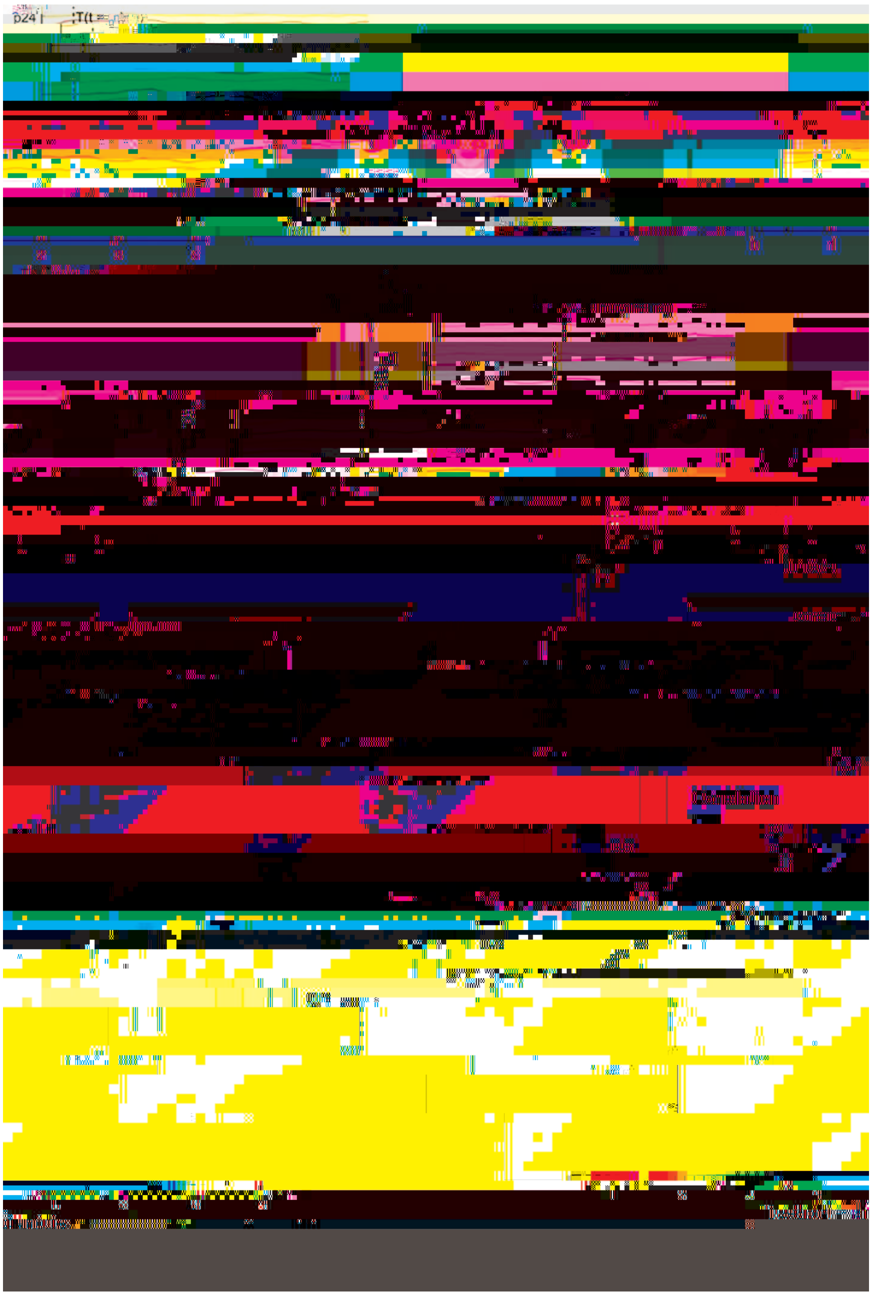

F 2. Results of the novel data-driven correlation method. For each data point of the time series signals, we correlated proportional eye-looking time across participants at time with proportional looking time on the gazed-at object (FLO in the congruent condition or NFLO in the incongruent condition) at time (0 ≤ ≤ ≤ 4 s; top panel). This results in a 480 (data points) × 480 (data points) upper triangular matrix (bottom panel). Each value in the matrix represents a correlation coefficient between eye-looking time pattern at time and looking time on gazed-at object at time (0 ≤ ≤ ≤ 4 s). That is, correlations are between the proportion of time spent looking at eyes and proportion of time spent looking at objects at any given time point throughout the trial, with the restriction that eye-looking time happens before object-looking time. Areas showing significant correlations are delimited by white borders (multiple comparisons were controlled by using the cluster-based permutation test). This analysis was done separately for each participant group and experimental condition. AOIs for the object and eyes (within the blue rectangles or regions pointed by arrows) are also illustrated in this figure. ASD = autism spectrum disorder; TD = typically developing. See the online article for the color version of this figure.

sponses, that is, whether their looking time at the object would be modulated by others' following or not following their own gaze.

period from 0.75 to 4.00 s, $_{\text{sum}} = -80{,}820$, $= .046$. Correlations were not significant after correction in the congruent condition.

Discussion

Using a computer-based gaze-contingent design and novel time-course analyses, we investigated the eye movements in TD and ASD children in response to others' gaze following with respect to their own gazes. Specifically, we tested (1) how children attended to the objects in response to others' gaze following or failure to follow, (2) whether children with ASD displayed atypical attention to the partners' eyes during JA, and (3) whether attention to eyes influenced subsequent attention to objects.

First, we found that TD children's attention to the objects was modulated by others' gaze responses: They spent higher proportional FLO-looking time in the congruent condition than they did in the incongruent and closed-eye gaze conditions, and they spent higher proportional NFLO-looking time in the incongruent condition than they did in the congruent and closed-eye gaze conditions. Such sensitivities occurred approximately 1.8 s after the virtual face started to shift its gaze. Given that the virtual face's gaze-shifting lasted approximately 1.2 s, this finding suggests that TD children made gaze responses after fully extracting the face's gaze information. However, children with ASD did not differentiate their attention to objects among the three conditions, suggesting their insensitivity to virtual faces' gaze response. Contrary to the findings in our study, previous studies suggest that the ability to eyes play during gaze-based interactions in both TD and ASD children. A related issue is whether the relationship between eye-looking time and object-looking time during JA is relevant to theory of mind. Since monitoring a person's gaze/attention is an example of monitoring a person's mental state (Baron-Cohen, 1991), the absence of positive correlations between eye-looking time and object-looking time in ASD children might be attributed to their deficits in theory of mind. However, we did not examine what kind of role theory of mind played in children's gaze following in our study, a topic that could be further investigated by follow-up studies. Fourth, as in a real-life situation, we did not instruct children to attend to the faces or eyes. Whether instructing children with ASD to attend to the interactive face's gaze will improve their JA is an interesting question and may shed light on developing intervention methods aiming to improve JA in individuals with ASD. Fifth, having one's own gaze followed affects how a social partner is perceived (Bayliss et al., 2013); for example, adults favor others who follow their gaze (Bayliss et al., 2013). Likewise, children could also learn and establish that association (e.g., face in the congruent condition = good face, face in the incongruent condition = bad face, and face in the closed-eye gaze condition = ignorant face). It would be interesting to test how learning outcome influences children's gaze following and how gaze following changes during learning course. However, these issues were not testable in our current study due to the limited trial numbers and absence of learning outcome measurements, making them a topic for future research. Lastly, previous fMRI studies using a similar paradigm set both the gaze-shift duration and the final gaze phase duration for 1 s (Oberwelland et al., 2016, 2017). We used similar gaze-shift durations (1.2 s) but longer final-gaze durations (3 s) to collect more eye-movement data. The length of the stimulus presentation time might influence the outcome, which could be examined in future investigations.

In conclusion, this study bridged a significant gap in the literature by studying gaze response to others' gaze following in children with and without ASD. TD children, but not ASD children, responded effectively and flexibly to others' gaze following of their own gazes. This study contributes to an understanding of the process of a more complex and reciprocal JA in TD children and abnormal social cognition in children with ASD in the context of ecologically valid social interactions.

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