Abnormal adaptive face-coding mechanisms in children with autism spectrum disorder

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Summary

In low-level vision, exquisite sensitivity to variation in luminance is achieved by adaptive mechanisms that adjust neural sensitivity to the prevailing luminance level. In high-level vision, adaptive mechanisms contribute to our remarkable ability to distinguish thousands of similar faces [1]. A clear example of this sort of adaptive coding is the face identity aftereffect [2-5], where adaptation to a particular face biases perception towards the opposite identity. Here we investigated face adaptation in children with autism spectrum disorder (ASD), by asking them to discriminate between two face identities, with and without prior adaptation to opposite-identity faces. The ASD group discriminated the identities with the same precision as the age- and ability-matched control group, showing that face identification *per se* was unimpaired. However, children with ASD showed significantly less adaptation than their typical peers, with the amount of adaptation correlating significantly with current symptomatology, and face aftereffects of children with elevated symptoms only one third those of controls. These results show that while children with ASD can learn a simple discrimination between two identities, adaptive face-coding mechanisms are severely compromised, offering a new explanation for previously-reported face-perception difficulties [6-8], and possibly for some of the core social deficits in ASD [9-10].

Results and Discussion

We analyzed face identification data from 14 high-functioning boys with ASD and 15 age- and ability-matched typically developing boys, obtained using a developmentally-appropriate version of the face identity aftereffect task (see Experimental Procedures and Table 1). After appropriate training on identification of two target faces (see Fig. 1A), and prior to any adaptation, children were presented with a series of face identities varying in strength between -0.9 (Jim) and +0.9 (Dan), and required to classify them as belonging to the Jim or Dan "team". This initial phase ensured children were able to identify the faces reliably and demonstrated sensitivity to identity strength. Children were subsequently required to identify the same faces after adapting to Anti-Dan or Anti-Jim (see Fig. 1A). Figure 1B shows results for two representative children (top panels), and for the two groups, pooled across all children in each group (lower panels). In all cases, the responses vary smoothly from 0% "Dan" responses for strong Jim identities to 100% "Dan" for strong Dan identities. The individual data were well fit by cumulative Gaussian functions (mean R^2 over all conditions = 0.85±0.05, typical; 0.91±0.02, ASD) and the fits for the pooled group data were excellent (all R^2>0.98).

As previously reported in adults [2, 3], adaptation to Anti-Dan caused faces to appear *more* Dan-like, manifested by the psychometric function shifting towards the Jim extreme (more negative) (Fig. 1B). Similarly, adapting to Anti-Jim shifted the functions towards Dan. It is clear from inspection of both the individual examples and group data (Fig. 1B) that the difference in the position of the psychometric functions after adaptation to Anti-Dan and Anti-Jim is larger for typically developing children than for children with ASD. The position of the curves can be quantified by the point of subjective equality (PSE), defined as the mean of the cumulative Gaussian (where responses are 50% 'Dan'). Figure 2A shows average individual PSEs of the typically developing group (filled circles), the ASD group (open squares) and a subset of ASD children showing higher levels of autistic symptoms (scores ≥ 22 on the Social Communication Questionnaire (SCQ) [11]: filled triangles).

Since the two adaptation conditions contained the same trial structure (i.e., adapting face; target face), we defined the size of the aftereffect as the difference in PSE between the two adapting conditions (PSE after adapting to Anti-Jim minus PSE after adapting to Anti-Dan). Both typical and ASD groups showed significant aftereffects (typical: M=0.36, SE=0.05, $t(14) = 6.98$, $p < 0.001$; ASD: M=0.22, SE=0.04, $t(13) =$

4.94, $p < 0.001$). However, the aftereffect was significantly reduced for the ASD group, $t(27) = 2.11$, $p < 0.05$. This result was confirmed by a boot-strap t-test [12], $p < 0.05$ (3000 reiterations) on the pooled data (ASD: M=0.22; typical: M=.33). As a further test, which does not rely on curve-fitting, we compared the proportion of trials on which the identity opposite the adapting face was attributed to the identity-neutral average face (0 identity strength) [2] in the two groups. It was significantly reduced for the ASD group (M=0.54, SE=0.04) compared with the typical group (M=0.68, SE=0.04), $t(27) = 2.34$, $p < .03$.

Figure 2B plots the aftereffect against scores on the SCQ [11]. For the ASD group, the aftereffect correlated strongly (and negatively) with SCQ score, $r(12) = -0.60$, $p < 0.05$, indicating weaker adaptation with increasing number of current symptoms. There was no significant correlation for the typically developing group, $r(13) = 0.45$, $p = 0.10$, who had little variance in SCQ scores. The magnitude of the aftereffect did not correlate significantly with chronological age, verbal ability, or nonverbal ability in either group of children (ps > 0.18 in all cases), and nor did it correlate with a retrospective measure of symptomatology [13] in the ASD group ($p > .15$). Given the significant link between adaptation effect and current symptomatology, we examined the aftereffects of a subgroup of children with ASD (n=9) with elevated SCQ scores (≥ 22) – those children displaying more symptoms in areas of socialization, communication, and restricted/repetitive interests. Although this subgroup showed a significant aftereffect (M=0.14, SE=0.05), $t(8) = 2.66$, $p < 0.05$, it was highly attenuated, around one third the size, relative to that shown by typically developing children (M=0.36, SE=0.05), $F(1, 23) = 8.18$, $p < 0.01$.

The psychometric functions of Figure 1B provide not only an estimate of PSE, but also of identification precision, with precision thresholds given by the standard deviation (reflecting uncertainty) of the functions. Average standard deviations for the two groups (for baseline and adapting conditions) are shown in Figure 2C. Precision thresholds did not differ for the ASD and control groups, $F(1, 27) = 0.42$, $p = 0.52$, indicating that the ASD group was as precise as the typically developing group in distinguishing faces on this two-choice identification task, in baseline and adaptation conditions. Nor were ASD children with elevated SCQ scores (≥ 22) any less precise in identification than ASD children with lower SCQ scores, for any condition, all Fs < 1. This result is also apparent in the pooled data, with average standard deviations (across all three conditions) of 0.51 and 0.49 for the typical and ASD groups respectively.

Similar precision thresholds for the two groups show that reduced aftereffects in the ASD children cannot be attributed to poorer identification performance or task motivation. Nor can they be attributed to failure to inspect adapting faces, because observation of children's gaze during testing confirmed good inspection. Reduced attention to adapting faces could potentially contribute to the weaker aftereffect in autism, and we see the relationship between adaptation and attention as a promising direction for future research [14, 15].

Adaptive coding mechanisms, which can calibrate a limited neural response range to the prevailing visual environment, are fundamental for efficient coding of many sensory attributes [1]. It is highly likely that similar mechanisms play an important role in face perception, where the average face functions as a perceptual norm for coding identity. Direct support for such a functional role comes from evidence that adaptive tuning of face norms facilitates identification of faces from an adapted population [16]. That children, like adults, show significant adaptation to faces suggests that they may be using norm-based coding for face recognition. However, the significantly reduced aftereffect in children with ASD, particularly those scoring very high on the SCQ, suggests that the tuning of face norms by visual experience is disrupted in children with this condition.

Notably, children with ASD showed normal identification precision for the simple two-choice identification task used here. While this finding might appear inconsistent with previously-reported face memory difficulties in autism [e.g., 6, 17], it likely reflects the simplicity of the discrimination required (between only two identities) and the extensive training received. Notwithstanding, their reduced updating of face norms in response to experience should impair performance under normal conditions, where many thousands of subtle differences must be coded between faces, and should have a detrimental effect on the development of face perception skills. Abnormal adaptation of face-coding networks therefore offers a new perspective on the reported face-perception difficulties in autism [6-8, 17], and suggests that early deficits in norm-based face coding could be closely related to some of the core social deficits associated with the disorder [9, 10]. This finding of a link between adaptive face-coding skills and autistic symptomatology warrants further research, focused especially on elucidating the direction of causality: while early face-reading difficulties might generate the social problems characteristic of ASD, it is also plausible that an early lack of interest in social phenomena could contribute to the development of atypical face-coding mechanisms [18].

Our results are also consistent with the idea that individuals with autism have difficulty abstracting across perceptual experiences [19, 20]. Indeed the weaker aftereffect observed here may reflect a more pervasive problem in generating (and maintaining) norms or prototypes. Our findings, combined with previous evidence of impaired prototype formation in the disorder [21], point towards the intriguing possibility that abnormal adaptive coding mechanisms might not be limited to face recognition *per se*, but could extend to the coding of other non-face stimuli, in all sensory modalities.

Face perception in autism is an area of intense investigation, largely because face-reading difficulties may be instrumental in generating some of the social difficulties experienced by those with the disorder. The present findings offer new insight on these difficulties, highlighting the role of abnormal adaptive mechanisms. Whether these abnormalities are specific to faces or related to general difficulties integrating across perceptual experiences warrants more detailed investigation.

Experimental Procedures

Participants

Data were analyzed for 29 children aged between 8 and 13 years. Three additional children were assessed but their data were excluded from analysis on the basis of either baseline identification performance of less than 80% for target faces of 0.9 identity strength (1 child with ASD) or poor goodness of fit of functions (1 typically developing child and 1 child with ASD, with $R^2 < 0.50$).

Fourteen boys with idiopathic ASD (M age 11.0 years; SD=1.7) were recruited through a longitudinal study on cognitive skills in autism. All participants met DSM-IV criteria [22] for autism (n=12) or Asperger syndrome (n=2) according to an independent clinician, and the Autism Diagnostic Interview - Revised [13], and were considered 'high-functioning': they were verbally fluent, obtained nonverbal IQ scores in the normal range (standard score ≥ 85), and attended mainstream schools. The SCQ [11], a 40-item questionnaire, was completed by parents of children with ASD and used to index degree of current symptomatology. Following Rutter et al. [11], SCQ scores of 15 or more are indicative of clinically-significant symptomatology, and scores of 22 or more reflect elevated levels of symptomatology.

Fifteen typically developing boys (M age 11.1 years; SD=1.9), with no current or past medical or psychiatric diagnoses, served as control individuals. Typically developing children were screened for autistic symptomatology using the SCQ. All typically developing children scored well below the cut-off of 15 for ASD (Table 1 and Figure 2C).

The ASD group was well matched to the control group for chronological age and nonverbal ability (Table 1), as measured by Raven's Standard Progressive Matrices [23], but scored slightly worse on the assessment of verbal ability, the Peabody Picture Vocabulary Test – Third Edition (PPVT-III) [24], consistent with poor communication skills being part of the diagnostic criteria for ASD [22]. Notably, all children obtained a verbal IQ score of at least 80, demonstrating a level of receptive language that ensured comprehension of task instructions. No child had a medical or developmental disorder other than ASD, was on medication, or obtained a verbal or nonverbal IQ score below 80. Participants were tested individually in a quiet room either at home or at the University. Tests of nonverbal and verbal ability were always administered prior to the face identity aftereffect task. The entire session lasted approximately 1 hour.

Stimuli

Grayscale photographs of three male target faces (Dan, Jim, and Rob) served as basic stimuli. A series of test images of graded identity strength (e.g., 0.3, 0.6, and 0.9 Dan) were created for each target face by morphing (Gryphon Morph 2.5, Duane Maxwell, Gryphon Software Corporation 1992-1994) between the target and the average face (constructed from the pool of 20 male faces). For each target face an anti-face was constructed, lying on the same identity trajectory but extrapolated beyond the average face (0.8 of original target strength). All faces were presented on an Apple Macintosh G3 laptop computer within a 320x420 pixel oval mask, which hid the outer hairline.

Procedure

Training. Children were introduced to two target faces (Dan and Jim or Dan and Rob) at full identity strength (1.0), as 'team captains'. (Note that analyses with 'version' (Dan-Jim, Dan-Rob) as an additional between-subjects variable revealed no significant interactions with group (ASD, typical development). Therefore, these data were combined.) These faces were then presented five times in random order and children were asked to identify them by appropriate key press. Trial sequences comprised a black fixation cross (150 ms), an inter-stimulus interval (500 ms) followed by presentation of the target face. In the first 10 trials, target faces remained visible until a response was made. In the second 10 trials, target faces appeared for 400 ms, followed by a blank screen. Feedback was provided during training, but not during testing.

Following success on at least 4 out of the final 5 trials, children were introduced to Dan and Jim's 'team-mates' (0.4 and 0.6 identity strengths of Dan and Jim). In the first 12 trials, faces were presented twice at each of 3 identity strengths (0.4, 0.6, and 1.0 Dan and Jim) until children identified to which 'team' the target face belonged. In two successive blocks of 12 trials, target faces were displayed for 400 ms. Again, children needed to succeed on 4 out of the final 5 trials to proceed to the next phase. To meet this criterion, the training block was repeated once for 2 children with ASD and 3 typically developing children and twice for 3 children with ASD and 2 typically developing children.

Baseline. Children were then required to identify all members of Dan and Jim's teams. Four identity strengths of each target face (0, 0.3, 0.6, and 0.9 Dan and Jim) were shown eight times in a randomized order for a total of 64 trials, divided into three blocks. Each face was presented briefly (400 ms) followed by a screen asking, "Which team did he belong to?". Successive trials commenced 500 ms after the child responded. All children achieved baseline performance of at least 80% correct when identifying target faces of 0.9 identity strength.

Adaptation. The adaptation phase was embedded within a story: two robbers (anti-faces) were planning to rob a jewelry store, and the child's task was to identify which team caught the robber (i.e., a person from either Dan's team or Jim's team).

Trials consisted of a black fixation cross (150 ms), a blank screen (500 ms), the adapting face or ‘robber’ (5000 ms) followed by the target face (400 ms). To allow the child brief breaks, a series of rest trials (requiring no response) were included in which the adapting face was presented, but there was no target face as ‘the robber had escaped’. A total of 108 trials were presented to children, including 96 adaptation trials (48 adapting to Anti-Dan and 48 adapting to Anti-Jim, with 6 trials for each target face at 4 identity strengths of 0, 0.3, 0.6, and 0.9) and 12 rest trials, which were divided into 6 blocks of 18 trials (16 adaptation trials and 2 rest trials) and presented in a randomized order. Examiners monitored the children during this phase and ensured that children fixated on the adapting face for the full exposure duration.

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Figure legends

Figure 1. A. A simplified two-dimensional face-space in which faces are coded as unique trajectories originating from the average face (norm) located at the centre. Reduced identity strengths (e.g., 0.3, 0.6, and 0.9 Dan) were constructed by morphing the original face (100% Dan) towards the average face. Anti-faces (0.8) lie along the same identity trajectory, extrapolated past the average face. **B.** The top part of the panels shows example psychometric functions from one typically developing child (EB: top left) and one child with ASD (MB: top right) for the pre-adaptation baseline condition (open triangles) and for the two adapting identities (filled circles: adapt Anti-Dan, filled squares: adapt Anti-Jim). The bottom panels show data pooled over all comparison children (left) and all children with ASD (right). Proportion of "Dan" responses are plotted as a function of identity strength, which ranges from –1 (full-strength Jim) to +1 (full strength Dan). The data are fitted with two-parameter (mean and standard deviation) cumulative Gaussian functions, whose means estimate PSE and standard deviations estimate precision.

Figure 2. A. Effect of adaptation on perceived identity (PSE) for typically developing children (filled circles), all children with ASD (open squares), and children with ASD with a SCQ [11] score ≥ 22 (filled triangles). **B.** Size of the aftereffect plotted as a function of SCQ score (typical: filled circles, ASD: open squares). The vertical bars near the clusters of data show the average SEM of individual participants, calculated by bootstrap [12], and the filled and open arrows near the right ordinate show the mean aftereffects for the typical and ASD groups respectively. The line shows the regression for the ASD group. **C.** Mean precision for typical and ASD children for face identification in baseline and adaptation conditions. The bars show the geometric means (with 1 SEM) of precision threshold, calculated from the standard deviations of Gaussian-fitted psychometric functions.

Table 1. Descriptive statistics for chronological age, nonverbal ability, verbal ability, and Social Communication Questionnaire [11] scores.

Measure	Group: ASD (n = 14) M (SD) range	Typical development (n = 15) M (SD) range	F	df	p
Chronological age (months)	132.57 (19.96) 103 – 163	132.93 (22.35) 106 – 168	.002	1, 28	.96
Nonverbal ability (Raven's raw score)	36.93 (8.82) 24 – 49	35.60 (9.72) 24 – 53	.15	1, 28	.70
Verbal ability (PPVT-III raw score)	122.57 (29.14) 85 – 184	140.20 (24.07) 107 – 181	3.17	1, 28	.09
Social Communication Questionnaire (out of 40)	23.28 (5.04) 16 – 30	3.69 (2.58) 0 – 8	177.41	1, 28	<.001

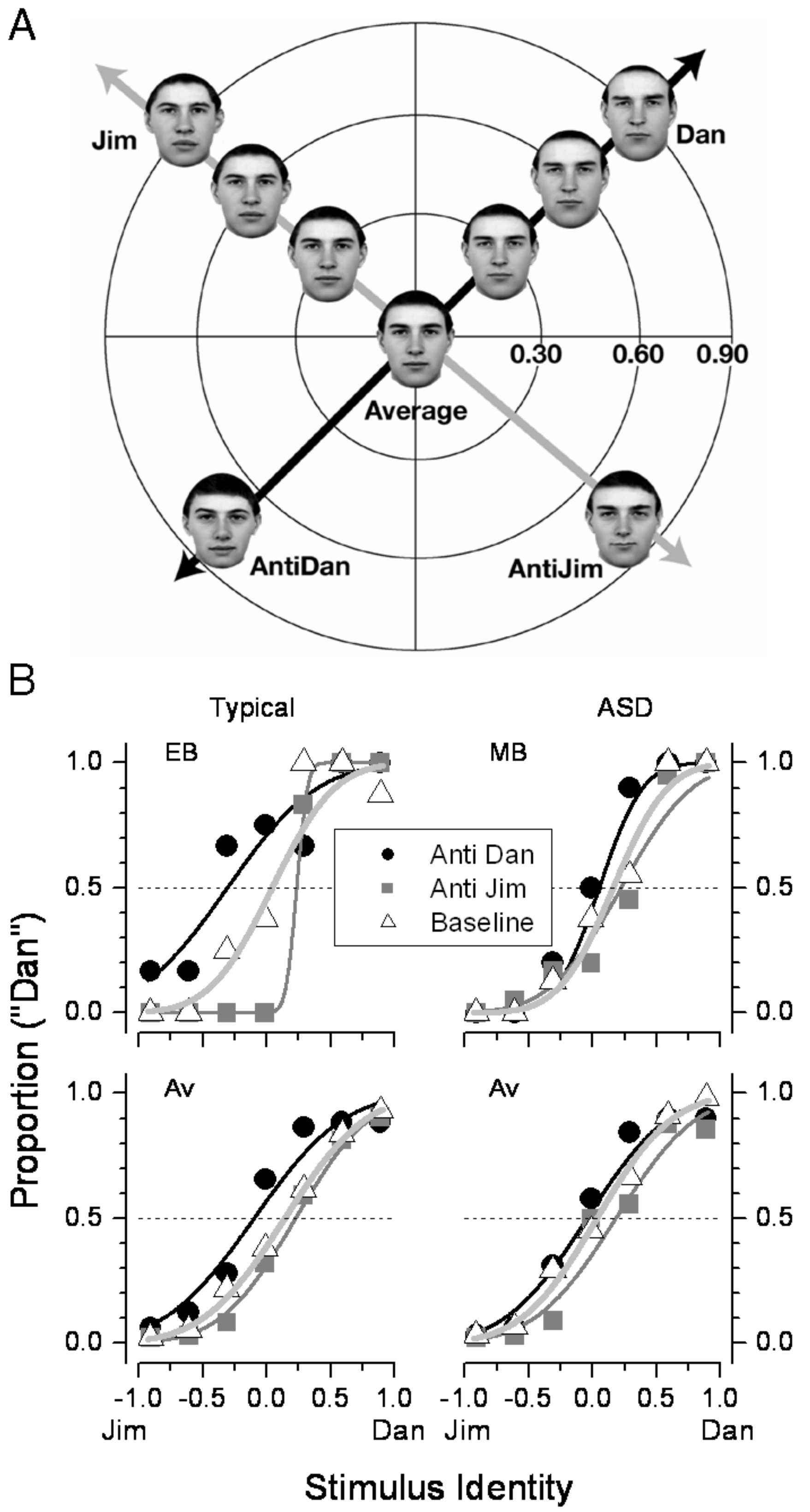
A
Jim
Dan
0.30
0.60
0.90
Average
AntiDan
AntiJim
B
Typical
ASD
EB
MB
Av
Av
Anti Dan
Anti Jim
Baseline
Proportion ("Dan")
1.0
0.5
0.0
-1.0 -0.5 0.0 0.5 1.0
Jim
Dan
Stimulus Identity

Figure 1.

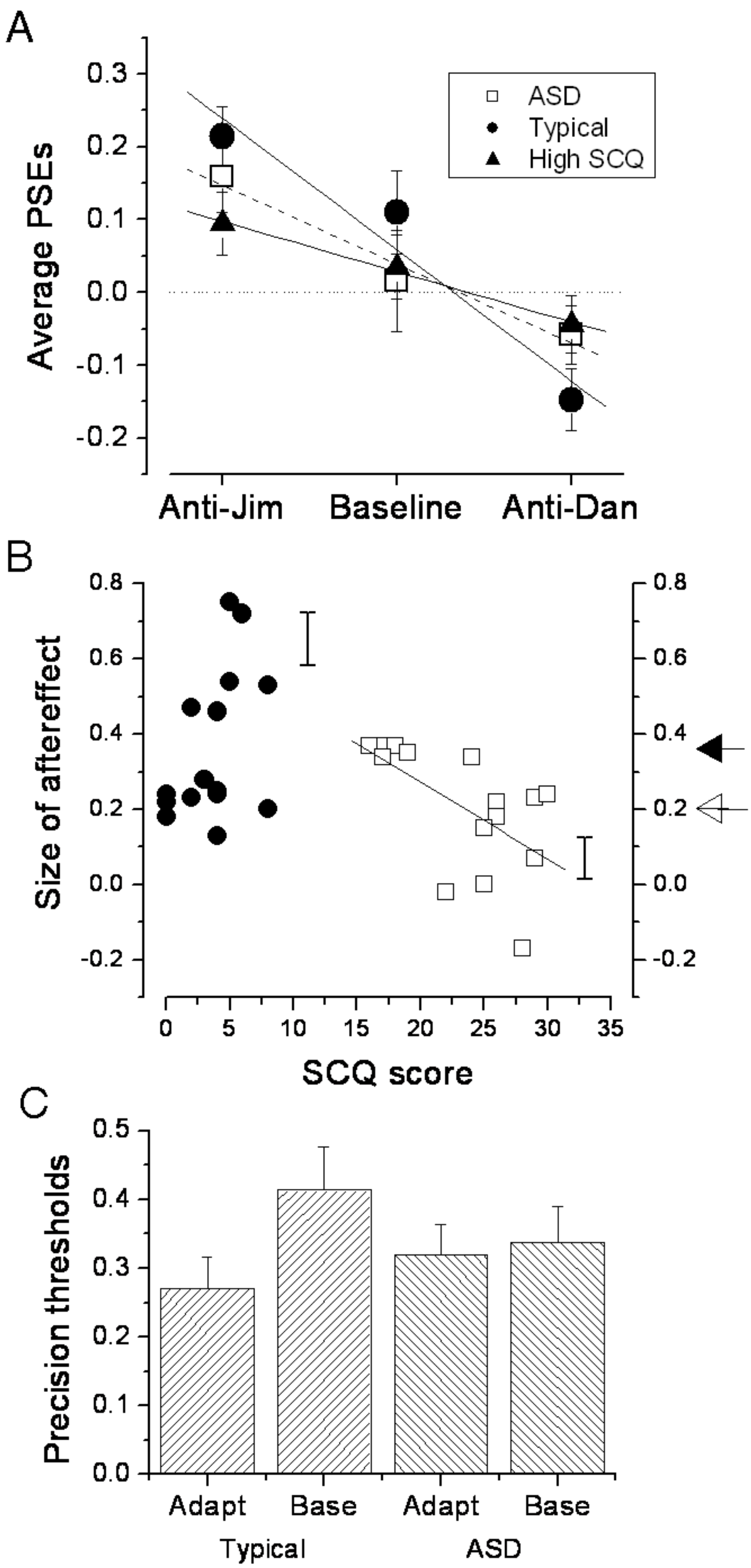
A
Average PSEs
0.3
0.2
0.1
0.0
-0.1
-0.2
ASD
Typical
High SCQ
Anti-Jim
Baseline
Anti-Dan
B
Size of aftereffect
0.8
0.6
0.4
0.2
0.0
-0.2
0
5
10
15
20
25
30
35
SCQ score
C
Precision thresholds
0.5
0.4
0.3
0.2
0.1
0.0
Adapt
Base
Adapt
Base
Typical
ASD

Figure 2.