The neural mechanisms  
54 of how children recognize social dominance cues and the underlying cognitive ability that supports  
55 social strategy learning have rarely been studied.

56 Social hierarchies, from the neural mechanisms of dominant behaviors to the impacts of social  
57 status on a variety of phenotypes, have also been studied in laboratory model organisms. For rodent

58 species, including mice and rats, aggression was used to be the major assay to evaluate social status  
59 and explore the relationships of social hierarchy with innate behaviors, anxiety/depression-like  
60 behaviors, cognitive ability and other physiological phenotypes<sup>21-25</sup>. However, because mainly adult  
61 males perform aggressive behaviors, the social hierarchies of female and young animals have rarely  
62 been explored<sup>26-28</sup>. On the other hand, tube test, in which one mouse forces its opponent backward out  
63 of a tube, is relatively easy for mice to complete and has been used largely to study social dominance<sup>29-</sup>  
64 <sup>31</sup>. Since the assay only requires mice moving forward and backward inside the tube, it presents as a  
65 platform to investigate the relationship between social hierarchy and other traits not only in adult but  
66 also in young animals<sup>28,32</sup>.

67 Mice have been used widely as a standard model organism for different human biology fields,  
68 including psychological and neurological diseases<sup>33-36</sup>. However, parallel studies between humans and  
69 mice, especially in behavioral research, have been rare in the past. In recent years, neuroscientists have  
70 started to study these two species together and found surprising similarities, not only in behaviors but  
71 also in underlying mechanisms<sup>37</sup>. Mouse studies could offer various techniques (including intrusive  
72 designs and manipulative approaches) to investigate the mechanistic questions that could not be  
73 conducted in human subjects; the verification and extended exploration in human studies further  
74 emphasized the biological significance for the discovery. The findings from these two species therefore  
75 could complement each other and provide important information from different perspectives. By  
76 taking advantage of this comparative and complementary approach to study social dominance

77 behaviors, our recent study has presented comparable social ranks between young human children and  
78 weanling mice and further revealed important intrinsic factors involved in the early formation of social  
79 hierarchy<sup>32</sup>. This study, however, did not identify the potential role of learning and memory in  
80 hierarchical formation in mice and children.

81 While the influence of social status on different behavioral or physiological characteristics have  
82 been investigated largely, the relationship between memory and social hierarchy was much less  
83 explored. Studies in rat and anolis have suggested that memory could play a role to enhance the  
84 stability of the hierarchical relationship<sup>38,39</sup>. Whether there is a difference between dominant and  
85 subordinate individuals in memory abilities, however, remains controversial as an open question. From  
86 an evolutionary perspective, abilities to remember own social status or recognize others should be  
87 important especially for subordinate animals to avoid conflict<sup>39-42</sup>. On the other hand, better memory  
88 could potentially help dominant animals to memorize surrounding environments or acquire new skills  
89 to control resources. Unfortunately, previous studies in mice were unable to provide a conclusive  
90 answer<sup>25,43,44</sup>. In human children, to our knowledge, this question has never been asked. In order to  
91 address this question, in this report, we examined memory performance in mice and children and found  
92 a positive correlation between social hierarchy and memory abilities. Mechanistically, dominant mice  
93 showed higher expression of memory-related genes and a greater long-term potentiation (LTP) in the  
94 hippocampus than subordinates. Functionally, better memory in human children contributes to the  
95 learning and adoption of social strategies as well as the neurocognitive processing of social dominant

96 cues for acquisition of social dominance status. The findings of this study therefore provide new insight  
97 into the research field of social interaction in both animals and human children and have beneficial  
98 implications for early childhood education.

99

## 100 **Results**

### 101 **High-rank mice exhibited better memory ability.**

102       Based on our previous study<sup>32</sup>, a social hierarchy in weanling mice can be established in 4 mice  
103 in a cage by tube test (Figure S1). To study the correlation between social ranks and memory ability,  
104 we first conducted the novel object recognition (NOR) test with a 1-hour interval between training and  
105 test sessions to evaluate short-term recognition memory in weanling mice<sup>45</sup>. Surprisingly, we found  
106 that only 1<sup>st</sup>- and 2<sup>nd</sup>-rank mice spent significantly more time exploring a novel object but not 3<sup>rd</sup>- and  
107 4<sup>th</sup>-rank mice (Figure 1A), suggesting that, in contrast to dominant mice, subordinate mice had more  
108 difficulties recognizing a familiar object in the test. The difference in discrimination index between  
109 1<sup>st</sup>- and 4<sup>th</sup>-rank mice was close to significant ( $p = 0.0771$ ) (Figure 1B), and the index was negatively  
110 correlated with the four levels of social rank evaluated (Figure 1C). Next, we tested long-term memory  
111 using the NOR test with a 24-hour interval between training and test sessions. Similar to the results  
112 for short-term memory, there was no difference in exploring time between the familiar and novel  
113 objects in 4<sup>th</sup>-rank weanling mice (Figure 1D). The discrimination index was significantly different  
114 between 1<sup>st</sup>- and 4<sup>th</sup>-rank mice and negatively correlated with social ranks (Figure 1E and 1F). The

115 higher discrimination index in dominant mice was unlikely due to higher curiosity, since there was no  
116 correlation between social ranks and exploratory behavior in Novelty investigation test (Figure 1G).  
117 Together, for both short- and long-term tests, weanling mice with higher rank generally had better  
118 ability in recognition memory. In addition, in adult animals, dominant mice also exhibited better  
119 performance than subordinate mice for both short-term and long-term memory (Figure S2A-F).

120 To further explore the correlation between social ranks and memory ability, we also applied the  
121 spontaneous alternation Y maze to examine spatial working memory in weanling mice<sup>46</sup>. The results  
122 showed a significantly higher alternation rate in 1<sup>st</sup>-rank mice than in 4<sup>th</sup>-rank mice (Figure 1H), again  
123 indicating better memory in dominant mice than in subordinate mice. The negative correlation between  
124 alternation rate and social ranks was also significant (Figure 1I). In adult mice, we observed a similar  
125 phenomenon in the difference and correlation of alternation rates, although the data were not  
126 statistically significant (Figure S2G and S2H).

127

### 128 **High-rank mice showed higher expression levels of memory-related genes**

129 Identifying better memory in high-rank mice led us to investigate the expression levels of  
130 memory-related genes in the hippocampus, one of the crucial brain regions for memory consolidation  
131 and storage<sup>47</sup>. The results of quantitative PCR showed that the social ranks were negative correlated  
132 with the expression levels of *GRIN2B* (NR2B)<sup>48</sup>, a subunit of NMDA receptor that improves synaptic  
133 plasticity and memory in neurons, and *Phf2*, a histone demethylase (Figure 2A and B). The negative

134 correlation between ranks and *Creb* expression was also at the margin of statistical significance (Figure  
135 2C). *Phf2* and *Creb* have been reported to be involved in the TrkB-CREB signaling pathway for  
136 memory consolidation<sup>47</sup>. It is worth noting that other genes involved in this pathway, including *Bdnf*,  
137 *Ntrk2* (TrkB), *Cdk5*, and *Camk2*, all showed decreasing trends with ranks, although the data is not  
138 statistically significant (Figure S3).

139

140 **There was higher LTP in hippocampal neurons in 1<sup>st</sup>-rank mice than in 4<sup>th</sup>-rank mice.**

141 The TrkB-CREB signaling pathway has been implicated in hippocampal LTP<sup>47</sup>, which is critical  
142 for memory formation and memory consolidation<sup>49</sup>. To test whether augmented LTP caused the  
143 enhanced memory ability in mice with a higher social rank, we measured the field excitatory  
144 postsynaptic potentials (fEPSPs) on the dendritic fields of CA1 neurons and stimulated CA3 to CA1  
145 Schaffer collaterals in acute hippocampal slices prepared from either 1<sup>st</sup>- or 4<sup>th</sup>-rank weanling mice  
146 (Figure 2D). Our data showed that acute hippocampal slices prepared from 1<sup>st</sup>-rank mice had greater  
147 augmented LTP than slices isolated from 4<sup>th</sup>-rank mice (Figure 2E-G). The result therefore supported  
148 positive correlations between social ranks and memory. A similar phenomenon has also been shown  
149 in slices prepared from adult mice (Figure S4).

150

151 **High-rank children exhibited better memory ability.**

152 The discovery in weanling mice raised a new question of whether the correlation between social  
153 ranks and memory could also be observed in young human children. To answer this question, we  
154 conducted behavioral tests on 164 preschool children. Based on the experimental design in the mouse  
155 tube test, we first arranged the young children into groups of four and established their social  
156 hierarchies by evaluating their behaviors while they played a competitive bunny game with a round  
157 robin design. The bunny game has been used as a comparable task to the mouse tube test in a previous  
158 study<sup>32</sup>. We next used the Picture memory subtest (for recognition memory) and Zoo subtest (for spatial  
159 working memory) from the Wechsler Preschool and Primary Scale of Intelligence through one-by-one  
160 testing to compare memory ability between 1<sup>st</sup>-rank and 4<sup>th</sup>-rank children (n=82) (Figure 3A)<sup>50</sup>. For  
161 both assays, 1<sup>st</sup>-rank children tended to perform better than 4<sup>th</sup>-rank children (Figure S5A and B). The  
162 working memory index (WMI) that integrated two memory subtests showed a significantly higher  
163 score in 1<sup>st</sup>-rank children than in 4<sup>th</sup>-rank children (Figure 3B). In addition to the bunny game  
164 evaluation conducted in a well-designed experimental context, we also asked the preschool teachers  
165 to evaluate the children's social dominance level according to their daily observations using the Social  
166 Dominance Rating Scale (Figure 3A), which has been shown to be consistent with the social ranks by  
167 the bunny game<sup>32,51</sup>. The dominance levels in these 82 children showed trends correlated with memory  
168 scores in both Picture memory and Zoo subtests (Figure S5C and D). The correlation between the WMI  
169 and dominance levels was also statistically significant (Figure 3C).

170 To further validate better memory in dominant children, another 175 young children from 3 other  
171 preschools were recruited for the inventory study (Figure 3D). The Working Memory subscale of the  
172 Childhood Executive Functioning Inventory was used to evaluate the children's working memory  
173 performance based on teachers' observations in preschool classrooms and was thought to reflect the  
174 children's abilities to retrieve classroom rules or learning experiences from long-term memory for  
175 application in daily interaction<sup>52</sup>. Consistent with previous data based on the Wechsler scale, the  
176 memory score evaluated by the Childhood Executive Functioning Inventory was also correlated with  
177 dominance levels (Figure 3D). Together, the results from both behavioral tasks and inventories  
178 suggested that memory ability in children was positively correlated with social status as well as  
179 dominance levels.

180

181 **Memory ability was correlated with prosocial strategy use but not coercive strategy use.**

182 To investigate the potential functions of memory in the formation of social hierarchy, for 175  
183 children in inventory study, we applied the Resource Control Strategy Scale to measure children's  
184 resource control ability and strategy usage<sup>53</sup>. As expected, children with higher social dominance levels  
185 possess better abilities in resource control, prosocial strategies and coercive strategies (Figure 4A-C).  
186 However, the memory score was surprisingly only related to resource control with children's use of  
187 prosocial strategies (Figure 4D and 4E) but not coercive strategies use (Figure 4F). These results  
188 suggested that memory may play a crucial role in the acquisition and adoption of prosocial strategies.

189 We therefore further asked whether the relationship between children's memory and social status is  
190 mainly due to the mediation of prosocial strategy learning. The regression analysis of the mediation  
191 effect showed that all  $\beta$  values in the four regression analysis steps reached significant levels (Table  
192 S1). According to Baron Kenny's (1986) criterion<sup>54</sup>, this result demonstrated a "partial mediation  
193 effect". The Sobel test was further conducted with a 95% confidence interval and showed a significant  
194 mediation effect (Sobel  $z=5.221$ ,  $p < 0.001$ ). The results suggested that prosocial strategy learning  
195 mediates the relationship between children's memory ability and their social dominance (Figure 4G),  
196 whereas direct effects still need to be investigated.

197

#### 198 **Children with higher social rank were superior in processing facial cues of social dominance.**

199 Last, to further explore the direct function of memory on social dominance formation, we  
200 designed an Event-related potential study (ERP) to investigate how social status affects children's  
201 processing of social dominance cues. In the task, 1<sup>st</sup>- and 4<sup>th</sup>-rank children based on the bunny game  
202 ( $n=24$ ) were asked to watch the peer faces with different social facial expressions (dominant, neutral  
203 and subordinate faces) on the screen (Figure 5A)<sup>55-57</sup>. To remove other irrelevant effects and ensure  
204 that the experimental stimulus specifically triggered the processing of social dominance information,  
205 all the face photos were not repeated to avoid the face recognition effect and the presentation order of  
206 the facial expression types was randomly assigned to avoid the old/new effect.

207 Our ERP study focused on FN400, a negative component elicited approximately 300-450 ms at

208 frontal areas<sup>58,59</sup>, which is related to implicit memory during semantic category-based inferences<sup>60-62</sup>.  
209 Employing difference waves to exclude the individual difference (by subtracting the averaged  
210 amplitude of neutral-face condition) (Figure 5B), the two-way ANOVA of FN400 showed that both  
211 the main effect of social status and social dominance facial expressions, as well as their interaction,  
212 were significant (Table S2). In the between-group comparison, when processing the dominant facial  
213 expression, 1<sup>st</sup>-rank children displayed a smaller FN400 amplitude than that of 4<sup>th</sup>-rank children  
214 (Figure 5C and Table S3). In the within-group comparison, 1<sup>st</sup>-rank children exhibited a smaller FN400  
215 amplitude in response to dominant faces than to subordinate faces; by contrast, such a difference in  
216 FN400 amplitude was not found in 4<sup>th</sup>-rank children. Since a larger FN400 amplitude is evoked by the  
217 processing of unexpected fluency compared to previous social knowledge<sup>63</sup>, a smaller FN400  
218 amplitude in response to dominant faces implies that 1<sup>st</sup>-rank children have a better fluent ability in  
219 processing dominant faces than 4<sup>th</sup>-rank children. The results of our ERP study, therefore, implied that  
220 children with higher social rank have superior implicit memory in recognize social dominance cues.

221

## 222 **Discussion**

223 In this study, by examining the relationships of social hierarchy with memory abilities in mice,  
224 we found that dominant mice showed better performance in recognition and spatial working memory,  
225 along with higher expressions of memory-related genes and augmented LTP in the hippocampus. To  
226 explore this phenomenon across species, we combined multiple approaches to demonstrate that

227 children with higher social status also have better memory ability. The data further suggested that better  
228 memory may assist children in acquiring social strategies and recognizing social dominance cues. We  
229 believe this is the first report to present an association between social hierarchy and memory in two  
230 species in parallel, especially in humans. While mouse model indicated the possible molecular and  
231 neural mechanisms underlying the association, children study revealed the functional importance of  
232 memory in acquiring and maintaining dominance status. By making a breakthrough in the use of  
233 different species to answer specific questions and reveal information that could not be approached  
234 solely by one species, our study not only presented a remarkable similarity between children and mice  
235 but also provided new insight into the research of social interaction as well as of learning and memory  
236 in the fields of biology, psychology, and education.

237       Animals in the wild are constantly facing changing environments. Better memory could therefore  
238 enhance individuals' opportunities to access the resources and potentially obtain higher social status.  
239 However, although dominance with better spatial learning has been implicated in few studies<sup>25,64,65</sup>,  
240 recent research in mice failed to detect any connection between social ranks and memory<sup>43,44</sup>. Our data  
241 consistently showed this correlation in short- and long-term memory, in young and old mice, in  
242 recognition (NOR) and spatial working memory (Y maze). More importantly, the findings in mice led  
243 us to identify better memory in dominant children, which, to our knowledge, has never been reported  
244 in previous research. Similar to mice, children with higher social ranks showed better short-term and  
245 long-term memory, recognition memory, spatial working memory and perhaps implicit memory. Since

246 neural mechanisms underlying different types of memory may not be all identical, how social  
247 dominance correlates with these broad memory enhancements remains to be explored. While the  
248 functions of hippocampus in recognition memory, working memory and implicit memory have all  
249 been documented<sup>66-68</sup>, our studies suggested there were higher expressions of memory-related genes  
250 and greater LTP in dominant mice. In addition to the hippocampus, a previous study based on the tube  
251 test also suggested greater strength of excitatory synaptic inputs in mice with higher ranking in the  
252 medial prefrontal cortex<sup>31</sup>, which is essential for both short-term and long-term memory<sup>69</sup>. Therefore,  
253 these two regions present potential neuronal substrates for future research on neurophysiological  
254 connections between social hierarchy and memory ability in both mice and children.

255       Identifying social status associated with memory provided new insight into human children's social  
256 interactions. Our previous research found that the formation of social hierarchy is affected by intrinsic  
257 characteristics<sup>32</sup>. The differences in temperament between individuals make the early formation of  
258 social hierarchy easier and less conflicting. However, young children still need to learn to interact with  
259 their peers while the social hierarchy is initially formed. Our present study found that social dominance  
260 level and resource control ability were strongly correlated and that better memory was related to  
261 increased adoption of prosocial strategies. To compete for resources and status in the classroom,  
262 children might instinctively use coercive strategies, which are usually prohibited by teachers and  
263 ostracized by peers. The flexible adoption of prosocial strategies is obviously more acceptable and  
264 effective during social interaction<sup>9,12</sup>. Previous studies have shown that the use of prosocial strategies

265 could be influenced by parenting or school moral education or could be due to the accumulation of  
266 interaction experience. However, the reason some children can effectively learn and flexibly use these  
267 “smarter” prosocial strategies while other children from the same school instruction cannot has been  
268 barely investigated. Our studies based on both behavioral tasks and inventories suggested an advantage  
269 of better memory in learning and using prosocial strategies. Through reciprocal exchange or acting  
270 cooperation, regardless of whether their behavior is motivated by altruism, dominant children can  
271 enhance their opportunities to obtain more resources and maintain their position in a group.

272       Though memory could affect social status indirectly through learning social strategy, the  
273 regression analysis of the mediation effect also suggested a direct influence of memory on social status.  
274 ERP studies focusing on FN400 implied another advantage of memory in processing socially dominant  
275 facial expressions. FN400 has been proposed to reflect the familiarity of recognition and has been  
276 treated as an indicator of conceptual fluency/priming across different stimuli<sup>58-60,62</sup>. The amplitude of  
277 FN400 is usually negatively correlated with the coherence/homogeneity of the conceptual category in  
278 the brain<sup>61</sup>. Based on this hypothesis, a smaller FN400 amplitude in high-rank children in response to  
279 a dominant face possibly reflected better fluency in recognizing signs of social dominance. Social  
280 status significantly correlated with different abilities in processing social expression, particularly better  
281 implicit memory pertinent to dominant facial information in high-rank children. Previous  
282 observational studies have shown that preschool children used coercive strategies to compete for  
283 resources at the beginning of a new semester but gradually incorporated prosocial strategy use<sup>4,70</sup>.

284 Notably, once the social hierarchy was initially established, high-status children did not utilize  
285 prosocial strategies all the time; instead, they applied coercive strategies while interacting with low-  
286 status children but flexibly adopt prosocial strategies or even dual strategies when encountering high-  
287 status children<sup>53,70,71</sup>. Our ERP study further showed that high-rank children had better implicit  
288 memory of dominant cues, suggesting that identifying individuals who are possible opponents that  
289 need to be handled more carefully and determining effective strategies could be the keys to achieving  
290 social status.

291 Last, the causality between social hierarchy and memory ability remains to be investigated.  
292 Whereas better memory could potentially help animals learn new strategies to acquire social  
293 dominance, such as prosocial strategies in human children, it is also possible that memory ability is  
294 modulated by social status. For example, it has been suggested that subordinate animals constantly  
295 experience chronic social stress<sup>21</sup>, which could affect learning and memory through multiple  
296 mechanisms, including modulation of neuronal activity, gene expression, and neurogenesis in the  
297 hippocampus<sup>72</sup>. Similarly, stressful environments, such as less social interaction, less attention from  
298 parents/teachers/peers or fewer resources, could also affect children's memory ability. In the future,  
299 an intervention design to further evaluate mice and a cross-lagged longitudinal study to assess children  
300 would be helpful for us to answer this chicken-and-egg question between social hierarchy and memory.

301 In sum, our study revealed a positive correlation between social hierarchy and memory ability in  
302 mice and children. We believe that better memory is advantageous for young children both in acquiring

303 advanced dominance strategies and detecting social dominance cues to achieve and maintain higher  
304 social status. The abundant resources and ample interaction opportunities accompanied by higher  
305 social status potentially further create a favorable environment for memory development for these  
306 children. This finding has important implications for child education. Most children want to be the  
307 center of the group, hope that their opinions can be taken seriously, and desires to play with the toys  
308 they want. According to the findings of this study, however, social strategy using and resource control  
309 ability are largely influenced by learning and memory. To assist young children in achieving better  
310 social adaption, we cannot just provide moral education or behavioral requirements. Instead, we should  
311 take the level and limitations of children's cognitive development into account. It is difficult for those  
312 who are not yet able to learn better social strategies or are not yet mature in detecting social cues to  
313 strive for social dominance or obtain classroom resources. The relatively few resources and poor  
314 interaction quality caused by low social status may in turn lead to frustration, anxiety and fewer  
315 opportunities to encounter cognitive stimuli, consequently leading to poor memory development.  
316 Therefore, parents and teachers should not just punish children when they use improper strategies but  
317 should also set class rules to ensure that every child has the opportunity to be listened to and to play  
318 with the toys they want. For children with better memory and learning abilities, we should pay attention  
319 to their underlying motives behind their seemingly prosocial behaviors. Through more discussion and  
320 guidance and by leading them to be concerned about others' needs, parents and educators can help  
321 children develop genuine altruism.

322

323 **Methods**

324 **Mice.**

325 C57BL/6J adult male mice between the ages of 8 to 10 weeks and weanling mice between the ages of  
326 3 to 4 weeks were purchased from the National Laboratory Animal Center in Taiwan. Mice were housed  
327 in a controlled animal room with a 12-h light/dark cycle (0700–1900 hr). All tests were conducted  
328 during the light period. All animal procedures were in compliance with institutional guidelines  
329 established and approved by the Institutional Animal Care and Use Committee of National Tsing Hua  
330 University and Academia Sinica.

331

332 **Behavioral assay for mice**

333 **Tube test.** The tube test was based on a previous study<sup>32</sup>. The assay was modified from the standard  
334 tube test<sup>73</sup>, but the mice were not trained first. A clear Plexiglas tube (3.75 cm diameter, 60 cm length)  
335 was used for adult mice, and a narrower tube (2.5 cm diameter, 60 cm length) was used for weanling  
336 mice. Mice were habituated to the procedure room for 1 hour on two consecutive days. On the third  
337 day, a tube test trial was carried out involving two mice that were simultaneously released at opposite  
338 ends of the tube and then ran toward the middle. When a mouse retreated and set all four paws outside  
339 the tube, the test trial was over and that mouse was considered the loser. A round robin design was  
340 applied to the four mice housed in each cage to allow the six possible pairs to compete. For each

341 pairwise, mice were tested against one another in this manner in 4 consecutive trials, with each mouse  
342 starting at an alternative end of the tube for each trial. The interior of the tube was cleaned after every  
343 pairwise with 70% ethanol. Final social ranks were based on 4 trials between two individuals. If the  
344 winning numbers between two individuals were equal, i.e. 2 and 2, the rank would be determined by  
345 total winning times for each animal across all comparisons.

346

347 ***Novelty investigation test.*** The novelty investigation test was modified from the novel object recognition  
348 test<sup>45</sup>. A mouse was introduced into a box with one unfamiliar object in the center of an empty open cage  
349 [28 cm x 16.5 cm x 13 cm] for free exploration for 10 minutes. The investigation time to the object was  
350 recorded to represent exploration activity. The apparatus was cleaned with 70% ethanol between each trial.

351

352 ***Novel object recognition.*** The novel object recognition test was performed as described previously<sup>45</sup>.  
353 The experiment was divided into familiar and testing phase. In the familiar phase, each mouse was  
354 placed at the edge of an empty open cage [28 cm (L) × 16.5 cm (W) × 13 cm (H)] contained two  
355 identical plastic blockers at the bottom of the cage. Mice were placed into the cage to freely explore  
356 the cage for 10 minutes to familiarize the blockers, then returned to homecage for 1 hour (short-term  
357 memory) or 24 hours (long-term memory). In testing phase, the mouse was moved back to the same  
358 open cage for 5 minutes with one familiarized blocker used in familiar phase and one different  
359 blocker with contrasting color and shape. Total time of mice exploring the blockers (nose touching)

360 were recorded. The apparatus was cleaned with 70% ethanol between each trial. The exploring time  
361 difference between familiar object and novel object divided by total exploring time was calculated as  
362 discrimination index by individuals.

363

364 ***Spontaneous Alternative Y maze.*** The experiment design was based on previous study<sup>46</sup>. The Y maze  
365 consists of three white, opaque arms [30 cm (L) × 7 cm (W) × 16 cm (H)] at a 120° angle from each other.  
366 Each mouse was placed at the center of the maze and allowed to freely explore the maze for 5 min. The  
367 behavior of mice performed in Y maze was recorded by camera and evaluated by SMART VIDEO  
368 TRACKING Software (Panlab) to obtain the number of entries into each arm. The number of arm entries  
369 was used to calculate the alternative rate. The apparatus was cleaned with 70% alcohol and air-dried  
370 between each mouse.

371

### 372 **RNA extraction, cDNA synthesis and Quantitative Real-Time PCR**

373 After identifying social ranks, mice were sacrificed for isolation of hippocampus. Total RNA was  
374 extracted using RNeasy Mini Kit (Qiagen), including a DNase (Qiagen) treatment. cDNA of mRNA  
375 was generated by FIREScript® RT cDNA Synthesis Mix (Solis Biodyne) using oligo dT as primer.  
376 The qPCR reactions were performed under qTOWER<sup>3</sup> real-time PCR system (Analytik Jena) using  
377 5x HOT FIREPol® EvaGreen® qPCR Mix Plus (Solis Biodyne) following the manufactures protocol.  
378 The. Relative expression was calculated using the  $\Delta\Delta CT$  method and *GAPDH* as normalization control.

379 Primer sequences used for qPCR are shown in Table S4.

380

381 **Electrophysiology in mouse hippocampal slices.**

382 Mice at 4 or 8 week-old were first anesthetized by isoflurane (Panions & BF Biotech INC.) then sacrificed  
383 by decapitation. The brain was taken out rapidly, and the hippocampi were dissected out in the icy-cold  
384 artificial cerebrospinal fluid (aCSF) containing (in mM) 119 NaCl, 2.5 KCl, 1 NaH<sub>2</sub>PO<sub>4</sub>, 1.3 MgSO<sub>4</sub>, 26.2  
385 NaHCO<sub>3</sub>, 2.5 CaCl<sub>2</sub>, and 11 D-glucose and oxygenated with 95% O<sub>2</sub>/5% CO<sub>2</sub>. 300- $\mu$ m thick Hippocampal  
386 slices were cut along its long-axis using a 5100mz vibratome (Campden Instruments Ltd.) in the icy-cold  
387 aCSF. Then the slices were first recovered in the aCSF at 34 °C for 30 min, then switched to room  
388 temperature for at least 2 hours. For field recording, a slice was transferred to the recording chamber and  
389 continuously perfused with aCSF (1 ml/min) at room temperature. The afferent input from CA3 was  
390 severed by making a cut between the CA1 and CA3. The recording electrodes were pulled from  
391 borosilicate glass capillary tubes (1.5-mm outer diameter, 0.86-mm inner diameter, World Precision  
392 Instruments) using a single-stage glass microelectrode puller (PP-830; Narishige) and filled with 3M NaCl.  
393 The field excitatory postsynaptic potentials (fEPSPs) were evoked by placing a bipolar tungsten electrode  
394 (A-M SYSTEMS) placed on the Schaffer collateral/commissural pathway. An Axon200B amplifier  
395 (Molecular Devices Corp.) together with Digidata 1440 was used for data acquisition. Data were filtered  
396 at 1 kHz and sampled at 25 kHz with Clampex10.7 software (Molecular Devices Corp.). The stimulation  
397 strength was varied between 10 to 100  $\mu$ A, and the intensity that elicited 50% of the maximum response

398 was chosen for the LTP experiments. The stimulation pulse was delivered every 15 s. Once a 20-min long  
399 stable baseline was achieved, a train of 100 Hz stimulation was delivered for 1 s to induce LTP, followed  
400 by the fEPSP recording every 15 s for 2 hours.

401

## 402 **Children participants.**

403 The study participants were recruited from five preschools in Hsinchu City, Taiwan. For the behavioral  
404 studies, 164 children from two preschools (88 boys and 76 girls, average age,  $67.18 \pm 9.09$  months)  
405 participated in a competitive bunny game to establish social ranks. The memory abilities of the 1<sup>st</sup> and  
406 4<sup>th</sup> rank children among the 164 participants were further tested individually by *Wechsler Preschool*  
407 *and Primary Scale of Intelligence*. The dominance level and resource control abilities in 1<sup>st</sup> and 4<sup>th</sup>  
408 rank children were also evaluated by *Social dominance rating scale* and *Resource Control Strategy*  
409 *Scale*. For the inventory studies, another 175 children from three of the other preschools (102 boys and  
410 73 girls; average age,  $66.52 \pm 8.33$  months) were evaluated by *Social dominance rating scale*,  
411 *Childhood Executive Functioning Inventory* and *Resource Control Strategy Scale*. For the ERP study,  
412 each 12 children in 1<sup>st</sup> and 4<sup>th</sup> ranks participated in the behavioral and electroencephalogram (EEG)  
413 data collecting. Consent forms were provided by parents for all children in this research (Approved by  
414 the National Tsing Hua University Research Ethics committee 10804HT020).

415

## 416 **Behavioral studies for children**

417 **Bunny game.** The social ranks of 164 children were evaluated by the competitive Bunny game based  
418 on a previous study<sup>32</sup>. Briefly, children were divided into groups of four randomly. Paired encounters  
419 were staged with a round robin design (comparable to the design in mouse), such that each child would  
420 encounter every other child in the same group, leading to a total of six combinations of pairs. For each  
421 round of the bunny game, a tester presented a picture card showing the required placement of three  
422 wooden blocks, colored red, blue, and yellow. The children were told to place the blocks in the correct  
423 positions before putting rabbit into the hole representing its home. The first child to place his or her  
424 bunny doll into its hole was declared the winner. All games were conducted at preschool before lunch  
425 time (9am-11am).

426

427 **Memory tests.** After one month of the Bunny game, the two subscales of the Chinese version of the  
428 Wechsler Preschool and Primary Scale of Intelligence (WPPIS-IV)<sup>50,74</sup>, "Picture memory subtest" and  
429 "Zoo subtest," were used in order to measure the working memories of children in the 1<sup>st</sup> and 4<sup>th</sup> rank  
430 children (n = 82). The Picture memory test required the child to memorize objects in a picture during  
431 a designated period, and then to identify the items viewed within several objects after turning the page.  
432 In the Zoo test, the tester first placed animal cards at specific locations on a zoo map. After withdrawing  
433 the map, the child was then asked to return the animal cards to their correct positions, using only their  
434 memory. The sum of the two scores was then converted into Working Memory Index (WMI), which  
435 is the measure of each child's working memory capabilities.

436

437 **Inventory studies**

438 The teachers who worked with the children every day carried out the evaluations with respect to the  
439 children's daily behaviors in the classroom. A total of fifteen teachers carried out the evaluations (6 for  
440 the behavioral studies and 9 for the inventory studies), and the chief teacher of each preschool helped  
441 to check for differences in ratings across the teachers and made the final decision.

442

443 ***Social dominance rating scale.*** Dodge's teacher rating scale was adopted for assessing the social  
444 dominance levels of the young children<sup>51</sup>, which was based on the Teacher Checklist of Dodge and  
445 Coie<sup>75</sup>. There were five items related to social dominance (Cronbach alphas = .89): "this child is a  
446 leader", "this child gets what he or she wants", "this child is competitive", "this child suggests to other  
447 children how things should be done", and "this child is frequently the center of the group". The teachers  
448 respond to each statement with a seven-point Likert scale, with "1" indicating "never" and "7"  
449 indicating "always". The five scores were averaged and represented a child's social dominance score.

450

451 ***Resource Control Strategy Scale.*** The teacher-rated Resource Control Strategy Scale<sup>53</sup> was used to  
452 assess the children's prosocial strategies of control (e.g., "This child promises friendship to get what  
453 s/he wants," "This child promises to do something in return to get what s/he wants";  $\alpha=.74$ ) and  
454 coercive strategies of control (e.g., "This child gets what s/he wants by bullying others," "This child

455 gets what s/he wants by making verbal threats or threats of aggression”;  $\alpha=.87$ ). Using a 7-point Likert  
456 scale, high scores indicate higher endorsement of strategy employment. The teachers also rated the  
457 children’s resource control effectiveness (e.g., “This child usually gets first access to preferred toys  
458 when with peers,” “This child usually plays with the favored toys when with peers”;  $\alpha=.85$ ). (From  
459 hardly true to mostly true in the 7-point scale)

460

461 ***Childhood Executive Functioning Inventory.*** The Working Memory subscale of the Chinese version  
462 of Childhood Executive Functioning Inventory<sup>76</sup> was adopted in this study. The original version of this  
463 inventory was developed by Thorell and Nyberg<sup>52</sup> and then translated into different languages. The  
464 teachers were asked to evaluate the children’s working memory performance based on the children’s  
465 daily behavior in the classroom. Ratings are made on a 5-point Likert scale and a higher score indicates  
466 worse performance. The ratings were therefore scored in reverse for the following statistics.

467

#### 468 **Event-related potential studies**

469 The ERP study was performed in the silenced room of the preschool. The children were told that they  
470 were selected to participate in computer games. Wearing a cap with special super power (the EEG cap),  
471 their mission was to watch the photos on the screen carefully. Children who complete the task can get  
472 mysterious gifts (animal-shaped biscuits). Three classes of facial expressions (dominant, subordinate  
473 and neutral) were built with peer of preschool children and based on studies that demonstrated dominant

474 and submissive feelings evoked by specific facial features<sup>55-57</sup>. At the beginning of each trial, a fixation  
475 cue was presented for 500 ms to alert the appearance of a facial photo. Before real test, 12 photos  
476 (three trials for each type) were presented randomly as the practice session to familiarize the children  
477 with the entire procedure. Then the photos continuously showed up for 500 ms with a blank screen as  
478 the inter-stimulus interval for 800–1100 ms. Each subject needed to complete 90 trials (30 for each  
479 facial type) with a random order. In this study, all the children were finally told that they completed  
480 the task mission successfully and got the gifts.

481

## 482 **Electrophysiological Recording and Processing**

483 Electroencephalogram (EEG) signals were recorded from 32 Ag/AgCl–sintered electrodes with the  
484 SynAmp2 system (Quik-Cap Neo Net, Compumedics Ltd., VIC, Australia). The recording was  
485 referenced to the bilateral mastoids. A vertical electrooculogram (EOG) was positioned at left eye and  
486 horizontal EOG was placed at left and right orbital rim. All impedance of the electrode was maintained  
487 below 5 k $\Omega$  throughout the recording. The acquisition sample rate was 1000 Hz with a DC-100 Hz  
488 band-pass filter. The ERPs were analyzed with Curry 8 software (Compumedics Ltd., VIC, Australia).  
489 The brain signals were first filtered with a low-pass filter down 12 dB at 50 Hz and a high-pass filter  
490 down 12 dB at 1 Hz. Artifacts of EEG signals were corrected by using independent component analysis  
491 (ICA)<sup>77</sup>. Then, all continuous EEG signals were epoched from 100 ms pre-stimulus (-100~0 as the  
492 baseline correction) to 900 ms post-stimulus. Visual inspection was first used to confirm the window

493 rang of FN400 (300–450 ms). The value of FN400 were averaged within the time window per subject  
494 and per condition. The FN400 amplitudes of each facial expression were further corrected by  
495 subtracting the averaged amplitude of the neutral facial condition.

496

#### 497 **Quantification and Statistical Analysis**

498 All statistics were completed using SPSS 22.0 or GraphPad Prism 6.0 software. The Shapiro-Wilkinson  
499 normality test was used to determine the nature of the data's distribution. For pairwise comparison, paired  
500 or unpaired t-test was applied for normally distributed parameters, and Wilcoxon signed-rank or Mann-  
501 Whitney test was applied for non-normally distributed data. Two-way ANOVA analyses were used in ERP  
502 studies. All the correlation analyses were tested by Pearson correlation. The mediation effect was  
503 examined by regression analysis followed by the Sobel test. All data are represented as mean +/- standard  
504 error of the mean (S.E.M.).

505

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516

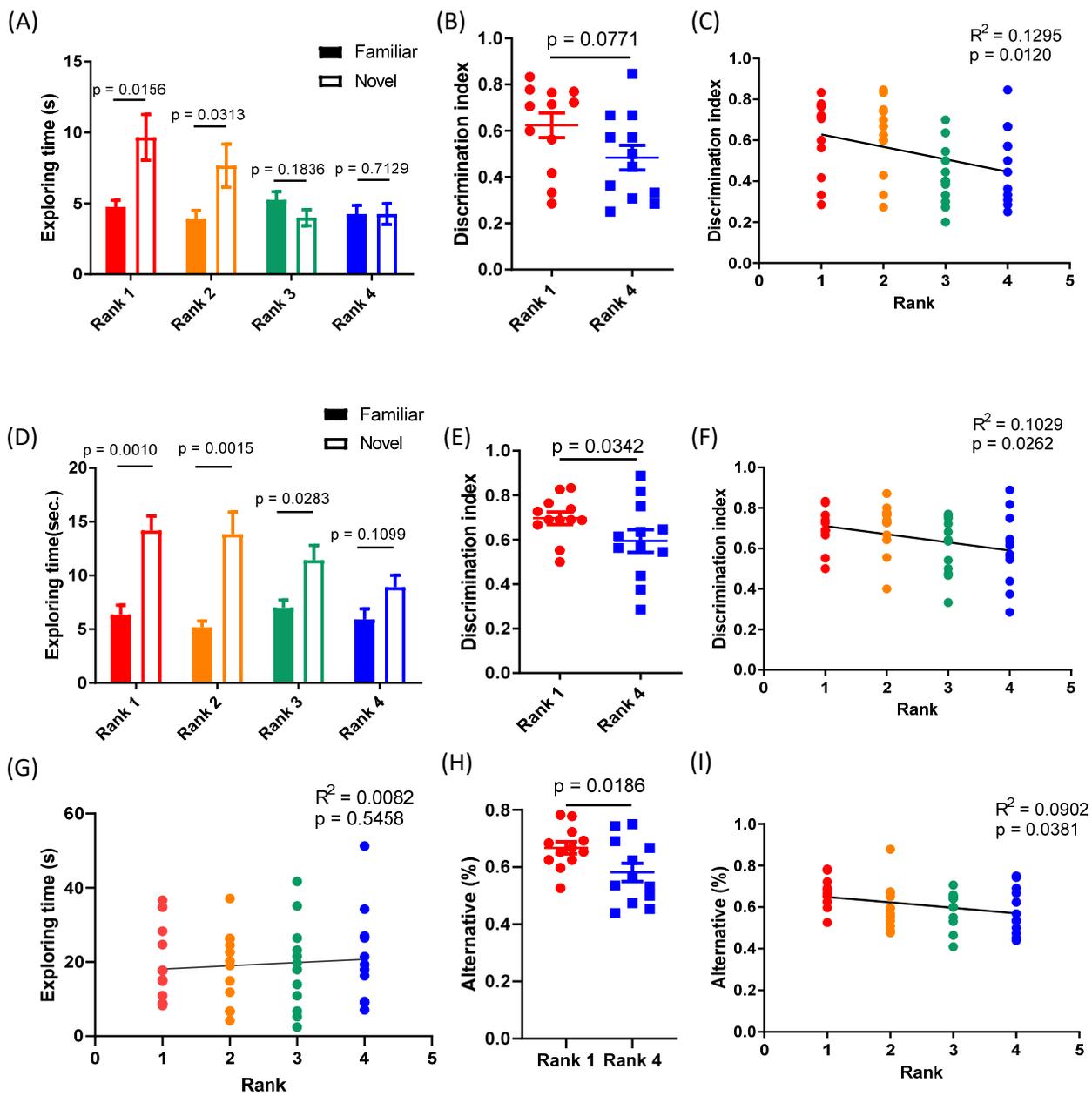
517 **Author contributions**

518 YJ Chou, SB Yang, and TH Kuo designed the experiments; YJ Chou, YH Lu, YK Ma, and WS Tasi  
519 performed the experiments; YJ Chou, YH Lu, YK Ma, JT King, WS Tasi, and TH Kuo analyzed the  
520 data, and YJ Chou, JT King, SB Yang and TH Kuo wrote the manuscript.

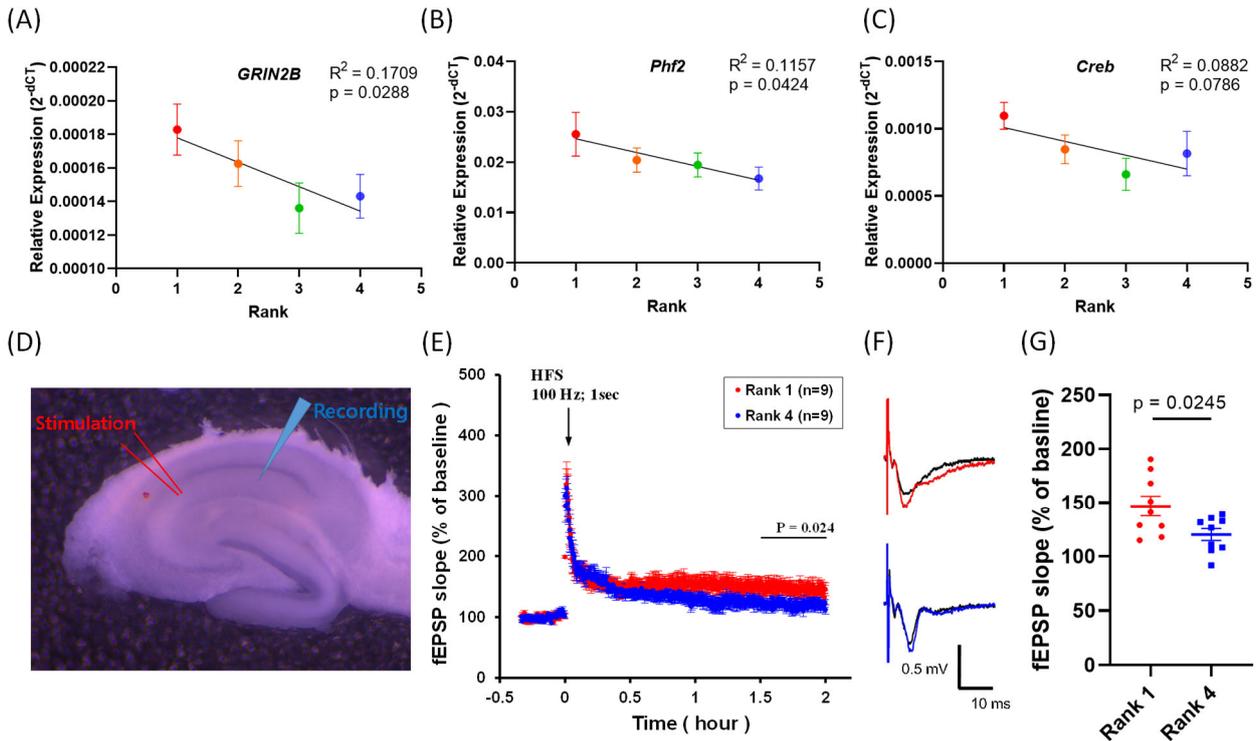
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522 **Declaration of interests**

523 The authors declare no competing financial interests.



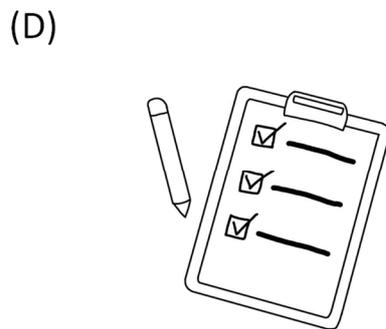
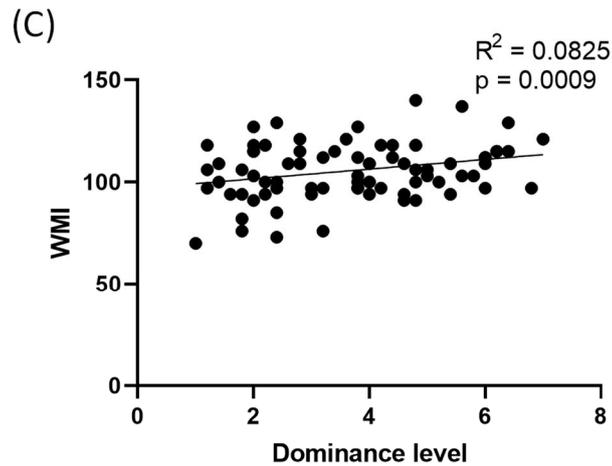
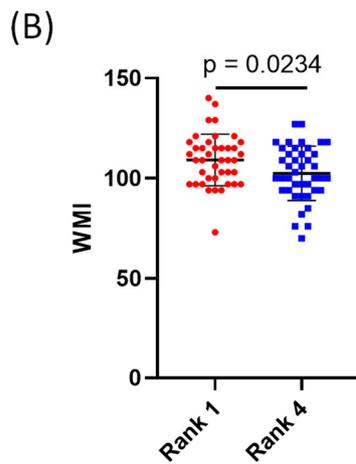
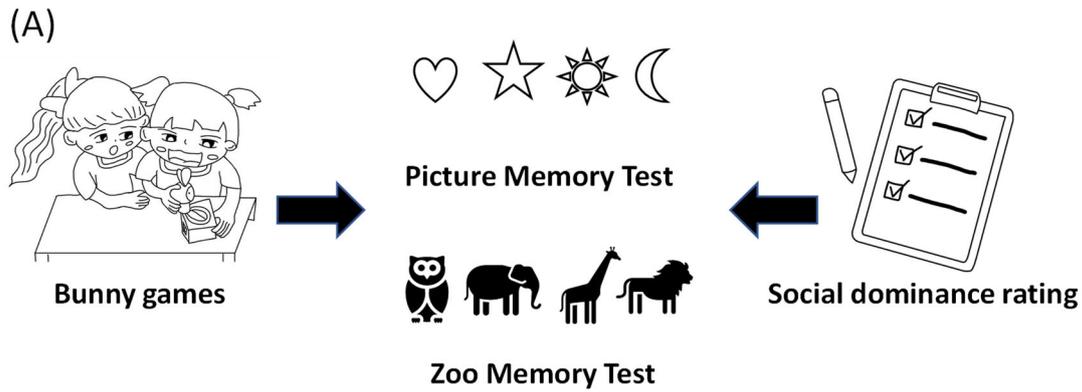
525 **Figure 1. Weanling mice with higher rank showed better memory performance.** (A) Exploration  
526 time to familiar and novel objects in weanling mice with different social ranks in the 1-hour NOR test  
527 (Wilcoxon signed-rank test, n = 12 cages). (B) Discrimination index between 1<sup>st</sup>- and 4<sup>th</sup>-rank weanling  
528 mice in the 1-hour NOR test. (Wilcoxon signed-rank test, n = 12 pairs). (C) The correlation between  
529 social ranks of weanling mice and the discrimination index in the 1-hour NOR test (Pearson correlation,  
530 n = 12 cages). (D) Exploration time to familiar and novel objects in weanling mice with different social  
531 ranks in the 24-hour NOR test (Wilcoxon signed-rank test, n = 12 cages). (E) Discrimination index  
532 between 1<sup>st</sup>-rank and 4<sup>th</sup>-rank weanling mice in the 24-hour NOR test. (Wilcoxon signed-rank test, n  
533 = 12 pairs). (F) The correlation between social ranks of weanling mice and the discrimination index in  
534 the 24-hour NOR test (Pearson correlation, n = 12 cages). (G) The correlation between ranks and  
535 exploratory time in the Novelty investigation test. (Pearson correlation, n = 12 cages). (H) The  
536 spontaneous alternation rate between 1<sup>st</sup> and 4<sup>th</sup> rank weanling mice in the Y maze (Wilcoxon signed-  
537 rank test, n = 12 pairs). (I) The correlation between social ranks of weanling mice and the spontaneous  
538 alternation rate in the Y maze (Pearson correlation, n = 12 cages). Mean ± S.E.M.



539

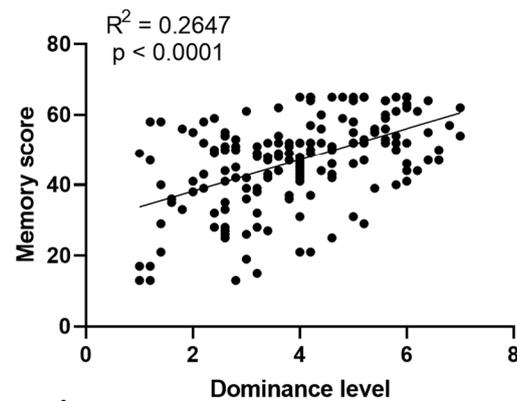
540 **Figure 2. Higher rank weanling mice showed higher expressions of memory-related genes and**  
 541 **greater LTP in hippocampal slices.** (A) The correlation between social ranks of weanling mice and  
 542 the *Grin2b* expression (Pearson correlation,  $n = 7$  cages). (B) The correlation between social ranks of  
 543 weanling mice and the *Phf2* expression (Pearson correlation,  $n = 9$  cages). (C) The correlation between  
 544 social ranks of weanling mice and the *Creb* expression (Pearson correlation,  $n = 9$  cages). (D) A  
 545 representative image of field recording in a hippocampal slice. fEPSPs were recorded in the dendritic  
 546 field of CA1 pyramidal neurons and stimulated at the CA3-to-CA1 Schaffer collateral. (E) Augmented  
 547 LTP induced by a one-second high-frequency stimulation (100 Hz) in hippocampal slices of 1<sup>st</sup>- and  
 548 4<sup>th</sup>-rank weanling mice. (F) Representative fEPSPs before (black) and after (red: 1<sup>st</sup> rank mouse; blue:  
 549 4<sup>th</sup> rank mouse) LTP induction. (G) fEPSP slopes measured two hours after LTP induction in 1<sup>st</sup>-rank  
 550 and 4<sup>th</sup>-rank weanling mice. (unpaired t-test,  $n = 9$  pairs). Mean  $\pm$  S.E.M.

551



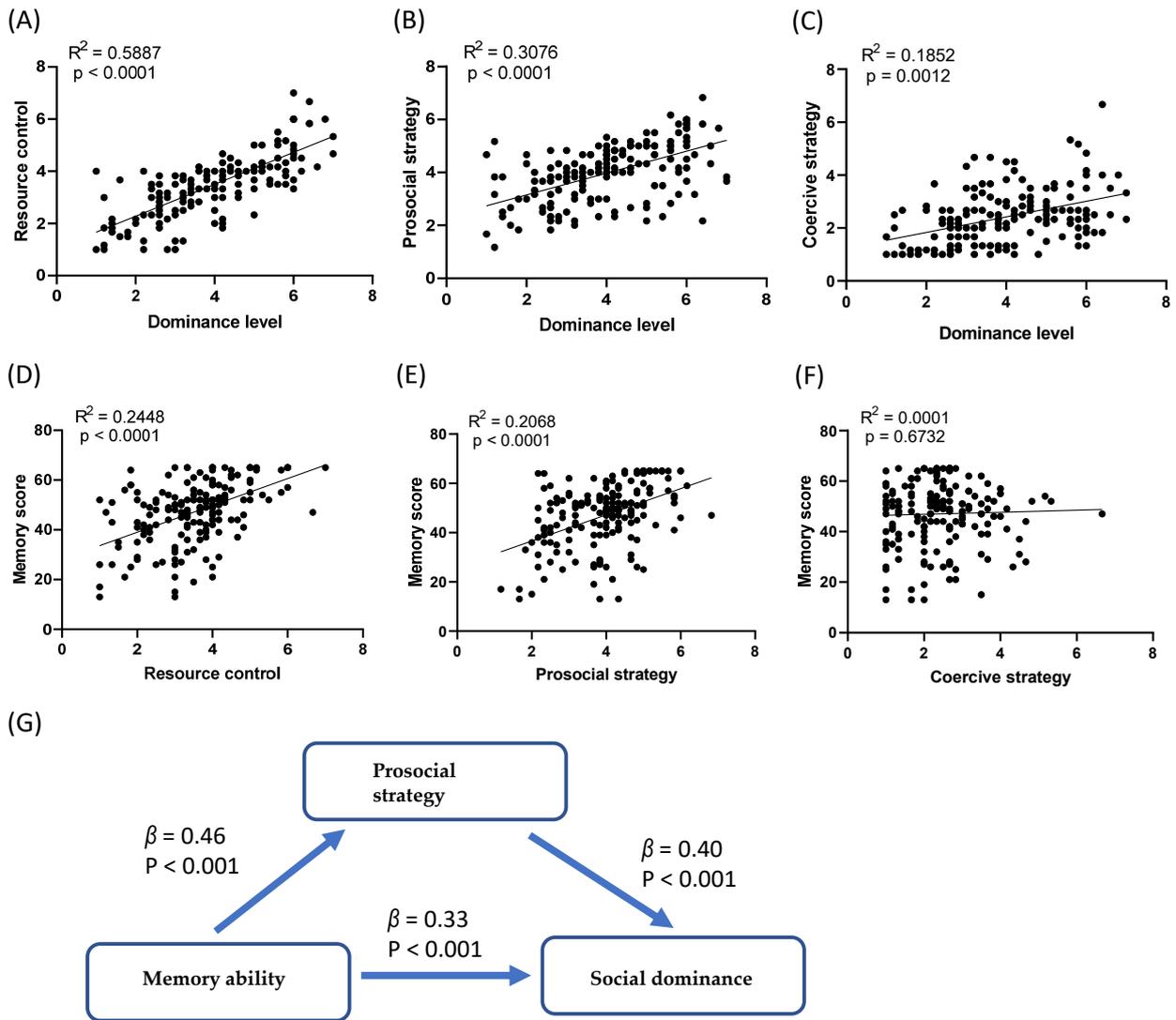
**Teacher Evaluation**

- Social dominance rating
- Childhood Executive Functioning Inventory



552

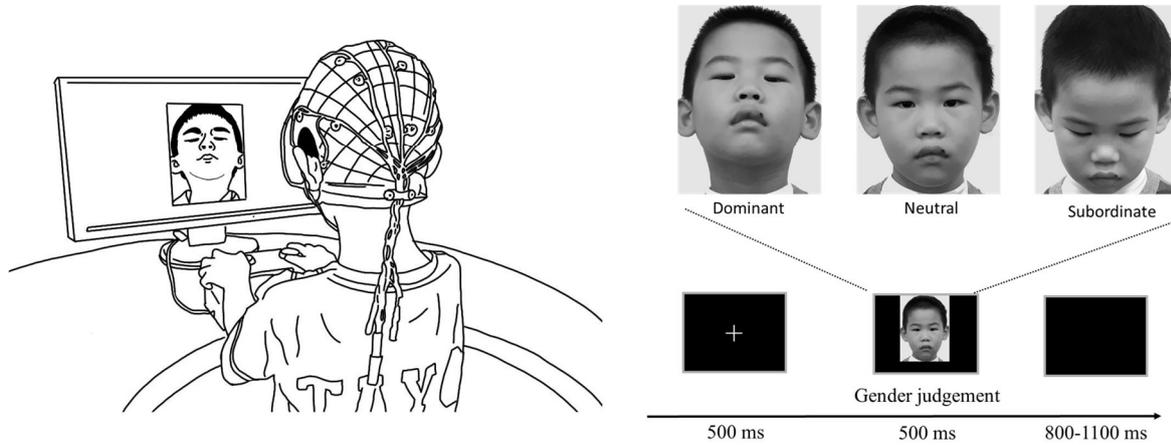
553 **Figure 3. Children with high rank or dominance levels showed better memory ability.** (A) Social  
 554 ranks were defined by Bunny games. The dominance levels were evaluated by Social Dominance  
 555 Rating. Working memory index (WMI) was evaluated and integrated by Picture memory and Zoo  
 556 memory tests. (B) The WMI for 1<sup>st</sup>- and 4<sup>th</sup>- rank children (unpaired t-test,  $n = 82$ ). (C) The correlation  
 557 between picture memory scores and dominance levels (Pearson correlation,  $n = 82$ ). (D) The  
 558 correlation between memory score evaluated by Childhood Executive Functioning Inventory and  
 559 dominance level evaluated by Social Dominance Rating (Pearson correlation,  $n = 175$ ).



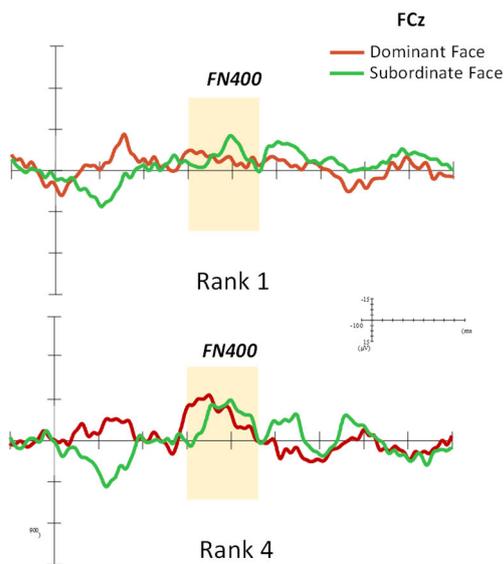
560  
561

562 **Figure 4. Memory ability was correlated with prosocial strategy use but not coercive strategy**  
 563 **use.** (A) The correlation between dominance level and resource control (Pearson correlation,  $n = 175$ ).  
 564 (B) The correlation between dominance level and prosocial strategy (Pearson correlation,  $n = 175$ ). (C)  
 565 The correlation between dominance level and coercive strategy (Pearson correlation,  $n = 175$ ). (D) The  
 566 correlation between memory score and resource control (Pearson correlation,  $n = 175$ ). (E) The  
 567 correlation between memory score and prosocial strategy (Pearson correlation,  $n = 175$ ). (F) The  
 568 correlation between memory score and coercive strategy (Pearson correlation,  $n = 175$ ). (G) The  
 569 mediated model linking children's memory ability and children's social dominance (regression  
 570 analysis,  $n = 175$ ).

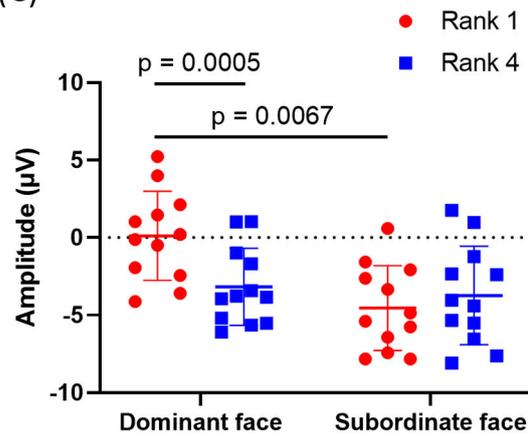
(A)



(B)



(C)



571

572 **Figure 5. Children with higher rank were more capable of processing dominance faces.**

573 (A) Experimental procedure and stimuli of the ERP study. EEG recordings were acquired from  
574 preschool children while they watched the photos of the faces of their peers (with representative images  
575 for dominant, neutral and subordinate facial expressions). (B) The difference wave amplitudes of  
576 FN400 in the FCz channel in response to dominant and subordinate faces in 1<sup>st</sup>- and 4<sup>th</sup>-rank children  
577 (n = 12 pairs). (C) The difference wave amplitudes of FN400 in response to dominant and subordinate  
578 faces in 1<sup>st</sup> and 4<sup>th</sup> rank children (two-way ANOVA, n = 12 pairs). *Note.* The FN400 amplitudes of  
579 each facial expression were corrected by subtracting the averaged amplitude of the neutral facial  
580 condition.

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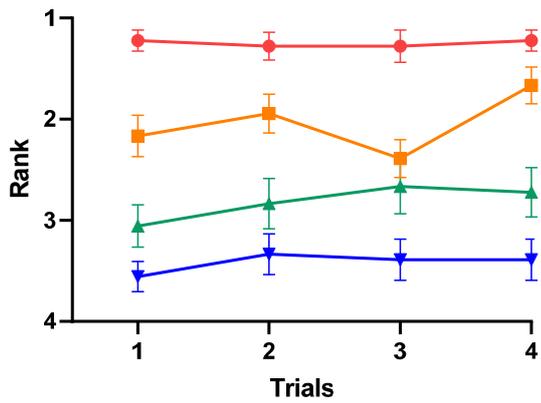
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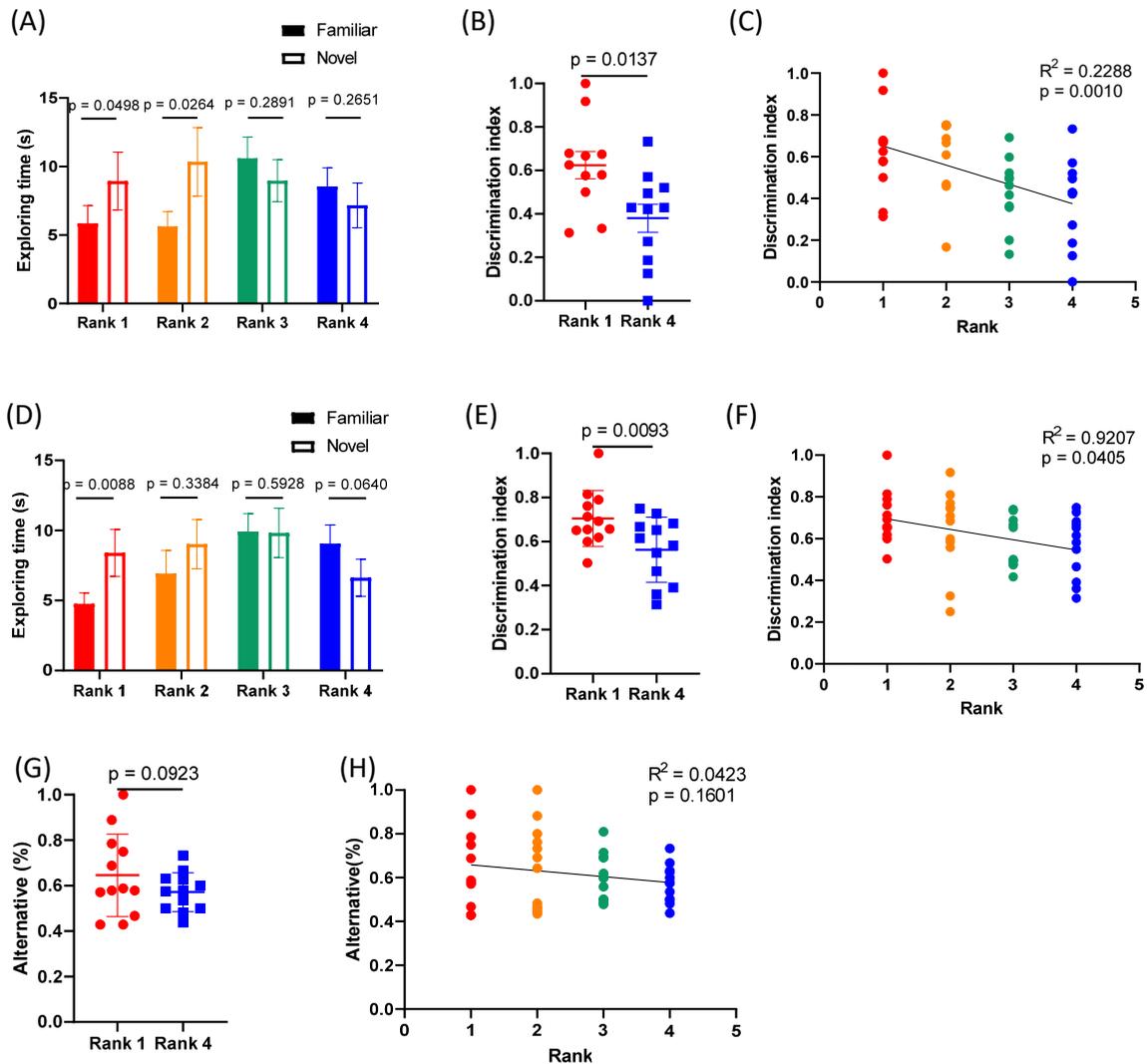
742 **Supplementary information**



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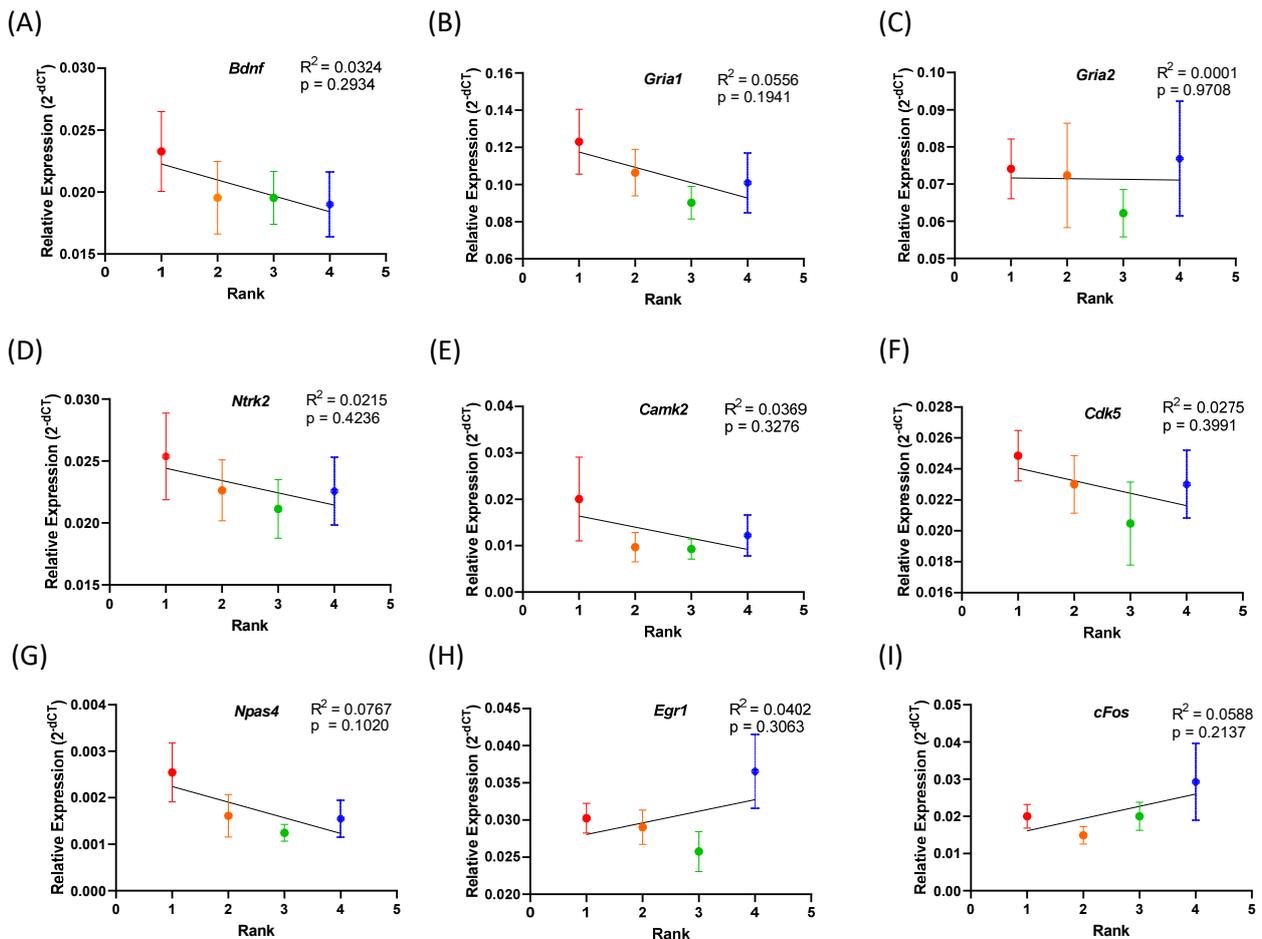
744 **Figure S1. Summary of social ranks.** Summary of the social ranks of the weanling mice as  
745 determined by the tube test over four trials (n = 14 cages).

746



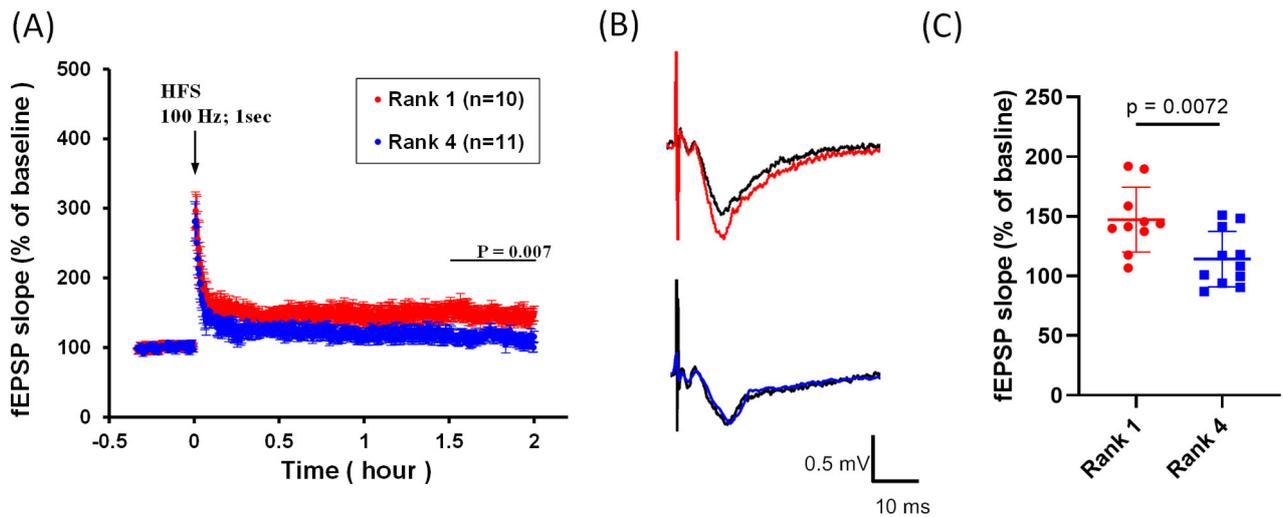
747

748 **Figure S2. Adult mice with higher rank showed better memory performance.** (A) Exploration  
 749 time to familiar and novel objects in adult mice with different social ranks in the 1-hour NOR test  
 750 (Wilcoxon signed-rank test, n = 12 cages). (B) Discrimination index in the 1-hour NOR test between  
 751 1<sup>st</sup> and 4<sup>th</sup> rank adult mice. (Wilcoxon signed-rank test, n = 12 pairs). (C) The correlation between  
 752 social ranks of adult mice and the discrimination index in the 1-hour NOR test (Pearson correlation, n  
 753 = 12 cages). (D) Exploration time to familiar and novel objects in adult mice with different social ranks  
 754 in the 24-hour NOR test (Wilcoxon signed-rank test, n = 12 cages). (E) Discrimination index in the  
 755 24-hour NOR test between 1<sup>st</sup>- and 4<sup>th</sup>-rank adult mice. (Wilcoxon signed-rank test, n = 12 pairs). (F)  
 756 The correlation between social ranks of adult mice and the discrimination index in the 24-hour NOR  
 757 test (Pearson correlation, n = 12 cages). (G) The spontaneous alternation rate between 1<sup>st</sup> and 4<sup>th</sup> rank  
 758 adult mice in the Y maze (Wilcoxon signed-rank test, n = 12 pairs). (H) The correlation between social  
 759 ranks of adult mice and the spontaneous alternation rate in the Y maze (Pearson correlation, n = 12  
 760 cages). Mean  $\pm$  S.E.M.



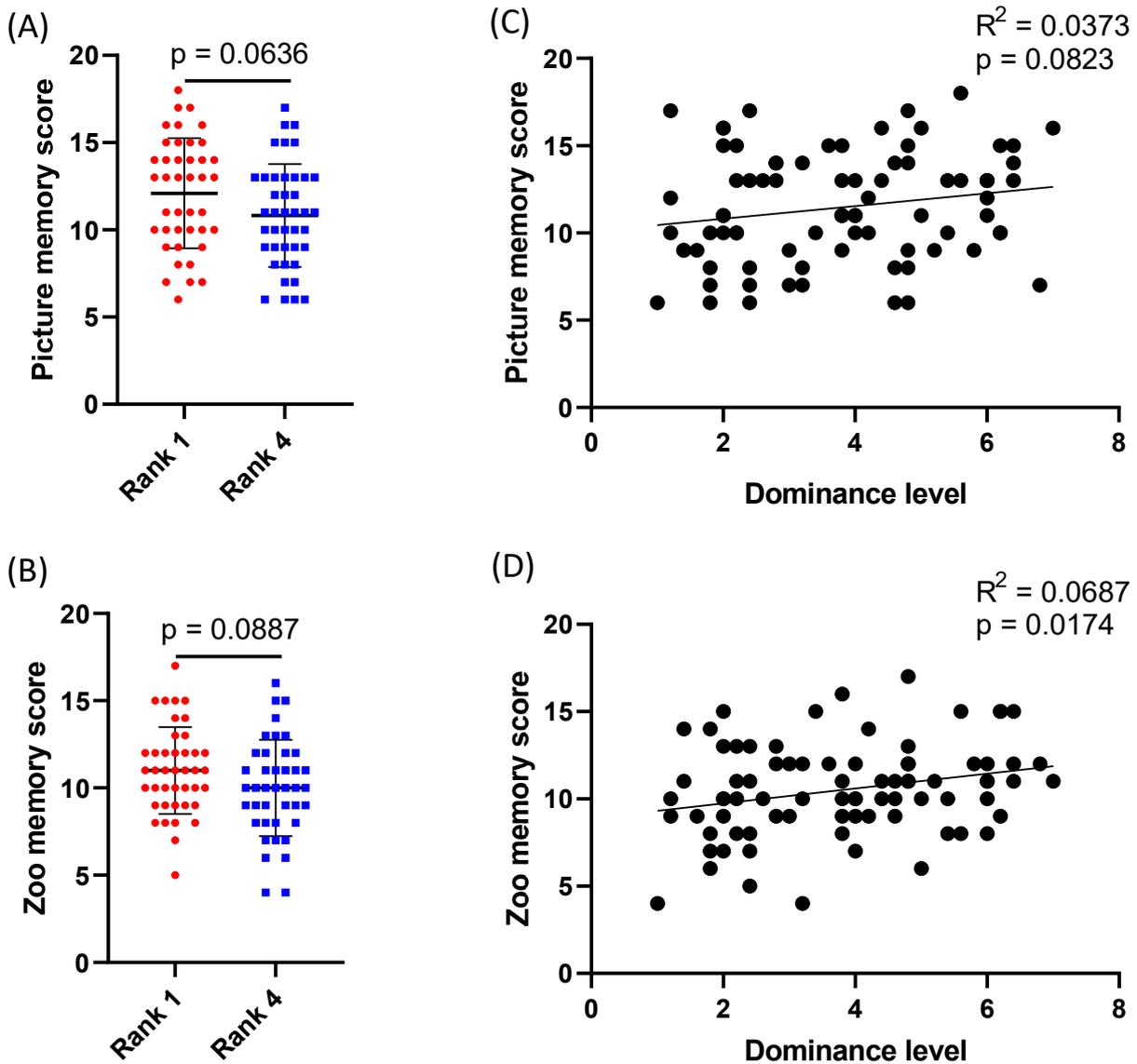
761

762 **Figure S3. Dominant mice tended to have higher expressions in several memory-related genes**  
 763 **than subordinate mice.** (A) The correlation between social ranks and the *Bdnf* expression. (n = 9  
 764 cages) (B) The correlation between social ranks and the *Gria1* expression. (n = 8 cages) (C) The  
 765 correlation between social ranks and the *Gria2* expression. (n = 9 cages) (D) The correlation between  
 766 social ranks and the *Ntrk2* expression. (n = 8 cages) (E) The correlation between social ranks and the  
 767 *Camk2* expression. (n = 7 cages) (F) The correlation between social ranks and the *Cdk5* expression. (n  
 768 = 7 cages) (G) The correlation between social ranks and the *Npas4* expression. (n = 9 cages) (H) The  
 769 correlation between social ranks and the *Egr1* expression. (n = 7 cages) (I) The correlation between  
 770 social ranks and the *cFos* expression. (n = 7 cages). (Pearson correlation. Mean  $\pm$  S.E.M.)



771

772 **Figure S4. Higher rank adult mice showed greater LTP in hippocampal slices.** (A) Augmented  
 773 LTP induced by delivering a train of one-second-long 100 Hz stimulation in hippocampal slices of 1<sup>st</sup>-  
 774 and 4<sup>th</sup>-rank adult mice. (B) Representative fEPSPs after LTP induction from one 1<sup>st</sup>-ranked adult  
 775 mouse (red) and one 4<sup>th</sup>-rank adult mouse (blue). (C) fEPSP slopes in 1<sup>st</sup>-ranked and 4<sup>th</sup>-ranked adult  
 776 mice. (unpaired t-test, n = 10-11 pairs). Mean ± S.E.M.



777

778 **Figure S5. Children with high rank or dominance levels showed better memory ability.** (A) The  
 779 picture memory test scores for 1<sup>st</sup>- and 4<sup>th</sup>-rank children (unpaired t-test, n = 82 pairs). (B) The zoo  
 780 memory test scores for 1<sup>st</sup>- and 4<sup>th</sup>-rank children (unpaired t-test, n = 82). (C) The correlation between  
 781 picture memory scores and dominance levels (Pearson correlation, n = 82). (D) The correlation  
 782 between zoo memory scores and dominance levels (Pearson correlation, n = 82).

783

784 **Table S1. Regression analysis of the mediation effect: children memory→prosocial strategy→**  
 785 **social dominance (n=175)**

	<u>Prosocial strategy</u>		<u>Social dominance</u>	
	<u>Model 1</u>	<u>Model 2</u>	<u>Model 3</u>	<u>Model 4</u>
	$\beta$	$\beta$	$\beta$	$\beta$
<b>Memory ability</b>	0.46***	0.52***		0.33***
<b>Prosocial strategy</b>			0.56***	0.40***
<i>R</i> <sup>2</sup>	0.21	0.27	0.31	0.39
<i>Adj R</i> <sup>2</sup>	0.20	0.26	0.30	0.39
<i>F</i>	45.09***	62.29***	76.82***	55.99***
<i>df</i>	1.173	1.173	1.173	2.172

786 \*\*\* $p < 0.001$ .

787

788

789 **Table S2. Two-way ANOVA of FN400 by social status (1<sup>st</sup>- and 4<sup>th</sup>-ranked children) and social**  
 790 **facial expression**

Source of variance	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>	$\eta^2_p$
<b>Social status (between)</b>	81.537	1	81.537	6.415*	0.019	0.226
<b>Error (between)</b>	279.626	22	12.710			
<b>Social facial expression (within)</b>	18.426	1	18.426	5.649*	0.027	0.204
<b>Social rank* social dominance face</b>	50.266	1	50.266	15.411**	0.001	0.412
<b>Error (within)</b>	71.760	22	3.262			

791 \*  $p < .05$ , \*\* $p < .01$ . Note. The FN400 amplitudes of each facial expression were corrected by  
 792 subtracting the averaged amplitude of the neutral facial condition.

793

794

795 **Table S3. FN400 comparisons between 1<sup>st</sup>- and 4<sup>th</sup>-ranked children when they were evaluating**  
 796 **different social facial expressions**

Social status	Face	<i>Mean</i>	<i>SD</i>	<i>t</i>	<i>df</i>	<i>p</i>	<i>Effect size (d)</i>
<b>Rank 1 vs rank 4</b>	<b>DF</b>	4.653	1.145	4.065**	22	0.001	1.659
<b>Rank 1 vs rank 4</b>	<b>SF</b>	0.560	1.163	0.482	22	0.635	0.197
<b>Rank 1</b>	<b>DF vs SF</b>	-3.286	2.480	-4.589**	11	0.001	1.223
<b>Rank 4</b>	<b>DF vs SF</b>	0.808	2.626	1.065	11	0.310	0.273

797 \*\* $p < .01$ . Note. DF = dominant face, SF = subordinate face. The amplitudes of FN400 were corrected  
 798 by subtracting the averaged amplitude of the neutral facial condition.

799

800

801 **Table S4. Primer used for quantitative PCR**

Gene	Forward primer (5'-3')	Reverse primer (5'-3')
<i>Bdnf</i>	<i>GGCTGACACTTTTGAGCACGTC</i>	<i>CTCCAAAGGCACTTGACTGCTG</i>
<i>Camk2</i>	<i>ACCCTGGCCTGGTCCTTCAATG</i>	<i>AGCCATCCTCACCCTATGCTGG</i>
<i>Cdk5</i>	<i>GGCTAAAACCGGGAAACTC</i>	<i>CCATTGCAGCTGTGCGAAATA</i>
<i>Creb</i>	<i>TCAGGGTACTACCATTC</i>	<i>TTCAGCAGGCTGTGTAGGAA</i>
<i>C-fos</i>	<i>TTCCTGGCAATAGCGTGTTT</i>	<i>TTCAGACCACCTCGACAATG</i>
<i>Egr1</i>	<i>CGAGCGAACAACCCTATGAG</i>	<i>CATTATTCAGAGCGATGTCAGAAA</i>
<i>Gria1</i>	<i>TTTTCTAGGTGCGGTTGTGG</i>	<i>CCT TTGGAGAACTGGGAACA</i>
<i>Gria2</i>	<i>AAGGAGGAAAGGGAAACGAG</i>	<i>CCGAAGTGGAAAACCTGAACC</i>
<i>Npas4</i>	<i>GCTATACTCAGAAGGTCCAGAAGGC</i>	<i>TCAGAGAATGAGGGTAGCACAGC</i>
<i>GRIN2B</i>	<i>TCTGCCTTCTTAGAGCCATTCAG</i>	<i>AGACAGCTACAGCAGAGAC</i>
<i>Phf2</i>	<i>TGCCCGAACTGCGAGAAAACCC</i>	<i>TTTCACGTCCGGTGTGGCCC</i>
<i>Ntrk2</i>	<i>GTGGTGTCATTAGTAGGTTCTTTGTT</i> <i>TT</i>	<i>ACTGAACCTGACCGTACAGAGTT</i> <i>TGGGTCTTTGCTGCC</i>
<i>Gapdh</i>	<i>GGCAAATTCAACGGCACAGT</i>	<i>GGGTCTCGCTCCTGGAAGAT</i>

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