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Visual search in typically developing toddlers and toddlers with Fragile X or Williams syndrome

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Abstract

Visual selective attention is the ability to attend to relevant visual information and ignore irrelevant stimuli. Little is known about its typical and atypical development in early childhood. Experiment 1 investigates typically developing toddlers' visual search for multiple targets on a touch-screen. Time to hit a target, distance between successively touched items, accuracy and error types revealed changes in 2- and 3-year-olds' vulnerability to manipulations of the search display. Experiment 2 examined search performance by toddlers with Fragile X syndrome (FXS) or Williams syndrome (WS). Both of these groups produced equivalent mean time and distance per touch as typically developing toddlers matched by chronological or mental age; but both produced a larger number of errors. Toddlers with WS confused distractors with targets more than the other groups; while toddlers with FXS perseverated on previously found targets. These findings provide information on how visual search typically develops in toddlers, and reveal distinct search deficits for atypically developing toddlers.

Introduction

Visual selective attention is the ability to attend to relevant information and ignore irrelevant stimuli. It is crucial for dealing with the cluttered visual environments of daily life (e.g. Pashler, 1998). Which cognitive processes underlie this ability, and how do they develop? Models of normal adult attention have relied heavily on how visual-search performance varies with the number of items in the display, and with the properties distinguishing targets from nontargets (e.g. Bundesen, 1990; Duncan & Humphreys, 1989; Treisman & Gelade, 1980; Wolfe, 1994). Initial work suggested a dichotomy between preattentively discriminated properties (e.g. simple visual features), versus those requiring focal attention and leading to serial search (e.g. conjunctions of features; Treisman & Gelade, 1980). But this dichotomy is now controversial in adult research, with some models (e.g. Duncan & Humphreys, 1989) suggesting a continuum of search efficiency, with increased efficiency as targets and distractors become more physically distinct, and as distractors become more homogeneous.

Typical development of selective visual attention

Much of the existing literature on the life-span development of visual search has also tended to dichotomize feature versus conjunction searches (e.g. Trick & Enns, 1998). For example, Gerhardstein and Rovee-Collier (2002) contrasted feature and conjunction searches by using a computer touch-screen to obtain search reaction times for 12-, 18-, 24- and 36-month-olds. These experiments were methodologically groundbreaking, being the first to investigate search in young infants and toddlers with reaction times, rather than novelty preference (e.g. Bhatt, Bertin & Gilbert, 1999). Gerhardstein and Rovee-Collier found steep versus flat search functions against set-size for conjunctive and feature searches respectively,

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which did not change with the age of the toddlers. They suggested that the different cognitive mechanisms underlying performance in adults across conjunctive and feature searches also underlie performance in infants and toddlers, and do not change qualitatively with age.

However, the adult literature suggests caution against inferring qualitatively different feature versus conjunction mechanisms from search-slopes alone, because these can be influenced by factors other than the specific need to integrate features (e.g. see Duncan & Humphreys, 1989). Moreover, recent evidence indicates that target–distractor discriminability on even a single feature can determine the speed and accuracy of search for older children (O'Riordan & Plaisted, 2001). Furthermore, infants as young as 5 months can be sensitive to manipulations of featural target–distractor similarity (tested with tasks relying on kicks to mobiles for familiar visual patterns; Gerhardstein, Renner & Rovee-Collier, 1999) and nontarget heterogeneity (tested with the novelty preference paradigm; Bertin & Bhatt, 2001). These studies provide evidence that a target's featural salience can play a role in selection at as early as 3 months of age, even when feature integration is not required. All currently published investigations of early developmental changes in search processes have focused on contrasting feature and conjunction searches (Gerhardstein & Rovee-Collier, 2002). However, no research thus far has sought any early developmental changes in the effects upon search of featural discriminability alone. Our first aim was therefore to design a developmentally appropriate task for studying any age-related changes in the effects of target featural salience, for visual search by typically developing toddlers (at 2–3 years of age).

Atypically developing visual selective attention

We further examined visual search and the role of target featural salience in toddlers with Fragile X syndrome (FXS) or Williams syndrome (WS), both developmental disorders of known genetic origin. Some difficulties with attention have been reported clinically and experimentally in adults and older children with both syndromes (e.g. Turk, 1998; Davies, Udwin & Howlin, 1998). Fragile X syndrome (FXS) has been associated with difficulties in executive control (e.g. Cornish, Munir & Cross, 2001) accompanied by relative strengths in visuo-perceptual skills (Cornish, Munir & Cross, 1999). While adults and older children with WS also display difficulties in executive control (Atkinson, 2000), recent electrophysiological (Grice, Spratling, Karmiloff-Smith, Halit, Csibra, de Haan & Johnson, 2001) and behavioural evidence (Grice & O'Riordan, unpublished) suggests atypical visuo-perceptual processing. Visual search represents an interesting paradigm for assessing any such deficits in both groups at even younger ages, since it involves both executive aspects (e.g. selectively attending to targets while ignoring distractors) and visual-perceptual aspects (e.g. encoding the visual properties that distinguish relevant from irrelevant information).

Although, based on the previous work in adults, one could suggest that executive or perceptual deficits be found in FXS and WS toddlers respectively, it should be noted that in fact adult end-states do not always predict infants' cognitive profiles (e.g. Paterson, Brown, Gsodl, Johnson & Karmiloff-Smith, 1999). Furthermore, behavioural strengths and weaknesses in developmental disorders have typically proven to be relative rather than absolute, with subtle patterns of atypical performance emerging even in domains of apparent proficiency, as for language or face processing in Williams syndrome. Adult phenotypic differences should thus always be considered the outcome of a developmental process whose early trajectory cannot be simply inferred but must be empirically investigated (Karmiloff-Smith, 1998). Our second experiment therefore examined visual search in toddlers with FXS or WS, compared to the typically developing toddlers matched for chronological or mental age.

We examined search for multiple targets with a computerized touch-screen method (cf. Gerhardstein & Rovee-Collier, 2002), while manipulating the presence of intermingled nontargets, and their physical salience relative to the targets. With this method one can assess not only search speed, and the distance between successively touched items, but also the nature of any errors (e.g. touching nontargets instead of targets; or perseverating on targets that have already been found).

Experiment 1: effects of target perceptual salience in typically developing toddlers

Our first aim was to test whether manipulations of target featural salience modulate the efficiency of toddlers' visual search, and whether this changes through early development. We focused on salience as determined by target–distractor similarity, since this has been extensively investigated in the adult literature as well as in young infants and older children (e.g. O'Riordan & Plaisted, 2001), but not in toddlers. Here we manipulated similarity by varying the distractors' size: target stimuli surrounded by smaller distractors are salient (Braun, 1994) and can capture attention (Yantis & Egeth, 1999).

By presenting multiple targets within each array, we could examine the search path used by the observer to find successive targets and the type of any errors committed when searching. Search path can be operationalized in a number of ways. For example, one can record the distance between successive touches. Shorter distances suggest a more systematic search through the visual display than longer ones. Using this method, Wilding, Cornish and Munir (2002) found that typically developing 10-year-old children who were rated as more attentive by teachers produced a shorter distance per hit than children rated as less attentive. Short distance per hit was a good predictor of belonging to the 'good attention' rather than the 'poor attention' group, and in a principal components analysis it loaded on the same factor as other measures of cognitive control. In a subsequent re-analysis of the data correcting for the time and distance wasted in errors, error types proved to be even more informative of group differences than search speed and distance (Wilding, 2003). Error types during visual search have also been used as indicators of underlying difficulties in adult neuropsychological patients (e.g. see Manly, Woldt, Watson & Warburton, 2002).

Previous studies (O'Riordan & Plaisted, 2001) elegantly investigated the effects of target–distractor similarity in older children using classical reaction-time paradigms. Here we aimed to measure any developmental changes in the effects of target featural salience on search speed, path, accuracy and error types, for toddlers. To ensure that any age differences depended on the requirement to search for targets among distractors, we also measured baseline performance on search displays that did not contain any distractors but only multiple targets, and then used these baseline measures as co-variates in our analyses. If toddlers develop in their ability to search for targets among distractors, this should result in age effects over and above those found in baseline trials. So, including nontargets may exert effects over and above individual differences in the systematicity with which different children explore a visual display containing multiple targets alone. In terms of search path, baseline performance alone may provide interesting information on age changes in the systematicity of search. In contrast, baseline age differences in search speed are representative of age-related changes in, say, motor speed rather than in visual attention. Given data from older children and adults, we expected that nontargets that were more similar to the targets (in size) should disrupt search performance more than smaller nontargets that render the large target more salient. There are, however, no existing data investigating any cross-sectional age changes for this.

Method

Participants

Fifty typically developing toddlers were recruited through local nurseries and came predominantly from middle-class Caucasian families. Parents and teachers reported children's vision as normal or corrected. Forty toddlers completed the task: 19 2-year-olds (range: 24–35 months; mean: 29 months, SD: 3.8 months; 10 girls), 21 3-year-olds (range: 36–48 months; mean: 42, SD: 3.8 months; 8 girls).

Materials

Pre-test acuity trials involved four laminated stimulus cards each displaying a single target circle and a single distractor circle (see below for dimensions).

During the demonstration phase, as well as practice and test runs, participants viewed stimuli on a 15″ portable touch-screen (Elo AccuTouch) connected to a portable laptop computer. Large black target circles were randomly placed on an 8×4 light green grid. Viewed from a 30-cm distance, each target subtended 5.7 degrees angle. Distractors were also black circles, subtending either 2.8 degrees (small distractors, very dissimilar from the target) or 4.2 degrees (medium distractors, more similar to the target). All search displays contained 10 target circles and either no distractors (baseline condition), or 6 or 24 dissimilar (small) distractors in addition, or 6 or 24 similar (medium) distractors in addition (see Figure 1). Distractor type and number were thus used as within-subjects manipulations.

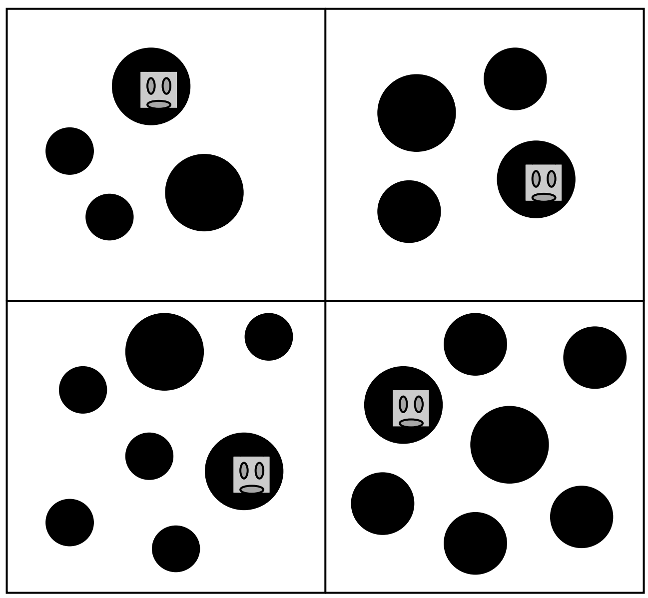

Figure 1 *Sample test displays maintaining the target–distractor ratio in the original test displays. Top-left: few small distractors, top-right: few medium distractors, bottom-left: many small distractors, bottom-right: many medium distractors.*

Procedure

Toddlers were tested in a quiet room either at their nursery, at home or in the Neurocognitive Development Unit infant testing lab. Toddlers sat at a little table approximately 30 cm from the touch-screen, either on their caregiver's lap or on an appropriately sized chair.

Pre-test acuity trials. During four pre-test trials, toddlers were asked to 'touch the big circle' on laminated cards displaying a single target and a distractor. Toddlers had to point to the large circle on the second acuity card for each distractor type to continue.

Demonstration, practice and test phases. The experimenter introduced the search game, explaining that funny monsters were hiding under the big target circles, but not under the little circles. She then gave a demonstration, touching the target (big) circles with her index finger. When a target circle was touched, a coloured square-shaped face covering approximately half the area of the target appeared and remained on display for the duration of the trial. This eliminated the requirement of remembering which targets had previously been found and therefore isolated differences in search from (possibly independent) memory differences. When a nontarget circle (small or medium) was touched instead, nothing happened. The search continued until the child had either found 8 targets or touched the screen 20 times. When the final target was touched or at the location of the twentieth touch, a large face appeared for a few seconds and the search was terminated. After the demonstration, toddlers undertook a practice run, during which they were verbally reinforced by both the experimenter and the parent for touching targets and encouraged to look for more monsters. Toddlers were presented first with the baseline run (10 targets alone, with no distractors) and then with the four experimental runs (with 6 or 24 small or medium nontargets in addition to the 10 targets) in randomized order across children. Each trial run was preceded by a practice run.

Data from 10 toddlers (7 2-year-olds) were discarded because they did not complete the pre-test phase successfully ($N = 2$) or they refused to complete the testing phase ($N = 8$). Two additional criteria determined inclusion in the final analyses, in order to ensure that all toddlers had understood the task and remembered it while performing the search:

1. The toddler touched more circles on the screen than empty space;
2. The toddler touched more targets than distractors.

Data from all toddlers satisfied these criteria.

Statistical analyses

Mean search time per hit (speed measure), mean distance between successive touches (path measure), total number of errors (accuracy measure) and error types (touches on distractors, or repetitions on previously found targets) were calculated for each toddler. Time was measured in seconds, and distance in centimetres. These measures were corrected for the time and distance spent while making errors, in order to obtain measures that would be independent of accuracy and error types. To correct time, we subtracted the time spent making any type of error and divided the remaining time by the total number of hits. To correct distance, we divided the total distance between successive touches (whether they were correct or not) by the total number of touches (excluding immediate repeats on targets, which did not accrue any distance). Additional corrections were used to remove near misses due to inaccurate pointing or touches with parts of the hand other than the index finger. Results were then analysed using standard statistical packages (SPSS, G-Power).

Dependent variables were checked for normality, homogeneity of variance and transformed where necessary before being entered in a $2 \times 2 \times 2$ mixed factorial ANOVA with target–distractor similarity (dissimilar vs. similar distractors), distractor number (6 vs. 24) as within-subject variables and age (2-year-olds vs. 3-year-olds) as the between-subject variable. Children in our sample spanned a large age range, and they were split into two age groups, a convenient way of looking at age differences. However, this arbitrarily separates children who are, for example, 35 months, from those who are 36 months, and groups them with children who are likely to be much more different (24 or 48 months). We therefore decided to further investigate age effects by also using age as a covariate (ANCOVA using sums of squares of type II) to provide converging evidence of robust age effects and test whether splitting the group introduced any spurious effects. Bonferroni adjustments for multiple comparisons were used for post-hoc tests of all main effects. Variables measured during baseline runs (with no distractors) were then used as covariates to establish whether any age effects could be attributed specifically to the requirement for search among distractors.

Results

In overview, 2-year-old toddlers were slower than 3-year-olds when searching for targets among nontargets, even after accounting for variability in mean speed to touch targets in the condition without distractors. Search for targets was fastest when distractors were dissimilar from them (small rather than medium) and when displays contained fewer distractors, again regardless of baseline variability. In contrast, the overall effects of these display manipulations on search path (i.e. on the distance between successive touches upon items on the screen) disappeared once baseline variability was taken into account. However, the age differences in search path for displays with non-targets present still remained significant, with younger toddlers producing longer overall distances between successive touches than older children did. Two-year-olds produced longest distances for the displays containing many distractors that were similar to the targets; whereas 3-year-olds' distances were longest with these similar distractors but were unaffected by their number. Furthermore, 2-year-olds made more errors (including both repetitions on targets and touches on distractors) than the older children. These findings were supported statistically as follows.

First, preliminary analyses with gender as a between-subject factor did not reveal any statistically significant difference between boys and girls on any of the dependent variables (p levels ranged from .103 and .902) and therefore gender was dropped from the further analyses described below.

Analyses of search speed

Mean time per hit was significantly affected by target–distractor similarity, $F(1, 38) = 16.288$, $p < .001$. Distractors that were similar (medium in size) to the large targets resulted in longer search times than dissimilar (small) distractors (2.06 vs. 1.76 seconds per hit), and this effect remained statistically significant after co-varying performance on trials without distractors, $F(1, 37) = 6.741$, $p = .013$. Mean hit time was also affected by distractor number, $F(1, 38) = 12.863$, $p = .001$, with many distractors resulting in longer search time per hit than few distractors (2.1 vs. 1.76 seconds per hit), even with baseline performance as a co-variate, $F(1, 37) = 5.236$, $p = .028$. None of the interactions was statistically significant (p levels from .11 to .47). Age had an overall effect on search time, $F(1, 38) = 14.951$, $p = .001$, with 2-year-olds being slower (2.21 seconds per hit) than 3-year-olds (1.63 seconds per hit). Analysing age as a continuous rather than as a dichotomous variable provided an equivalent effect of age, $F(1, 38) = 17.334$, $p < .001$. Furthermore, this age difference remained when baseline speed was co-varied, $F(1, 37) = 8.607$, $p = 0.006$ and when both age and baseline performance were analysed as co-variates, $F(1, 37) = 12.105$, $p = .001$. This suggests that the age effect on search speed was not simply due to differences in motor speed between 2- versus 3-year-olds.

Analyses of search path

Figure 2 displays mean distance between successive touches as a function of target–distractor similarity, number of distractors and toddlers' age. Mean distance was affected by target–distractor similarity, $F(1, 38) = 5.048$, $p = .031$, due to similar (i.e. medium) distractors resulting in longer distance per hit than dissimilar distractors.

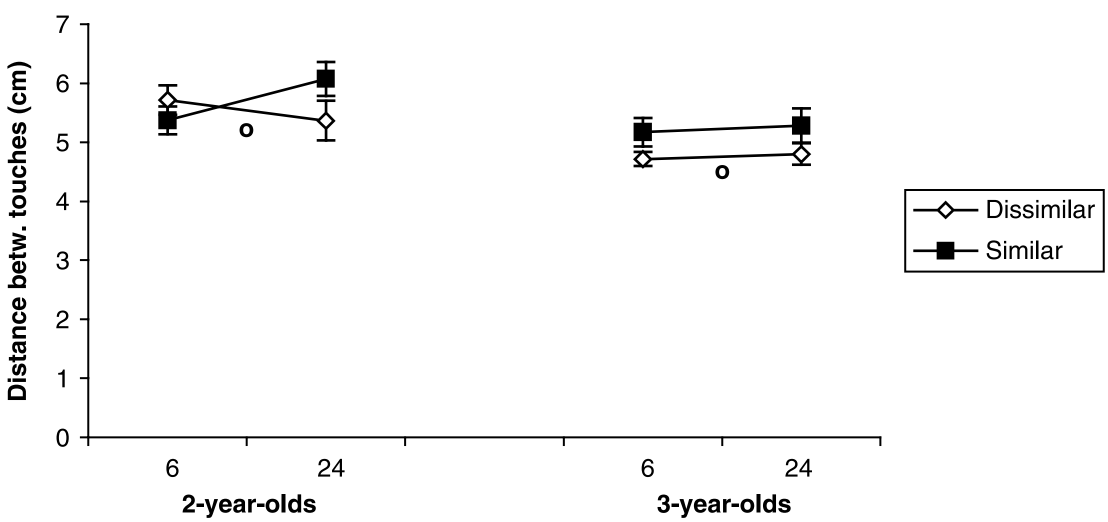

Figure 2 *Mean corrected distance between successive touches (cm, +/– SEM) as a function of target–distractor similarity (medium and small sized distractors), distractor number (6, 24) and age (2- and 3-year-olds) for typically developing toddlers.* ***o*** *= Distance between successive touches in target-only displays.*

Target–distractor similarity and distractor number interacted, $F(1, 38) = 4.910$, $p = .033$. However, these effects disappeared when baseline distance was co-varied, $p = .125$, and .440, respectively.

Age had a main effect on distance, $F(1, 38) = 12.737$, $p = .001$, with younger toddlers producing longer distances between successive touches (mean distance of 5.84) than older toddlers (5.0 cm). The effect was also statistically significant when age was treated as a continuous rather than as a dichotomous variable, $F(1, 38) = 7.709$, $p < 0.008$. This effect remained significant even with baseline distance per hit as a co-variate, $F(1, 37) = 11.485$, $p = .002$ and when both age and baseline distance were entered as co-variates, $F(1, 37) = 6.232$, $p = .017$. Most importantly, the Similarity × Distractor number × Age interaction was significant, both when age was treated as a dichotomous variable, $F(1, 37) = 4.780$, $p = .035$ and as a continuous variable, $F(1, 38) = 4.067$, $p = .05$. This effect also reached significance when baseline performance was co-varied, $F(1, 37) = 3.984$, $p = .05$. The data were entered into separate ANOVAs for each age group to investigate the source of this interaction. For 2-year-olds, the interaction between Similarity and Distractor Number was significant, $F(1, 18) = 6.721$, $p = .018$. This was due to longer distances on runs with many medium distractors than either few similar distractors ($t(18) = 2.437$, $p = .025$) or many dissimilar distractors ($t(18) = 2.132$, $p = .047$). For 3-year-olds, Similarity alone was statistically significant, $F(1, 20) = 4.477$, $p = .047$, due to these toddlers producing longer distances between successive touches with medium compared with small distractors.

Search accuracy and error types

Two-year-olds produced more incorrect touches (on average 3.52 errors) than 3-year-olds (.89 errors), $F(1, 38) = 22.185$, $p < .001$. The effect of age was also significant when age was considered as a co-variate, $F(1, 38) = 27.133$, $p < .001$. Furthermore, the effect of age remained significant when total baseline errors were taken into account, $F(1, 35) = 10.115$, $p = .003$ and when both age and baseline errors were treated as co-variates, $F(1, 37) = 25.810$, $p < .001$. When the overall number of hits was calculated and errors were categorized into touches on distractors or repetitions on previously found targets, the data were not normally distributed and transformations did not succeed in fully normalizing the data. Nonparametric tests were therefore used and age was considered only as a dichotomous variable. Younger and older toddlers produced equivalent numbers of hits both across the experimental conditions (overall means of 7.54 vs. 7.99 hits) and for the baseline condition (7.89 vs. 7.91 hits), Mann-Whitney U, p levels from .107 to .533. Two-year-old toddlers produced more errors of both types than 3-year-olds. Younger toddlers touched more nontargets than 3-year-olds across conditions (overall means of 1.63 vs. .5, Wilcoxon test, p levels from .05 to < .001) and they repeated touches on previously touched targets more often (1.22 vs. .131, Wilcoxon tests, p levels from .06 to < .001). However, this group difference did not occur for repetitions in the baseline data, independent t-test, $t(38) = 1.463$, $p = .152$.

Discussion

Experiment 1 sought to investigate whether a manipulation of target featural salience would affect toddlers' search for multiple targets among nontargets, and how this ability may change between 2 and 3 years of age. It provides the first investigation of the effects of target featural salience on toddlers' performance, with speeded responses, that does not focus on the feature versus conjunction dichotomy (cf. Gerhardstein & Rovee-Collier, 2002). It also provides the first study integrating speed measures with search path measures in toddlers, extending a rationale previously employed only with older children (e.g. Wilding, Munir & Cornish, 2001). Target featural salience had a strong effect on search speed, suggesting that featural salience should perhaps be investigated as extensively as the requirement for conjunction versus feature searches. Our findings showed that manipulations of perceptual salience for targets can affect toddlers' search speed, even when search does not involve conjunctive search but is limited to search for a feature within a single dimension (here size).

How do these effects change across early development? The effects of display manipulations on search speed were stable across age groups, as found by Gerhardstein and Rovee-Collier (2002) using a different reaction time paradigm (concerned with feature vs. conjunction tasks). Nevertheless, the age difference (for 2- vs. 3-year-olds) found here for search speed could not be explained by simple differences in motor speed. It remained significant even when we accounted for age differences in baseline performance on target-only trials, suggesting an increased ability to deal with search among distractors. Similarly, the age difference in search path suggests an increase in the systematicity with which children search for targets among distractors, regardless of individual variability with target-only displays. While younger toddlers' search paths appear sensitive to both the salience and the number of distractors, older toddlers' paths appear mostly sensitive to the salience of distractors. This interaction of display manipulations with age for search path suggests that this path measure may be more sensitive to some age-related changes in the sensitivity to target salience than search speed is (cf. Gerhardstein & Roveee-Collier, 2002). The typical developmental trajectory observed here was also characterized by a decrease in the number of errors of both types with age (repetitions on particular targets, or touches on distractors). This suggests that older children are better able to discriminate targets from distractors and that they can inhibit repetitions on previously found targets better than younger toddlers.

Our second experiment examined performance on the same search task in toddlers with Fragile X syndrome (FXS) or Williams syndrome (WS), in comparison to the typically developing toddlers from Experiment 1. Control children were individually matched to the atypically developing children either by chronological age (to control for the level of experience) or on the basis of overall cognitive functioning (to isolate attentional difficulties over and above what was expected given general delay).

Experiment 2: effects of target perceptual salience in atypically developing toddlers: Fragile X syndrome and Williams syndrome

The attentional profile of individuals with FXS and WS has been relatively well studied in late childhood or adulthood, but not for the toddler age groups studied here.

WS is a neurodevelopmental disorder caused by a micro-deletion on chromosome 7, with a prevalence of one in 20,000 live births (Donnai & Karmiloff-Smith, 2000). Adults and children with WS display an uneven cognitive profile with relative strengths in language (Wang & Bellugi, 1994) and difficulties in executive control, planning (Atkinson, 2000) and visuo-construction (Mervis, Robinson & Pani, 1999). The latter difficulties have been contrasted with seemingly unaffected visuo-perceptual abilities (Mervis *et al.*, 1999), but electrophysiological (Grice *et al.*, 2001) and behavioural evidence (Deruelle, Mancini, Livet, Casse-Perrot & de Schonen, 1999) from older children and adults now indicates atypical visuo-perceptual processing. Furthermore, even when tested on standard conjunctive and feature search tasks, that have no clear constructive component, children with WS performed no better than at the level predicted by their visuo-constructive abilities (Grice & O'Riordan, unpublished). There is thus some evidence for executive deficits, and debated evidence for visuo-perceptual and visual search deficits, in adults or children with WS, but there has been no study of visual attention in WS *toddlers* to date, so this was investigated here.

Fragile X syndrome (FXS) is the most common form of inherited mental retardation, with a prevalence of 1 in 4,000 male and 1 in 6,000 female births and is due to silencing of a single gene, the Fragile X Mental Retardation-1 (FMR1) gene (de Vries, van den Ouweland, Mohkamsing, Duivenvoorden, Mol, Gelsema, van Rijn, Halley, Sandkuijl, Oostra, Tibben & Niermeijer, 1997). Clinically the syndrome presents with mild to severe mental retardation, severe problems of inattention and hyperactivity (Turk, 1998) and uneven abilities across and within domains. Relative strengths in language accompany relative weaknesses in visuo-spatial cognition (Freund & Reiss, 1991). Visuo-spatial deficits appear to affect particularly skills requiring visuo-spatial and visuo-constructional abilities, with visuo-perceptual skills functioning within the range expected from the overall developmental level (Cornish *et al.*, 1999). Moreover, adults (Cornish *et al.*, 2001) and older children with the syndrome (Munir, Cornish & Wilding, 2000) differ from typically developing and other atypically developing control groups in their inability to inhibit task-irrelevant repetitive responses. Munir, Wilding and Cornish used a conjunctive search task for multiple targets with older children with FXS and found that they produced equivalent search times but longer distance per hit than both typically developing children matched for verbal mental age and children with Down's syndrome (DS). Subsequently, Wilding, Cornish and Munir (2002) also found that children with FXS, and to a lesser extent children with Down's syndrome, produced a very large number of repetitive errors on previously found targets. The authors suggest that these repetitive errors may result from a weakness in inhibiting repetition of successful responses, an important component of top-down executive control. Indeed, the number of repetitions was pervasive across conditions, but most apparent when the children were required to switch successively between two target types, a manipulation of executive load (but one that may be hard to implement in toddlers). It is unknown, however, whether manipulations of the *perceptual* characteristics of the display would also affect error numbers and types in FXS, and search by *toddlers* with the syndrome has not been investigated previously.

Predictions for the visual-search performance of toddlers with WS and FXS might be derived from the attentional profiles of adults with the syndrome, although as noted earlier, due to the developmental nature of the disorders (Karmiloff-Smith, 1998; Paterson *et al.*, 1999), the adult and toddler profiles might in fact differ. If toddlers with FXS display early executive difficulties analogous to those in older children with the syndrome (see Wilding *et al.*, 2002), their search performance should be characterized by repetitive errors and longer mean distances between touches, i.e. by decreased systematicity of their search path relative to typically developing toddlers. If their visuo-perceptual abilities are relatively unaffected, we do not expect differential effects of the target–distractor similarity manipulation compared to mental age controls. Both predictions might also hold for toddlers with WS, if, as suggested for adults with the syndrome, their difficulties affect mainly visuo-construction and executive control, but not visuo-perception. Search performance by the two groups of atypically developing toddlers would then be similar, but distinct from that of typically developing matched controls. Alternatively, since visual-perceptual deficits have been emphasized by some studies of older WS subjects (e.g. Grice & O'Riordan, unpublished; Grice *et al.*, 2001), while executive deficits have been emphasized more for FXS than WS older subjects in other studies, it could be that FXS toddlers will show problems primarily with executive aspects of the search task (e.g. perseverating on targets already found), whereas WS toddlers may show problems with visual-perceptual aspects (e.g. touching nontargets that are visually similar to the targets). The experimental results should distinguish these possible outcomes.

Method

Participants

Toddlers with FXS and WS were recruited to take part in a larger ongoing study, through the national family support groups for individuals with the syndromes in the United Kingdom. Eight boys with FXS completed the present search task (age range = 34 to 50 months; mean chronological age = 43.5 months; SD = 4.9 months). Their developmental level was assessed using the Bayley Scale of Development II-Mental Subscale (BSDM-II; Bayley, 1993), which revealed a mean mental age equivalent of 29.1 months (SD = 4.9 months; range = 23 to 36). They were individually matched, by mental age equivalent within 1 month, to eight typically developing toddlers, all of whom had participated in Experiment 1 and had also been assessed with the BSMD-II (MA controls, mean = 29.1 months; SD = 4.7 months; mental age range: 24 to 36 months), henceforth referred to as the MA controls. They were also matched by chronological age (within 1 month) to eight typically developing children (CA controls, mean = 43.3 months; SD = 5.0 months; range = 34–50), seven of whom had participated in Experiment 1, henceforth referred to as CA controls.

Eight toddlers with WS (4 girls) were also selected and matched to the toddlers with FXS on both chronological age (mean = 45.8 months; SD = 3.9 months; age range = 37–50) and mental age on the BSDM-II (mean = 27.9 months; SD = 6.2 months; range = 24–37). There were no significant differences in CA between the CA controls and the toddlers with FXS (paired *t*-test, $p = .9$) and WS ($p = .28$), nor in MA between the MA controls and the toddlers with FXS ($p = .95$) and WS ($p = .69$). Toddlers with FXS and WS also did not differ either in MA ($p = .33$) or CA ($p = .66$).

Apparatus and procedure

As in Experiment 1.

Statistical analyses

As in Experiment 1, except that the occurrence of more errors in the search task led to further division into subtypes. Errors were classified into three mutually exclusive categories: repetitive touches (due to toddlers touching a previously found target again); touches on distractors; and any other erroneous touches (due to toddlers touching the background, rather than any of the targets or distractors). The latter were then dropped from further analyses as they most likely reflect inaccuracies in motor control, rather than any of the attentional constructs of interest. Repetitive touches were further divided into immediate repetitions (i.e. another touch directly following a preceding touch on a particular target) versus later returns to targets (with at least one touch elsewhere intervening).

There are inevitable practical constraints when seeking to recruit toddlers with FXS and WS to complete experimental tasks. Due to the relatively small sample sizes, we conducted compromise power analyses (G-Power; Faul & Erdfelder, 1992) in order to establish whether the present sample sizes were too small to yield statistically significant results on the variables of interest. For a medium effect size (see Cohen, 1988), using ANOVAs and the sample sizes employed here, the power to detect a significant effect would be .80 for a main within-subject effect and .73 for an interaction or between-group effect, both of which can be considered satisfactory. However, the power to detect significant effects for ANCOVAs was much lower; .37 for a medium effect size. Therefore, we decided to focus our interpretation of the current data strictly on results from ANOVAs, on results which did reach statistical significance and not on any null findings.

Results

In overview, toddlers with WS and FXS made more errors in the search task than the control toddlers. While the WS and FXS groups did not differ from each other in the total number of errors, they did differ in the types of errors committed.

Toddlers with WS touched distractors more than both FXS toddlers and controls, increasingly so with displays containing many distractors that were similar (medium) to the large targets. Increasing the number of distractors did not increase touches upon them by toddlers with FXS, but they nevertheless touched similar (medium) distractors more than those dissimilar (small) to the large targets, a pattern not found in control toddlers.

Toddlers with FXS differed from all other groups in repeatedly touching targets that had already been found, on both experimental (nontargets present) and baseline (targets only) trials. When such repetitions were further divided into immediate repetitions versus later returns to previously touched targets, toddlers with FXS produced more of both types of repetitive errors per hit than the other groups. Immediate repetitions per hit for this group were not affected by the presence or appearance of distractors, but later returns per hit were, suggesting that the latter but not the former type of repetitions depended on the requirement to search among distractors.

Despite these striking differences in error patterns, the atypical groups did not produce longer search speed and path than expected given their developmental level.

All these empirical conclusions were supported statistically, as follows.

Analyses of accuracy

Non-parametric statistics were used to test differences in the number of hits, due to heterogeneous variance (mainly caused by low numbers of errors in the controls). Toddlers with FXS made fewer correct touches than MA controls (Mann-Whitney U, p levels ranging from .004 to .011) across all conditions except the baseline all-target displays ($p = .064$). Toddlers with WS made fewer correct touches than MA controls only in the conditions with few dissimilar distractors ($p = .027$) or many similar distractors ($p = .003$). Toddlers with FXS and WS produced a similar number of hits across conditions (p levels from .092 to .915).

An analysis of overall errors revealed main effects of target–distractor similarity, $F(1, 28) = 10.075$, $p = .004$ and group, $F(3, 28) = 21.655$, $p < .001$. Toddlers with FXS and WS made significantly more errors than both MA controls (means of 2.95 and 2.89 errors vs. 1.87, $p = .001$ and .002, respectively) and CA controls (mean = 1.25, $p < .001$ for both). However, toddlers with WS and FXS did not differ significantly in the total numbers of errors ($p = 1.0$). When baseline errors were co-varied, the effect of Group remained significant, $F(3, 26) = 10.635$, $p < .001$, and the same pattern of differences across groups was maintained. Similarly, target–distractor similarity continued to have an effect on the number of errors, $F(1, 26) = 5.307$, $p = .029$. Furthermore, ANCOVA revealed an interaction between Similarity and Group, $F(1, 26) = 3.986$, $p = .018$. Separate ANOVAs were conducted for each group to ascertain the source of this interaction. It originated from a main effect of target–distractor similarity on total errors only for toddlers with FXS ($F(1, 7) = 7.018$, $p = .033$) and WS ($F(1, 7) = 7.806$, $p = .027$) once the variability in baseline errors was accounted for. No other main effects or interactions reached significance (p levels between .075 and .951).

Erroneous touches on distractors

Figure 3a displays mean touches on distractors as a function of group, target–distractor similarity and number. Distractor number had a main effect for touches on distractors, $F(1, 28) = 6.733$, $p = .015$, with more errors of this type being produced when the display contained a larger amount of distractors. Target–distractor similarity also had a main effect on this error type, $F(1, 28) = 30.110$, $p < .001$, showing that many more distractor touches occurred with similar rather than dissimilar distractors. Group had a main effect on the number of touches on distractor circles, $F(3, 28) = 20.955$, $p < .001$. Critically, toddlers with WS committed more erroneous touches on distractors than toddlers with FXS (means of 4.8 distractor touches vs. 2.2, $p = .002$) and MA controls (1.1, $p < .001$). In contrast, toddlers with FXS did not differ significantly from MA controls on this measure ($p = .447$). CA controls produced fewer errors than toddlers with FXS and WS (.63 distractor touches, $p = .024$ and $< .001$, respectively). Importantly, Similarity and Group interacted, $F(3, 28) = 5.111$, $p = .006$. Touches on distractors were then entered into separate ANOVAs for each group to determine the source of this interaction. The analysis of simple effects revealed that, although toddlers with WS made more erroneous touches on distractors than toddlers with FXS, both groups made significantly more errors of this type when distractors were more similar to the targets, $F(1, 7) = 10.029$ and 15.577, $p = .016$ and .008, respectively. This effect did not hold for MA and CA controls (p levels respectively .423 and .155).

Repetitions on previously touched targets

Figure 3b displays mean repetitions per hit on previously found targets as a function of group, target–distractor similarity and distractor number. The total number of repeats was divided by the number of hits to account for the difference between groups in the overall number of hits. Group had a significant effect on the number of such repetitions, $F(3, 28) = 15.204$, $p < .001$. Critically, toddlers with FXS produced significantly more repeti-

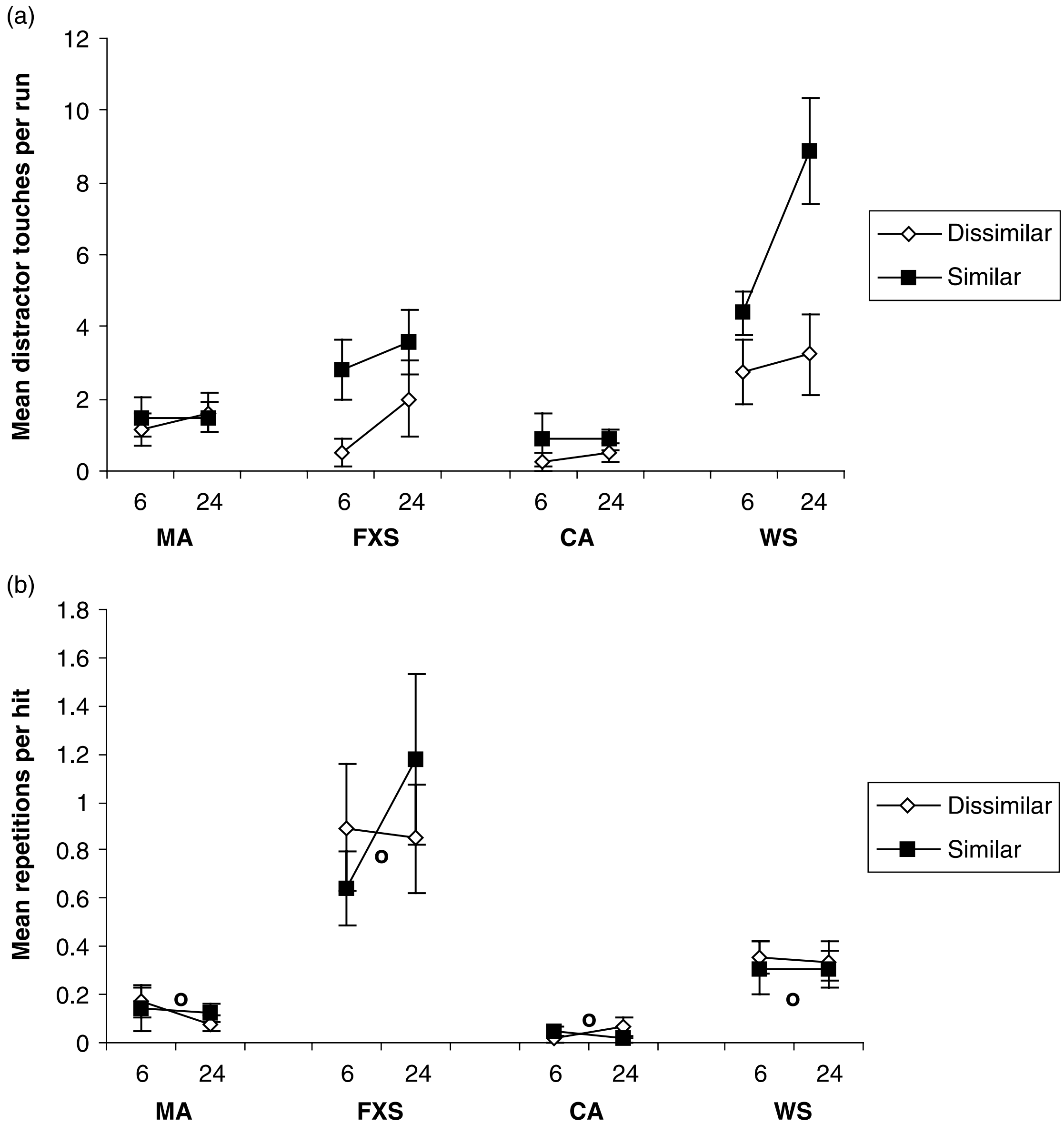

Figure 3 *Effects of target–distractor similarity (medium and small sized distractors), distractor number (6, 24) and group on (a) mean touches on distractors and (b) mean repetitions per hit on previously found targets (+ SEM) for toddlers with FXS, WS, MA and CA controls.* ***o*** *= Baseline repetitions per hit.*

tions on targets they had already touched (even though these were now clearly marked by a monster face), than toddlers with WS (on average .89 vs. .32 repetitions per hit, $p = .002$), MA controls (.13 repeats per hit, $p < .001$) and CA controls (.04 repeats per hit, $p < .001$). In contrast, toddlers with WS did not differ statistically from MA controls in the number of repetitive errors per hit, $p = 1.0$. CA controls produced fewer repetitive errors per hit than toddlers with FXS ($p < .001$) but not WS ($p = .272$). Other main effects and interactions were not significant.

The effect of Group remained significant when the variability in repetitions for baseline (targets only) trials was taken into account, $F(3, 28) = 6.412$, $p = .002$. The difference between toddlers with FXS versus MA and CA controls remained significant ($p = .004$ and $p = .006$, respectively). However, the difference between toddlers with FXS and WS was no longer reliable ($p = .361$). This suggests that the syndrome-specific high number of repetitions for toddlers with FXS is not particular to searching for targets among nontargets, but is found even when all items are targets (though note that a previously touched target in effect then becomes a non-target for correct search, being marked visibly with a monster face). Indeed, toddlers with FXS produced on average .78 (+/– SEM = .25) repetitive errors per hit on such baseline trials, in contrast with an average of only .18 (+/– .08) for toddlers with WS, of .18 (+/– .08) for MA controls and .02 (+/– .02) for CA controls. However, the difference with MA controls remained significant after co-varying baseline, suggesting that the presence of the distractors influenced repetitions by toddlers with FXS over and above what might be expected given their developmental level.

To investigate repetition errors further, these were subdivided into immediate repetitions versus later returns to previously touched targets (with the latter errors requiring at least one intervening touch on another item before returning to a particular target). Because many children in the control and WS groups committed few immediate repetitions per hit, these data were not normally distributed and so non-parametric statistics were used for group comparisons. Toddlers with FXS produced significantly more *immediate* repetitive errors than MA controls ($Z = 2.994$ to 2.526, $p = .006$ to .012) in the conditions containing distractors. In the baseline condition, FXS toddlers produced more immediate repeats than toddlers with WS ($Z = 2.763$, $p = .007$) and a trend was present for the comparison with MA controls ($Z = 1.861$, $p = .06$) in this condition as well. The high number of immediate repeats in toddlers with FXS appears consistent with a dysexecutive perseverative tendency (Shallice, 1988). WS toddlers did not produce more immediate repeats per hit than MA controls for any of the conditions ($Z = 1.236$ to 1.514, $p = .216$ to .130). FXS toddlers' immediate repetitions were not affected by target–distractor similarity, $F(1, 7) = .745$, $p = .417$, or number, $F(1, 7) = 1.763$, $p = .226$.

Most of the toddlers in the control groups and in the WS group did not produce any later returns to previously touched targets, so these were analysed parametrically only for toddlers with FXS and group comparisons were tested non-parametrically. Toddlers with FXS produced more such returns with similar than with dissimilar distractors, $F(1, 7) = 8.648$, $p = .022$, suggesting that this type of repetitive error by toddlers with FXS was influenced by the display properties, unlike their immediate repeats. They did not differ from the other groups in the number of returns per hit on baseline trials ($p = .105$ and .724 compared to MA controls or toddlers with WS), but they differed on the number of returns per hit in displays containing distractors from both toddlers with WS (with many and few similar distractors, $Z = 2.139$, 2.023, $p = .03$ and .04) and MA controls (many similar distractors, $Z = 2.085$, $p = .037$).

Analyses of search speed and search path

Group did not have an effect on overall time per hit, $F(3, 28) = 2.037$, $p = .131$, suggesting that once total search time was corrected for the time spent in incorrect touches, toddlers with FXS and WS found targets in the same amount of time as controls. The effect of distractor number reached statistical significance, with larger displays resulting in longer search times per hit, $F(1, 28) = 4.959$, $p = .034$. None of the other main effects or interactions was significant (p levels from .270 to .884).

In terms of search path, none of the main effects was significant and baseline distance between successive touches did not differ across groups, $F(3, 28) = 1.016$, $p = .401$. The effects of group, distractor similarity and number on distance between successive touches interacted, $F(1, 28) = 3.045$, $p = .045$, and this effect remained significant when the variability in baseline distance was taken into account, $F(3, 27) = 4.166$, $p = .015$. ANOVAs carried out on each group revealed that this interaction depended on longer distances being produced for many similar distractors for MA and CA controls ($F(1, 7) = 6.092$ and 5.917, $p = .043$ and .045, respectively), but not toddlers with FXS or WS. None of the other main effects or interactions was statistically significant (p levels between .183 and .510).

Discussion

Experiment 2 investigated any differences in search performance for two groups of atypically developing toddlers (FXS and WS), comparing these groups to each other and to typically developing controls. This is the first study to examine search performance in FXS and WS for toddler age groups.

Our findings reveal some differences between the atypical toddler groups (especially in the types of errors made), as well as some similarities on other measures. In terms of search speed and search path, both the FXS and WS groups displayed a similar level of performance, with no difference from that expected given their developmental level. The notable group differences related instead to the error types produced. Toddlers with FXS produced more repetitive errors (touching a previously found target again, even though it was now already marked by a monster face) than any other group. In contrast, toddlers with WS confused distractors with targets more often than any other group, false alarming to the distractors with erroneous touches, especially under conditions of low target perceptual salience and large set-size.

The pattern of repetitive errors by toddlers with FXS, which included both a high level of immediate repetitions and some later returns to previously rewarded

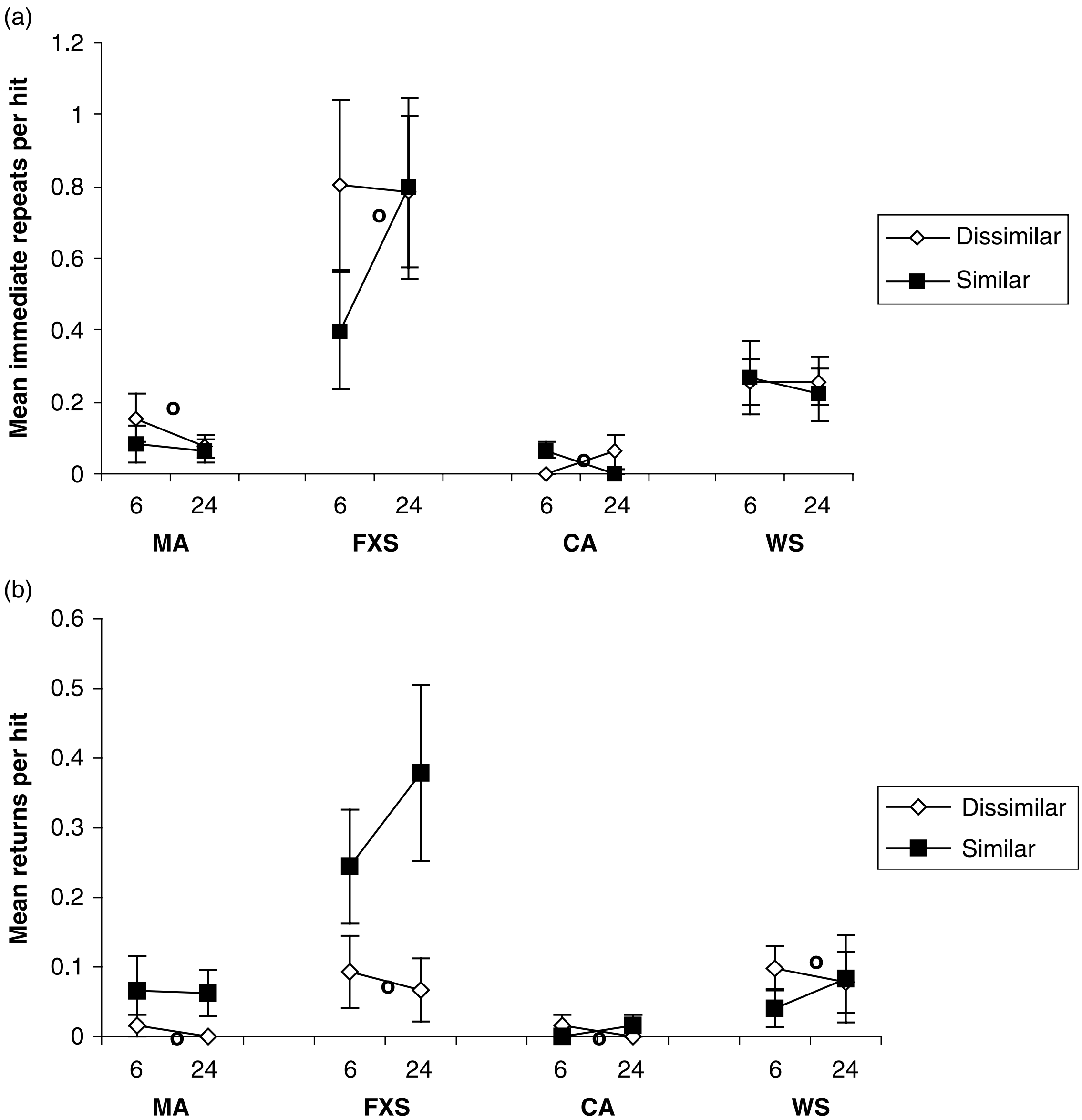

Figure 4 *Effects of target–distractor similarity (medium and small sized distractors), distractor number (6, 24) and group on (a) mean immediate repeats per hit on previously touched targets and (b) mean returns per hit on previously found targets (+* SEM*) for toddlers with FXS, WS, MA and CA controls.* ***o*** *= Baseline repetitions per hit.*

responses, is similar to that reported by Wilding *et al.* (2002) in older FXS children (aged on average 11 years), and provides new evidence for an early core deficit in inhibition in FXS. These errors cannot be explained in terms of poor memory of visited locations, as previously touched targets were clearly marked throughout trials. They are better accounted for by the difficulty in suppressing a previously correct but now inappropriate response, a hall-mark of inhibitory problems (Shallice, 1988). A non-executive interpretation of these perseverations could suggest that, for example, children with FXS like the appearance of the monsters more than the other groups and are therefore more motivated to touch them repeatedly. We believe that these are not mutually exclusive interpretations: in general, rather than in this task alone, perseverations can be explained by either difficulties in inhibiting prepotent responses, by a higher reward value of a previously correct response or by a combination of the two processes. The repetitive errors in FXS also revealed a vulnerability to the manipulation of target salience, with FXS toddlers returning more frequently to previously touched targets when the display included similar rather than dissimilar distracters. The high level of immediate repetitions in FXS indicates executive dysfunction in inhibitory processes, while later returns may reflect an interaction of executive dysfunction with perceptual processes, with returns to old targets becoming more likely when a new target is perceptually harder to locate.

In contrast, toddlers with WS produced more distractor errors (i.e. mistaken touches on distractors) than any other group, especially under conditions of low target perceptual salience and large display size. This pattern of errors indicates a deficit in target–nontarget discrimination for visual attention, contrasting with some claims of visuo-perceptual 'intactness' in adults and older children with the syndrome (e.g. Mervis *et al.*, 1999), although to a lesser extent, toddlers with FXS also produced more distractor errors in conditions of low target perceptual salience.

Alongside these differences between the atypical groups, other aspects of their performance also revealed some similarities. Both groups committed more errors than expected given their developmental level, suggesting overall delay. Furthermore, errors by both groups were affected by display characteristics and both groups committed errors of all types, rather than producing just a single type, although as noted above, repetition errors were more common in FXS, and distractor errors in WS.

General discussion

Taken together, our search results for typically and atypically developing toddlers indicate that target featural salience affects several aspects of search in this age group, including speed, search path, accuracy, and the type and frequency of errors. Younger typically developing toddlers were in general slower, less systematic and less accurate than older toddlers, but search path proved the most sensitive measure for detecting differential age effects of target salience in the typically developing groups. In contrast with older toddlers, younger toddlers' search path (but not their speed) was affected by both target salience and display size. By contrast, it was primarily error patterns, rather than search speed or path, that clearly differentiated the two groups of atypically developing toddlers, supporting our earlier suggestion that differences in typical development may not overlay neatly on atypical development. Toddlers with WS confused distractors with targets more than any of the other groups, whereas toddlers with FXS produced more repeats on previously touched targets than the other groups.

In Experiment 1, the use of multiple measures during computerized search on a touch-screen allowed us for the first time to reveal age differences between younger and older toddlers that would not have been detected had we focused upon more traditional search measures only. Younger toddlers' search was slower than older toddlers', but this effect could not be attributed solely to age differences in motor speed alone (cf. Gerhardstein & Rovee-Collier, 2002), because it did not disappear when accounting for any differences in speed on baseline trials (where all items were targets). Younger toddlers also produced less systematic search paths in conditions of both low target salience and large display size; whereas older toddlers' search paths were only affected by target salience, suggesting distinct developmental changes in the ability to deal with changes in display properties during search tasks.

In Experiment 2, the pattern of errors suggested striking qualitative differences in search performance between toddlers with FXS versus WS, but also some similarities in their vulnerability to manipulations of target featural salience. Both atypically developing groups produced more errors than age-matched controls, at an overall level similar to the younger controls, suggesting overall delay in their ability to search. More importantly, over and above this general pattern of delay, the FXS and WS showed different types of errors at atypical rates. Toddlers with WS made the highest number of erroneous touches on distractors. They were more affected than the other groups by the combination of larger display size and target–distractor similarity (conjointly increasing the perceptual load of the search task). The distractor errors by toddlers with WS do not support claims of visuo-perceptual 'intactness' in this syndrome, which had been based previously only on adults and children with the syndrome (Mervis *et al.*, 1999), but this agrees with other claims for subtle visual deficits in WS (e.g. Grice & O'Riordan, unpublished).

Toddlers with FXS repeated previously successful responses, thus producing many repetitive errors, as older children with FXS also do (Wilding *et al.*, 2002). These perseverative errors in FXS toddlers are consistent with performance by older children and adults with the syndrome, both in search tasks and on other executive tasks (e.g. Munir *et al.*, 2000; Cornish *et al.*, 2001). Here we provide evidence for difficulties with executive control in the syndrome arising as early as in toddlerhood. However, the FXS toddlers also showed some vulnerability to manipulations of target featural salience, which might appear surprising given their reported later proficiency with standardized visuo-perceptual tasks (e.g. Cornish *et al.*, 1999), but could potentially relate to the attentional nature of the present task.

A number of issues for future investigation emerge from the new data presented here plus extant hypotheses about other age groups. First, there were some differences in the deficits observed here for FXS toddlers as compared with older children with the syndrome, in addition to the similarities such as more repetitive errors in FXS. For example, the toddlers here did not differ from controls in terms of search path (cf. Munir *et al.*, 2000). Similarly, the large effects of target salience on toddlers with WS countered predictions from some of the adult literature on WS (Mervis *et al.*, 1999). Given these differences, it would be useful to examine these aspects of performance in an extended longitudinal study, rather than the cross-sectional approach taken here. It could also be useful to manipulate target salience during search tasks in additional ways, for example by manipulating distractor heterogeneity (Duncan & Humphreys, 1989), or by looking at other featural dimensions in addition to size. Finally, there have been many recent suggestions that executive function may itself consist of several separable components (e.g. see Baddeley, 1996; Shallice & Burgess, 1996), such as the ability to inhibit prepotent responses, to switch attention from one dimension or concept to another, and to maintain in working memory the task in hand (Miyake, Friedman, Emerson, Witzki, Howerter & Wager, 2000). It might therefore be useful to compare search tasks against other tasks with different executive components in future studies of FXS and WS toddlers, to test the specificity of the present deficits found during search. The difficulty observed here in preventing response repetitions during search by FXS toddlers might conceivably relate to other characteristic behaviours seen in FXS groups at later age (e.g. repetition in speech, problems with sequences, difficulty with the WALK task of the TEAcH reported by Munir *et al.*, 2000).

We began this investigation by asking how the featural salience of a target may influence the typical developmental trajectory of visual search, and whether selective attention in atypically developing toddlers may break down in a manner that resembles the pattern obtained in later childhood and adulthood. We found that both typical and atypical search performance in toddlers is influenced by target featural salience. The distinctive patterns of errors for the two atypical groups highlight similarities to the adult phenotype, as well as some subtle differences. This in turn suggests the need to investigate empirically the developmental processes leading to the clearer dissociations found in adulthood, rather than simply inferring early selective impairments from the adult phenotype.

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