

Supplementary Material

1. Study 1 - Is social anxiety in autism associated with unique social behaviors?

1.1 Relationship between self-reported social anxiety diagnoses and self-reported social avoidance behaviors

Individuals' attestation of having social anxiety (SA) disorder diagnoses was significantly related to higher rates of self-reported social avoidance behavior ($\chi^2 = 27.81$, $\beta = 0.57$, S.E. = 0.11, 95% CI = [0.35, 0.79], $p < 0.0001$, Figure S1)

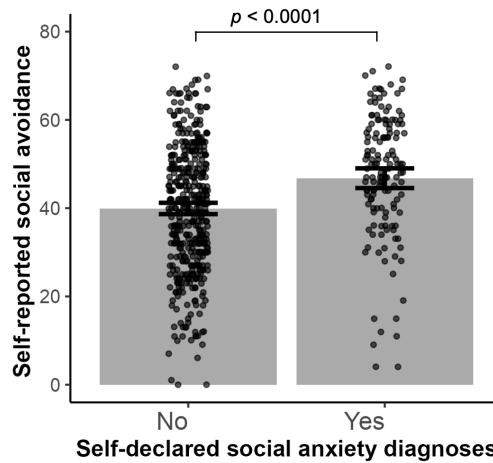


Figure S1. Relationship between self-reported social anxiety diagnoses and self-reported social avoidance behaviors in Study 1. Error bars represent 95% confidence intervals.

1.2 Demographic information comparing individuals with and without a self-reported history of social anxiety disorder diagnoses

Results show that for those autistic individuals who declared SA, they were more likely to be females, and they had lower education, lower cognitive function, higher self-rated autism symptom severity and higher social avoidance behaviors.

Table S1. Statistics of demographic information and main research variables for the online sample of autism (n = 575). Welch two-sample t-tests were performed to evaluate group differences of continuous variables based on self-reported depression diagnoses. Two-Proportion Z-Test was performed for proportion comparison. Significant differences are bolded.

Self-reported social anxiety Dx			
	YES (145, 25.22%)	NO (430, 74.78%)	test
Sex	32 males 113 females	134 males 296 females	$\chi^2 = 4.37$, $p = 0.037$
Age	25.09 (3.33) 18.5 – 30.92	25.47 (3.30) 18.42 – 30.92	$t = -1.20$, $p = 0.230$
Education	College and above 31	College and above 152	$t = -3.11$, $p = 0.002$

	High school and below 114	High school and below 278	
IQ	26.54 (6.35) 3 – 36	27.87 (5.33) 3 – 36	$t = -2.27, p = 0.024$
Cognitive delays	Yes 66 No 79	Yes 152 No 278	$t = 2.14, p = 0.033$
Self-rated autism symptom severity	153.6 (20.68) 106 – 211	143.40 (22.78) 66 – 202	$t = 4.11, p < 0.0001$
Social avoidance	47.86 (13.92) 4 – 72	39.56 (14.33) 0 – 72	$t = 41.42, p < 0.0001$
Affiliation behaviors	0.09 (0.31) -0.67 – 0.8	0.15 (0.30) -0.80 – 0.80	$t = -1.78, p = 0.076$
Power behaviors	-0.15 (0.21) -0.67 – 0.47	-0.11 (0.20) -0.60 – 0.40	$t = -2.05, p = 0.042$

Note: IQ was measured by standard cognitive test from TestMyBrain (<https://www.testmybrain.org>). Cognitive delays was self-reported conditions including intellectual disability, specific language impairment, or global developmental delays and others. Self-reported autism symptom severity was measured by Broad Autism Phenotype Questionnaire (BAPQ, 68% ($N = 391$) of the sample completed it). Social avoidance was measured by self-report Liebowitz Social Anxiety Scale.

1.3 Robustness tests

To further confirm the robustness of our findings, we conducted two additional analyses. First, we reversed the roles of the independent and dependent variables by using task-derived power behavior as the dependent variable and SA (with other demographic information, IQ and self-reported cognitive delays as covariates) as predictors. This analysis yielded consistent results showing that lower task-derived power behavior was related to self-reported SA ($F = 4.93, \beta = -0.21, S.E. = 0.10, p = 0.027$). When additionally adding task-derived affiliation behavior in the model as a covariate, the result was still significant ($p = 0.042$).

Next, our result also held when testing with those subset ($n = 391$, 68% of the total sample) who filled out the Broad Autism Phenotype Questionnaire for self-rated autism symptom severity ($\chi^2 = 6.20, \beta = -0.32, S.E. = 0.13, p = 0.013$).

Finally, we ran 1,000 bootstrap iterations on the relationship between task-derived power behavior and self-reported SA, which produced consistent findings ($\beta = -0.23, S.E. = 0.11, 95\% CI = [-0.46, -0.02]$). There were no significant sex differences in this association ($p = 0.868$). These results show that SA in autism was robustly related to acquiescent behaviors.

1.4 Social behaviors relation to social anxiety in ASD vs. neurotypical controls

In order to assess the SA relation to social behaviors for those with ASD and neurotypical (NT) controls, we conducted an exploratory analysis using a subset of participants from Study 1 who had no cognitive delays, and a matched NT online sample ($n = 357$) based on sex, age, and education. For Demographic comparisons between the ASD and NT groups of Study 1 see Table S2. The results show that compared with those non-autistic individuals who declared SA diagnoses, those autistic individuals who declared SA had lower income, higher self-rated autism symptom severity and higher social avoidance behaviors. Consistent with the broad literature, the ASD sample had greater proportion of SA than NT.

Table S2. Statistics of demographic information and main research variables for the comparison of ASD and neurotypical (NT) controls. Welch two-sample t-tests were performed to evaluate group differences of continuous

variables between the ASD and NT samples. Two-Proportion Z-Tests were performed for proportion comparisons. Significant differences are bolded.

	ASD (n = 357)	NT (n = 357)	test
Sex	M 84 F 273	M 93 F 264	$\chi^2 = 0.61, p = 0.435$
Age	25.33 (3.25)	25.01 (3.40)	$t = 1.28, p = 0.202$
Education	College and above 129 High school and below 228	College and above 187 High school and below 170	$t = -1.36, p = 0.173$
Self-rated autism symptom severity	145.52 (22.95)	113.00 (21.85)	$t = 19.10, p < 0.0001$
Social avoidance	42.11 (14.04)	31.47 (14.83)	$t = 9.84, p < 0.0001$
Affiliation behaviors	0.13 (0.30)	0.33 (0.25)	$t = -9.86, p < 0.0001$
Power behaviors	-0.13 (0.20)	-0.02 (0.19)	$t = -7.69, p < 0.0001$
Self-reported social anxiety Dx	Yes 79 (22.13%) Male 11 Female 68	Yes 25 (7.08%) Male 5 Female 20	$\chi^2 = 32.82, p < 0.0001$

Note: Self-reported autism symptom severity was measured by Broad Autism Phenotype Questionnaire (BAPQ, 68% (N = 391) of the sample completed it). Social avoidance was measured by self-report Liebowitz Social Anxiety Scale.

We also examined whether perceived social relations with game characters related to SA. We found that there was no main effect of SA on perceived affiliation ($p = 0.650$) or interaction of SA and group (ASD vs NT, $p = 0.941$), but there was a main effect of group where the NT group perceived greater affiliation with game characters than ASD group ($p = 0.004$), see Fig. S2A. There was no main effect of SA ($p = 0.482$) and no main effect of group ($p = 0.279$) on perceive power, and there was no interaction of group and SA ($p = 0.689$), see Fig. S2B.

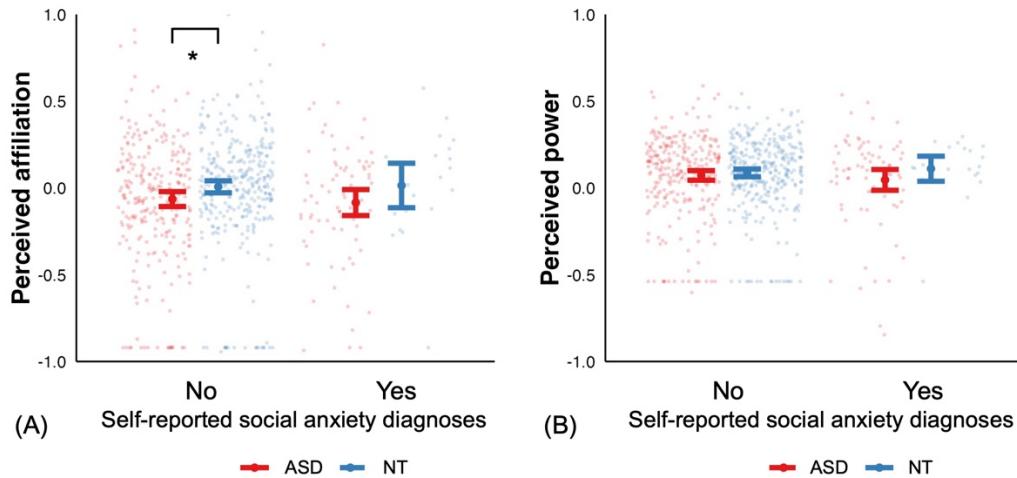


Figure S2. Relationship between perceived social relations during game and self-reported SA diagnoses in ASD and NT groups. Separate models predict perceived affiliation and perceived power by interaction term for group (ASD vs. NT) and SA (yes vs. no), with sex, age and education as covariates. Error bars represent 95% confidence intervals.

2. Study 2 – Are social anxiety and social behavior in autism associated with amygdala volume?

2.1 Relationship between self-reported social anxiety diagnoses and self-reported social avoidance behaviors

Individuals' attestation of having SA diagnoses was significantly related to higher rates of self-reported social avoidance behavior ($\chi^2 = 5.90$, $\beta = 0.89$, S.E. = 0.40, 95% CI = [0.11, 1.67], $p = 0.015$, Figure S3)

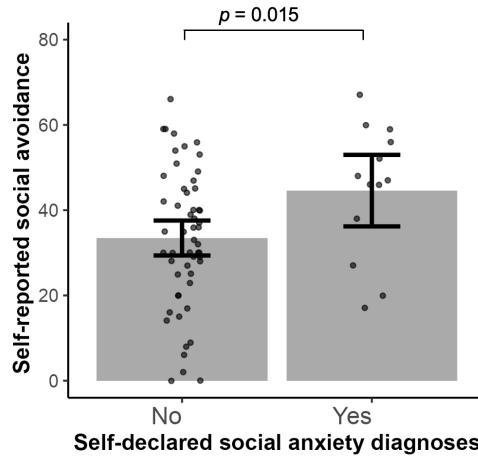


Figure S3. Relationship between self-reported social anxiety diagnoses and self-reported social avoidance behaviors in Study 2. Error bars represent 95% confidence intervals.

2.2 Demographic information comparing individuals with and without a self-reported history of social anxiety disorder diagnoses

Results show that for those autistic individuals who declared SA, they had less clinician-rated autistic symptom severity and higher self-reported social avoidance behaviors.

Table S3. Statistics of demographic information and main research variables for onsite neuroimaging sample of autism (n = 72). Welch two-sample t-tests were performed to evaluate group differences of continuous variables based on self-reported depression diagnoses. Two-Proportion Z-Test was performed for proportion comparison. Significant differences are bolded.

Self-reported social anxiety Dx		
YES (15, 21%)	NO (57, 78%)	test
Sex	5 males 10 females	29 males 28 females
Age	25.68 (7.56) 18.16 – 45.80	27.15 (7.82) 18 – 50.36
Education	College and above 8 High school and below 7	College and above 36 High school and below 21
IQ	102.80 (14.50) 77 – 131	106.17 (17.05) 67 – 140
Clinician-rated autism symptom severity	12.87 (3.04) 6 – 19	14.84 (4.03) 7 – 26

Self-rated autism symptom severity	149.10 (27.52) 96 – 189	137.80 (24.21) 93 – 187	t = 1.53, p = 0.141
Social avoidance	44.20 (14.55) 17 – 67	33.33 (16.15) 0 – 66	t = 11.77, p < 0.0001
Affiliation behaviors	0.11 (0.38) -0.43 – 0.80	0.17 (0.31) -0.60 – 0.73	t = -0.62, p = 0.540
Power behaviors	-0.07 (0.17) -0.29 – 0.31	-0.13 (0.19) -0.52 – 0.31	t = 1.31, p = 0.203
Right amygdala volume (mm ³)	1226 (203) 804 – 1664	1110 (282) 558 – 1765	t = 1.81, p = 0.081
Left amygdala volume (mm ³)	1279 (151) 1079 – 1580	1155 (280) 416 – 1688	t = 2.31, p = 0.026
Averaged amygdalae volume (mm ³)	1253 (132) 1041 – 1555	1133 (236) 531 – 1688	t = 2.60, p = 0.013
Intracranial volume (mm ³)	921025 (116193) 765682 – 1206785	988001 (156985) 716799 – 1369934	t = -1.83, p = 0.077

Note: IQ was measured by Wechsler Abbreviated Scale of Intelligence and Wechsler Intelligence Scale for Adults. Clinician-rated autism symptom severity was determined by licensed clinicians using Autism Diagnostic Observation Schedule, 2nd edition. Self-reported autism symptom severity was measured by Broad Autism Phenotype Questionnaire. Social avoidance is measured by self-report Liebowitz Social Anxiety Scale.

2.3 Robustness tests

To further confirm the robustness of our findings, we conducted two additional analyses. First, we reversed the independent and dependent variables by using amygdala volume as the dependent variable and SA (with other demographic information and IQ) as predictors. This analysis yielded consistent result showing that larger amygdala volume was related to self-reported SA ($F = 5.26$, $\beta = 0.67$, S.E. = 0.29, p = 0.025). Second, we ran 1,000 bootstrap iterations on the relationship between power behavior and self-reported SA, which produced consistent finding ($\beta = 0.88$, S.E. = 0.40, 95% CI = [0.15, 1.56]). There were no significant sex differences in this association (p = 0.868). These results show that SA in autism was robustly related to larger amygdala volume.

2.4 Amygdala volume relation to social anxiety in ASD vs. NT

We conducted an exploratory analysis of ASD with NT onsite sample. These two samples didn't differ by sex and age. For Demographic comparisons between the ASD and NT groups of Study 2 see Table S4.

Table S4. Statistics of demographic information and main research variables for onsite samples. Welch two-sample t-tests were performed to evaluate group differences of continuous variables between the ASD and TD samples. Two-Proportion Z-Tests were performed for proportion comparisons. Significant differences are bolded.

	ASD (n = 72)	NT (n = 72)	test
Sex	M 34 F 38	M 27 F 45	$\chi^2 = 1.39$, p = 0.2378
Age	26.85 (7.74) 18 – 50.36	25.89 (6.44) 18.87 – 50.02	t = 0.83, p = 0.4107
Education	College and above 44	College and above 64	t = -4.79, p < 0.0001
	High school and below 28	High school and below 8	
IQ	105.50 (16.54) 67 – 140	113.7 (13.91) 76 – 135	t = -2.91, p = 0.0043

Intracranial volume	974048 (151162)	963996 (120313)	$t = 0.44, p = 0.6596$
Self-rated autism symptom severity	140.30 (25.21) 44 – 150	93.11 (21.14)	$t = 11.90, p < 0.0001$
Social avoidance	35.60 (16.35) 1 – 51	21.16 (12.90)	$t = 18.48, p < 0.0001$
Affiliation behaviors	0.16 (0.33) -0.60 – 0.80	0.36 (0.25) -0.31 – 0.87	$t = -4.14, p < 0.0001$
Power behaviors	-0.12 (0.18) -0.52 – 0.31	-0.09 (0.22) -0.52 – 0.36	$t = -0.96, p = 0.341$
Right amygdala volume (mm ³)	1134 (271) 558 – 1765	1129 (245) 509 – 1534	$t = 0.12, p = 0.903$
Left amygdala volume (mm ³)	1181 (262) 416 – 1688	1131 (262) 396 – 1579	$t = 1.14, p = 0.257$
Averaged amygdala volume (mm ³)	1158 (223) 531 – 1688	1130 (205) 639 – 1521	$t = 0.77, p = 0.443$
Intracranial volume (mm ³)	974048 (151163) 716799 – 1369934	962581 (120565) 695642 – 1304039	$t = 0.50, p = 0.617$
Self-reported social anxiety Dx	Yes 15 (21 %) Male 5 Female 10	Yes 9 (12.5%) Male 3 Female 6	$\chi^2 = 1.8, p = 0.180$

Note: IQ was measured by Wechsler Abbreviated Scale of Intelligence and Wechsler Intelligence Scale for Adults. Self-reported autism symptom severity was measured by Broad Autism Phenotype Questionnaire. Social avoidance is measured by self-report Liebowitz Social Anxiety Scale.