Attention across modalities as a longitudinal predictor of early outcomes: the case of fragile X syndrome

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Background: Fragile X syndrome (FXS) is an early diagnosed monogenic disorder, associated with a striking pattern of cognitive/attentional difficulties and a high risk of poor behavioural outcomes. FXS therefore represents an ideal model disorder to study prospectively the impact of early attention deficits on behaviour. Methods: Thirty-seven boys with FXS aged 4–10 years and 74 typically developing (TD) boys took part. Study 1 was designed to assess visual and auditory attention at two time-points, 1 year apart. Study 2 investigated attention to multimodal information. Both tested attention markers as longitudinal predictors of risk for poor behaviour in FXS. Results: Children with FXS attended less well than mental-age matched TD boys and experienced greater difficulties with auditory compared to visual stimuli. In addition, unlike TD children, they did not benefit from multimodal information. Attention markers were significant predictors of later behavioural difficulties in boys with FXS. Conclusions: Findings demonstrate, for the first time, greater difficulties with auditory attention and atypical processing of multimodal information, in addition to pervasive global attentional difficulties in boys with FXS. Attention predicted outcomes longitudinally, underscoring the need to dissect what drives differing developmental trajectories for individual children within a seemingly homogeneous group. Keywords: Fragile X syndrome, attention deficits, longitudinal predictors of outcomes.

Introduction

Neurodevelopmental disorders diagnosed early in life with a clear genetic aetiology and a recognised phenotype can provide important clues to understanding the neurodevelopmental origins of other disorders that are currently defined only by their childhood phenotype (e.g. attention deficit/hyperactivity disorder, ADHD). Fragile X syndrome (FXS) represents a model disorder in this respect because it is a well-recognised cause of hereditary developmental delay, with an estimated incidence of 1 in 2,500 world-wide (Hagerman, 2008), associated with the silencing of a single X-linked gene (Garber, Visootsak, & Warren, 2008) and cases are identified as early as infancy, with an average diagnosis age of 37.9 months (Bailey, Raspa, Bishop, & Holiday, 2009). At the neurocognitive level, FXS is characterised by syndrome-specific proficiencies and deficiencies that distinguish it from other neurodevelopmental disorders (Bertone, Hanck, Kogan, Chaudhuri, & Cornish, 2010). Highly notable are the striking visual attention difficulties (e.g. Cornish, Scerif, & Karmiloff-Smith, 2007; Hooper et al., 2008; Munir, Cornish, & Wilding, 2000; Scerif, Cornish, Wilding, Driver, & Karmiloff-Smith, 2004, 2007; Scerif et al., 2005) that persist across development.

At the behavioural level and by mid childhood, FXS is associated with increased risk of clinically relevant difficulties (e.g. Rogers, Wehner, & Hagerman, 2001; Sullivan et al., 2006).

As such, FXS affords the opportunity to study the links between a single genetic aetiology, cognitive attention difficulties and subsequent behavioural outcomes prospectively from early childhood. Critically, however, both theoretical discussions and emerging evidence warn against construing these gene–brain–cognition–behaviour links as linear and unidirectional (Karmiloff-Smith, 2009; Scerif & Karmiloff-Smith, 2005): basic cognitive attentional difficulties characterise FXS from infancy and early childhood (Cornish et al., 2007; Scerif et al., 2004, 2005, 2007), and this in turn is likely to dynamically interact over development with atypical everyday experiences, leading to variable outcomes. Indeed, within this seemingly homogeneous genetic disorder, individual differences are noted as early as in infancy (Roberts et al., 2009) and outcome differences for individuals with FXS are clinically as crucial as known group differences from the normal population (Chonchaiya, Schneider, & Hagerman, 2009). However, the extent to which early neurocognitive attentional difficulties drive these poor and variable behavioural outcomes (e.g. classroom hyperactivity) has not been tested.

A further limitation is that existing work has focused primarily on visual difficulties, but growing
evidence, albeit scarcer, points to more general deficits including auditory processing and attention difficulties. Mouse models (e.g. Chen & Toth, 2001), as well as adults and school-aged boys with FXS (e.g. Castren, Paakkonen, Tarkka, Ryynanen, & Partanen, 2003) display atypical responses to auditory stimuli. A single study has thus far pitted visual and auditory attention measures directly against each other in children with FXS (Sullivan et al., 2007). Sullivan and colleagues used auditory and visual continuous performance tasks (CPT) with children with FXS (8- to 13-year-olds), a large proportion of whom were on stimulant medication. Only 61% of 56 boys tested on visual CPT and 54% of 52 boys tested on the auditory task were able to complete the two tasks, respectively. Furthermore, children with FXS performed poorly on both, and relatively more so for the auditory version. Although pioneering in the collection of data on attention across modalities, a number of concerns limit these conclusions. The tasks were neither matched in terms of stimulus complexity nor duration, and were not counterbalanced, with the auditory task always following the visual one. Yet, understanding whether attentional difficulties generalise across vision and audition is clinically relevant: if stimuli in a certain modality were relatively easier for young children with FXS to attend to, this might open opportunities for optimisation of learning materials through the development of targeted educational and clinical interventions that could begin prior to formal schooling.

Moreover, individuals with FXS show atypical sensitivity to complex or multimodal environments (e.g. Baranek et al., 2008). Yet, in typical development, multimodal information provides clear redundancies that aid perception, attention and learning (Spector & Maurer, 2009). For example, visual perceptual judgments (e.g. deciding whether a ball is small) are easier for young children with congruent auditory information (e.g. concurrent presentation of a high pitch sound), even when this is not directly relevant to the visual task. These cross-modal binding processes accrue invaluable benefits in a complex multimodal environment, but, to our knowledge, no study has assessed how attentional difficulties impact on processing stimuli in multimodal settings that more closely resemble everyday environments (e.g. classrooms) for individuals with FXS.

The current study therefore had three principal aims. The first was to investigate trajectories of attention across two modalities (visual and auditory) using directly comparable tasks to understand whether attentional difficulties in young boys with FXS are similar across modalities. The second aim was to investigate whether, and if so, how, children with FXS have difficulties in coping with attention in a multimodal environment. As there are striking developmental changes in attentional abilities over childhood, these first two aims required mapping typical developmental trajectories as well as those in children with FXS, starting from as early as possible. Third, through our prospective longitudinal design, we aimed to investigate attentional predictors of risk for subsequent poor classroom outcomes, such as inattention, hyperactivity, strengths and difficulties in the classroom a year later. The latter aim required larger samples than have normally been studied in the context of FXS, and to our knowledge, this is the first and largest experimental study of attention across modalities in medication-naïve boys with FXS as young as 4 years of age.

Study 1 – attention across modalities

In Study 1, we predicted that boys with FXS would find sustaining attention more difficult than TD children, regardless of modality, but that they would in addition experience greater difficulties with auditory compared to visual attention. Second, attentional markers would predict individual differences in outcomes a year later.

Method

Participants. Thirty-seven boys with a confirmed diagnosis of FXS (mean age at Time 1: 8 years; 6 months; range: 4–10 years) were recruited through the national support group for children and families with FXS as part of a larger study of attentional difficulties. To obtain as representative a sample as possible of abilities in all boys with FXS, we attempted to administer the current measures to all boys in the full sample with FXS, but desisted if boys failed to complete an experimental block, or clearly did not comprehend/comply with task instructions. So, differences across boys with FXS whose data are reported here or not but are still part of the broader sample define completion rates (see Table 1 for their characteristics and the Supplementary Information for full sample details).

A group of 74 typically developing (TD henceforth) boys with no reported family history of FXS (M = 6:10; range: 3–10 years) was recruited locally. From this larger TD sample, a comparison group of 33 TD boys (‘controls’) was obtained, whose mean and range of nonverbal ability (Leiter International Performance Scale-Revised, ‘Leiter’, Roid & Miller, 1997) matched that of the boys with FXS. All children were followed and re-assessed 12 months later (Time 2). Signed informed consent was obtained from parents following ethical procedures approved by the appropriate institutional review board.

The current sample (N = 37) excluded children who were taking medication for the treatment of inattention and hyperactivity symptoms, because work on ADHD highlights how stimulants modify neurocognitive function and structure. However, as part of our broader study and to maintain a clear
picture of the sample as a whole, all children who had volunteered to take part in the study \((N = 59)\) were followed at all time-points. At both time-points, this broader FXS study sample \((N = 59)\) contained a relatively small proportion of children on stimulant medication (max 11.8%, i.e. 7 of 59 children) compared to rates reported for other samples of boys with FXS (e.g. 33.4%, Sullivan et al., 2006) (see Supplementary Information details and for a discussion). Our TD control sample also excluded any child who scored at or above standardised clinical thresholds on the ADHD Index, and we excluded children with poor hearing or visual acuity in both groups.

**Measures.**

**Nonverbal IQ:** The Leiter International Performance Scale-Revised (Roid & Miller, 1997) is a standardised assessment for individuals aged 2–20 designed to be administered entirely nonverbally. The Brief IQ score is a composite of four different scales: Figure Ground segregation, Form Completion, Sequential Ordering and detecting Repeated Patterns. It was chosen because of the communication challenges experienced by boys with FXS.

**Behavioural outcomes:** The Conners Teacher Rating Scale (‘CTRS’, Conners, 1997) is a commonly used standardised screening instrument that targets ADHD symptomatology and consists of 28 items, measuring indices of oppositional behaviour problems, hyperactive behaviour and cognitive/inattention problems across the school setting in 3- to 17-year-olds. The Strengths and Difficulties Questionnaire, Teacher version (‘SDQ’, Goodman, 1997) is a 25-item behavioural screening questionnaire about 3- to 16-year-olds, asking more broadly about emotional symptoms, conduct problems, hyperactivity/inattention, peer relationship problems and prosocial behaviours. Both were completed at both time-points by teacher(s) best acquainted with individual children.

**Visual attention:** This task was an analogue to a standard CPT, providing a baseline measure of attention to centrally presented targets of higher contrast than other more frequent but low contrast nontargets (see Figure 1). These controlled stimuli allowed us to ensure that all children could discriminate targets similarly, as indeed demonstrated by performance in a separate task in which we established similar visual contrast thresholds for children with FXS and controls, \(t(60) = .254, p = .801\), and selected stimuli for the attentional task that were clearly supra-threshold for both groups. In contrast, using stimuli solely designed for TD individuals in standardised assessment tools could yield differences for perceptual (Bertone et al., 2010), rather than cognitive reasons.

**Auditory attention:** Temporal parameters of stimulus presentation and overall duration were identical to the Visual task, but the task presented pure tone targets of higher intensity amongst lower
intensity non-targets. Again, children with FXS and controls did not differ in their auditory intensity thresholds assessed through a separate but similar task, $t(59) = -1.112$, $p = .272$, and the intensity discrimination chosen for the attention task was supra-threshold for both groups.

**Procedure.** Children were seen at school, in a quiet space close to their classroom. For the attention tasks, they sat at a small table at ~30 cm from the monitor and two speakers, facing the button box. Individual short blocks for each task and standardized assessment scales were alternated in presentation across participants to limit differential effects of fatigue and practice. The visual attention task was presented as a fishing game. Children were asked to watch the ‘moving water’ (low contrast Gabor patches), and to look out for the ‘big waves’ (high contrast targets), as this meant ‘there was a fish swimming past’. When the target wave was detected, children pressed a target key with their dominant hand (to ‘catch the fish’). If they responded correctly, a cartoon fish image appeared during practice, alongside auditory feedback (‘yippee!’) throughout the experiment. For auditory attention, children were asked to help a hungry mouse grab some cheese delivered behind a closed door, and to do so they needed to listen to the knock at the door (the ‘cheese knock’) amongst a continuous run of quieter knocks. Pressing the target key opened the door and ‘caught the cheese’. If children responded correctly, an animated cartoon character grabbed the cheese. For both attention tasks, slow practice trials were followed by real-time practice and by test blocks. Test trials were divided into three blocks, each lasting 1 min and including a total of 15 targets presented at pseudo-random intervals. Children completed at least one block, providing a maximum total of 45 responses across the three blocks.

**Data analysis.** The primary dependent measures were accuracy of target detection (percentage hits) and reaction time to hits (time taken to press the target button). We also measured false alarms to the nontarget stimuli, and calculated an unbiased measure of discrimination, d-prime, appropriately adjusted for the low frequency of targets. The extent to which attention measures predicted outcomes a year later for boys with FXS was assessed through preliminary correlations, followed by multiple regression models for the significantly correlated variables.

**Results**

**Typical developmental attention across modalities.** We first aimed to establish the robustness of developmental changes for our experimental measures in a larger TD sample. As chronological age (CA) was continuously distributed, we assessed the
effects of CA through mixed design linear regression models (Thomas et al., 2009). There were significant main effects of Time and CA on accuracy (percentage hits) \(F(1,72) = 32.845, p < .001, \eta^2 = .313\) and \(F(1,72) = 72.382, p < .001, \eta^2 = .501\) and reaction time (RT in ms) \(F(1,72) = 95.954, p < .001, \eta^2 = .568\) and \(F(1,72) = 91.186, p < .001, \eta^2 = .559\), driven by an improvement in accuracy and faster responses from Time 1 to Time 2 and by lower accuracy and slower RT for younger compared to older children. For condition means, SEM, and other statistically significant effects, please see Supplementary Information.

Critically, we wanted to assess whether these longitudinal improvements indexed developmental change or more simply depended on practice effects. Performance at Time 2 by 20 control children (here labelled as ‘Time 2 sample’) was compared to that of a different group of 20 TD children who had performed the tasks at Time 1, and therefore for the first time (‘Time 1 sample’). The two groups were matched in terms of CA and MA (ps > .05). There was no significant main effect of Sample on accuracy \(F(1,38) = 1.513, p = .226, \eta^2 = .038\) or RT \(F(1,38) = .349, p = .558, \eta^2 = .009\), and no significant interaction effect of Sample and Modality on either accuracy \(F(1,38) = .917, p = .344, \eta^2 = .024\) or RT \(F(1,38) = .501, p = .483, \eta^2 = .013\), suggesting that improvements observed at Time 2 are unlikely to be accounted for by practice, because children presented with the tasks at Time 2 performed no better than children at Time 1 who had encountered them for the first time. Furthermore, task measures related specifically to everyday inattention and hyperactivity observed in the classroom (see Supplementary Information).

Attention across modalities in boys with FXS: trajectories and predictors of outcomes. Figure 2 presents accuracy and reaction times in Auditory and Visual Attention for boys with FXS and controls at Time 1 and Time 2. There was a main effect of Time \(F(1,68) = 47.572, p < .001, \eta^2 = .412\) with higher accuracy at Time 2 (67.9%) compared to Time 1 (57.2%), and a main effect of Group \(F(1,68) = 36.818, p < .001, \eta^2 = .351\) with higher accuracy for TD (76.5%) than FXS (48.6%), but no significant interaction effect between Time and Group, \(p = .806\). There was a significant interaction of Modality and Group \(F(1,68) = 11.709, p = .001, \eta^2 = .147\), driven by greater accuracy for auditory (78.9%) compared to visual stimuli \(F(1,68) = 74.2\%\, F(1,68) = 6.403, p = .014, \eta^2 = .086\) in controls, but the opposite pattern for FXS, that is, greater accuracy for visual (50.6%) compared to auditory stimuli \(46.6\%, F(1,68) = 5.310, p = .024, \eta^2 = .072\). None of the other main effects or interactions reached statistical significance.

In terms of RT, there were main effects of Group \(F(1,68) = 39.960, p < .001, \eta^2 = .370\), with boys with FXS responding more slowly (1278.79 ms) than controls (877.73 ms), and Time \(F(1,68) = 50.672, p < .001, \eta^2 = .427\), with slower responses at Time 1 (1171.11 ms) compared to Time 2 (985.41 ms). These were moderated by an interaction of Time and Group \(F(1,68) = 15.699, p < .001, \eta^2 = .188\), driven by smaller but significant improvements in speed from Time 1 to Time 2 for FXS \(F(1,68) = 1237.62 ms, F(1,68) = 5.282, p = .025, \eta^2 = .072\) compared to controls \(F(1,68) = 1022.25 vs. 733.19 ms, F(1,68) = 58.072, p < .001, \eta^2 = .461\). There was also a main effect of Modality \(F(1,68) = 8.206, p = .006, \eta^2 = .108\), with slower responses for auditory (1107.55 ms) compared to visual stimuli (1048.96 ms). None of the other main effects reached statistical significance.

Group differences in accuracy and reaction time indicated poorer attention in FXS overall, improvements with time for both groups, but relatively poorer auditory versus visual attention in FXS. However, boys with FXS also produced significantly more false alarms to nontargets overall compared to controls across conditions (Mann–Whitney U, lowest \(Z = -2.646, p = .008\), and more false alarms to visual than auditory stimuli, at both Time 1 (Wilcoxon Signed Ranks, \(Z = -5.062, p < .001\) and Time 2 \(Z = -3.600, p < .001\), suggesting they may have been responding more impulsively in general, and more frequently to visual compared to auditory stimuli. We therefore computed d’-prime, an unbiased

Table 2 Correlations across measures: Pearson correlation coefficients between experimental attentional measures at Time 1 (T1) and classroom outcome measures 12 months later (T2), for boys with fragile X syndrome (FXS). For significant correlations, residual predicted variance (after controlling for nonverbal IQ) is also reported, with the significance level of attentional markers as unique predictors for that step.

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|---|---|---|---|---|
| Study 1 attention measures (T1) | Study 2 attention measures (T1) |
| T2 Leiter IQ | T2 CTRS cognitive | T2 CTRS hyperactive | T2 CTRS ADHD Index | T2 SDQ emotional | T2 SDQ conduct | T2 SDQ hyperactivity | T2 SDQ Peer problems | T2 SDQ total difficulties |
| **.051** | **.034** | **.258** | **.266** | **.181** | **.087** | **.130** | **.040** | **.124** |
| **.241** | **.058** | **.010** | **.498** | **.150** | **.148** | **.481** | **.176** | **.378** |
| **.057** | **.040** | **.028** | **.141** | **.222** | **.115** | **.020** | **.044** | **.068** |
| **.173** | **.173** | **.199** | **.930** | **.198** | **.137** | **.378** | **.243** | **.361** |
| **.306** | **.318** | **.350** | **.119** | **.302** | **.351** | **.350** | **.243** | **.361** |
| **.055** | **.058** | **.024** | **.209** | **.068** | **.024** | **.024** | **.024** | **.024** |
| **.123** | **.044** | **.481** | **.010** | **.048** | **.173** | **.010** | **.048** | **.173** |
| **.233** | **.363** | **.174** | **.010** | **.010** | **.173** | **.010** | **.010** | **.173** |

SDQ, Strengths and Difficulties Questionnaire (Goodman, 1997). \( ^{1}p < .10, \) \( ^{*}p < .05, \) \( **p < .005, \) \( ***p < .001. \)

estimate of children’s ability to discriminate visual and auditory targets amongst nontargets. All main effects and interaction effects reported above were consistent with the analysis on percentage hits, including the critical interaction of Group and Modality, \( [F(1,68) = 7.721, p = .007, \eta^2 = .102]. \)

Table 2 reports Pearson’s correlations between accuracy and reaction time on Auditory and Visual Attention at Time 1, nonverbal ability and scores on subscales of the CTRS (indexing particularly ADHD-relevant behaviours) and SDQ (related to broader strengths and weaknesses) at Time 2 for FXS. It also reports regression model statistics for significant Time 1 predictors of Time 2 outcomes, controlling for nonverbal IQ. Greater Visual Attention accuracy and faster Visual Attention RTs significantly predicted lower Time 2 hyperactivity ratings in the classroom on the CTRS and on the SDQ, lower Total Difficulties on the SDQ and better prosocial Behaviour on the SDQ. Greater Visual Attention accuracy also strongly predicted lower Time 2 ADHD Index scores on the CTRS. None of the other relationships reached significance.

**Discussion**

To recapitulate, Study 1 embodied a prospective longitudinal approach to attention difficulties across modalities in FXS. We first traced trajectories in a large sample of TD children, to validate our experimental measures and their longitudinal changes. Against this backdrop, young boys with FXS showed clear difficulties in attending to visual stimuli, consistent with attentional difficulties being core impairments as reported later in the life span, but they also responded more poorly to auditory stimuli, for which control children showed an advantage. This difference across modalities is consistent with reports of auditory processing difficulties (e.g. Castren et al., 2003) and extends these to attention, ruling out gross differences in auditory versus visual paradigms (cf. Sullivan et al., 2007). Of note, clear attentional difficulties across modalities and the relative modality difference for boys with FXS are to be placed in the context of overall improvements over time, a pattern also found elsewhere (Cornish, Cole, Longhi, Karmiloff-Smith, & Scariff, in press) and one that therefore argues against a view of static developmental freeze in FXS.

Finally, within-group differences in attention markers at Time 1 predicted ADHD-relevant symptoms across multiple classroom measures as well as prosocial behaviours, highlighting the importance of understanding early predictors of individual differences for specific dimensions of everyday outcomes in the classroom, even within a group of relatively homogeneous genetic aetiology such as boys with FXS. Interestingly, visual attention measures were a stronger predictor of later differences than auditory attention measures in FXS (see Roberts et al., 2009, for parallel findings for nonattentional markers). This asymmetry across modalities lends further support to our emphasis on the need to study both general and specific attentional difficulties in FXS.

**Study 2 – attention in multimodal environments**

Having investigated similarities and differences in attention difficulties for boys with FXS when dealing with simple stimuli, we aimed to test empirically commonly reported clinical observations of atypi-
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...longitudinal predictor of early outcomes ...

Method

Participants. One boy with FXS who participated in Study 1 did not complete Study 2, whereas one TD child completed Study 2 and not Study 1. Group characteristics for Study 2 did not change significantly compared to those reported in Table 1.

Apparatus, measure and procedure. The standardised and outcome measures were identical to Study 1.

Crossmodal attention: The task was analogous to the Visual Attention task in Study 1, in that children were told to pay attention to the ‘big waves’ infrequently presented amongst lower contrast ‘waves’ to help a hungry boy catch fish. However, this time they were told that there would be noises in the background (the pure tones used in the auditory attention task), but that the noises would not help catch the fish. On the majority of nontarget trials, low contrast Gabors and quiet tones were presented simultaneously. Infrequent visual targets were presented under two conditions: in the Visual-only condition, in which target high contrast Gabors appeared but were not accompanied by a louder irrelevant tone; in the Bimodal condition (illustrated in Figure 1), in which the visual change was accompanied by a concurrent irrelevant louder tone. In auditory-catch trials, a loud tone was presented alone, to measure the extent to which children’s attention was nonetheless captured by the irrelevant tone, leading them to an incorrect button press. There were a maximum of 15 Visual-only trials, 15 Bimodal trials and 15 auditory-catch trials. Infrequent irrelevant tones were also presented alone (auditory-catch trials). As for the previous tasks, three blocks of trials (1 min each) were intermixed with the other tests to limit fatigue.

Results

Typical developmental trajectories of attention in multimodal environments. For our larger TD sample, there were main effects of Time and CA on accuracy \(F(1,73) = 20.052, \ p < .001, \ \eta^2 = .215, \ F(1,73) = 55.807, \ p < .001, \ \eta^2 = .433\) and RT \(F(1,72) = 13.041, \ p = .001, \ \eta^2 = .153, \ F(1,72) = 54.480, \ p < .001, \ \eta^2 = .431\), with greater accuracy and faster responses at Time 2 compared to Time 1, and more accurate and faster responses by older children. Auditory-only catch trials did not yield significant changes in accuracy over time \(F(1,73) = 8.24, \ p = .367, \ \eta^2 = .011\), but younger children committed more errors than older children \([F(1,73) = 42.66, \ p < .001, \ \eta^2 = .369]\). See Supplementary Information for condition means, SEM and other effects. Did improvements depend on simple practice? Again, there were no significant differences in accuracy \([F(1,38) = 1.356, \ p = .252, \ \eta^2 = .034\) or RT \([F(1,38) = 1.697, \ p = .201, \ \eta^2 = .043\) between the older Sample assessed at Time 1 and the longitudinal Sample (Time 2), nor significant interaction effects of Sample and Condition on either accuracy \([F(1,38) = 2.814, \ p = .102, \ \eta^2 = .069\) or RT \([F(1,38) = .001, \ p = .981, \ \eta^2 = .000]\), ruling out simple practice effects. Again, correlations supported the validity of our experimental attention measures as predictors of classroom behaviours (see Supplementary Information).

Atypical multimodal attention: trajectories and predictors of outcomes. Figure 3 represents accuracy and reaction times for Visual-Only and Bimodal targets for FXS and controls at Time 1 and Time 2. In terms of accuracy, there was a main effect of Time \([F(1,68) = 23.202, \ p < .001, \ \eta^2 = .254\), with better performance at Time 2 (66.3%) than Time 1 (57.3%), and a main effect of Group \([F(1,68) = 31.444, \ p < .001, \ \eta^2 = .316\], with boys with FXS performing significantly more poorly (48%) than controls (75.6%). In addition, there was an interaction effect of Time and Condition \([F(1,68) = 5.719, \ p = .020, \ \eta^2 = .078\), and an interaction effect of Condition and Group \([F(1,69) = 7.159, \ p = .009, \ \eta^2 = .095]\). The latter was...
driven by significantly better accuracy for controls on the Bimodal condition (79%) compared to the Visual-Only condition [72.3%, \( F(1,68) = 8.137, p = .006, \eta^2 = .107 \)], and no difference between the two conditions for boys with FXS [\( F(1,68) = .817, p = .369, \eta^2 = .012 \)], who performed more poorly than controls on both the Visual-Only [49%, \( F(1,68) = 19.929, p < .001, \eta^2 = .227 \)] and the Bimodal condition [47%, \( F(1,68) = 38.316, p < .001, \eta^2 = .360 \)]. The Time \times Condition interaction was driven by greater differences between Conditions at Time 2 [\( F(1,68) = 8.420, p = .005, \eta^2 = .110 \)] and by larger improvements in Time for Bimodal [\( F(1,68) = 28.888, p < .001, \eta^2 = .298 \)] than for Visual-Only trials [\( F(1,68) = 5.565, p = .021, \eta^2 = .076 \)].

In terms of RTs, there was a main effect of Time [\( F(1,62) = 7.858, p = .007, \eta^2 = .112 \)], driven by faster responses at Time 2 (959.48 ms) than Time 1 (1009.04 ms); one of Group \( F(1,62) = 30.340, p < .001, \eta^2 = .329 \), with boys with FXS being slower (1219.59 ms) than controls (838.92 ms), but no interactions between Time and Group [\( F(1,62) = 1.006, p = .320, \eta^2 = .016 \)], suggesting similar improvements across groups. On auditory-catch trials, there were no significant group differences [\( F(1,68) = 1.439, p = .235, \eta^2 = .021 \)], with, if anything, boys with FXS tending to produce fewer errors on auditory-catch trials (43.2%) than controls (49%), although this would also need to be assessed when relevant redundant stimuli are presented. Of note, this atypical attention to multimodal stimuli predicted subsequent difficulties related to specific behavioural outcomes in the classroom.

**Conclusions and implications**

Pervasive attention difficulties in young boys with FXS were more pronounced for auditory than for visual attention, consistent with clinical and empirical reports of auditory processing differences in individuals with FXS (Baranek et al., 2008; Castren et al., 2003; Sullivan et al., 2007). These relative weaknesses reinforce practical suggestions to present ‘to-be-attended’ materials in visual rather than auditory format. Furthermore, multimodal information did not benefit children with FXS, mirroring reports of atypical responses to multimodal environments (Hagerman & Hagerman, 2002) and suggesting that the common educational practice of providing redundant multisensory information may not necessarily help boys with FXS specifically, although this would also need to be assessed when relevant redundant stimuli are presented. Of note, despite poorer performance than ability-matched younger controls, boys with FXS improved significantly over time when followed longitudinally, counter to the prevailing view of static or plateauing profile that can emerge from cross-sectional data alone (Cornish et al., in press). Finally, better visual attention and more typical responses to multimodal stimuli predicted improved classroom outcomes a year later, stressing the need to move away from group findings of individual children and predictors of better outcomes (Chonchaiya et al., 2009; Roberts et al., 2009) even in a seemingly homogeneous group as
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Key points
• Neurodevelopmental disorders of known genetic origin can offer unique insights into the early pathways and mechanisms leading to childhood behavioural difficulties.
• Tracking attention trajectories in young children with fragile X syndrome revealed impaired attention, differentially greater difficulties when dealing with auditory stimuli and smaller benefits from multimodal information than control children.
• Individual differences in attention also predicted longitudinal differences amongst children with FXS in behaviours relevant to classroom outcomes.
• Our findings highlight the importance of capturing dynamic trajectories of attention over developmental time, as these predict differing longitudinal outcomes even for young children with a well understood monogenic disorder.

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