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Multiple-object tracking among individuals with Down syndrome and typically developing children

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Abstract

We investigated differences in multiple-object tracking among individuals with Down syndrome (DS) as compared to typically developing children matched on a visual–spatial mental age of approximately 5.5 years. In order to ensure that these effects did not originate in differences in encoding or reporting the positions of targets in distracters after a delay, immediate and delayed report were measured for static items. Although their immediate and delayed report for multiple static items was comparable to that of the typically developing children, the participants with DS performed as if they were only capable of tracking a single item at a time regardless of the number of targets that needed to be tracked. This finding is surprising because the operations used in multiple-object tracking are thought to be necessary for visuospatial tasks, which are an area of relative strength among persons with DS. These results call into question the idea that abilities or deficits in multiple-object tracking predict visuospatial performance, and highlight ways that atypical development can inform our understanding of typical development.

Within the context of the mutually informative relationship between the understanding of typical and atypical development that is the hallmark of the discipline of developmental psychopathology (Cicchetti, 1984), the study of persons with specific syndromes associated with intellectual disability plays a unique role. As in the case of all types of atypical development, typical development provides a context for evaluating the developmental intactness, strengths, and weaknesses in this group. In addition, like all types of development that are so atypical that they cannot be mimicked or induced in research settings, the occurrence of intellectual disability serves as an "experiment in nature" for the testing of the extremes of developmental integrity (see Hodapp & Burack, 1990). In this case, intellectual disability provides unique opportunities to assess whether patterns and associations that are evident in typical development are also seen when development is most slowed down and to observe development and developmental patterns in slow motion. The study of specific syndromes further extends the limits to which the developmental system can be stretched since, in addition to the slowed development, each syndrome is associated with a unique developmental pattern of relationships across areas of functioning (Burack, 1990; Burack, Hodapp, & Zigler, 1988; Cicchetti & Beeghly, 1990). Domains of functioning that appear to be intrinsically related when only considered within the context of typical development may not appear to be related at all in the development of persons with a specific syndrome (Burack, Russo, Flores, Iarocci, & Zigler, 2012). Thus, the unique relative strengths and weaknesses for each syndrome may contribute to the understanding of both the limits of the developmental system and the alternative ways that development can be constructed (Cicchetti & Pogge-Hesse, 1982; Hodapp & Burack, 2006).

The study of special populations may be especially informative to the research on typical development when performance is contingent on component abilities that may be "pulled apart" in populations with marked strengths and weaknesses in different areas of attention and related areas of cognitive function. In this study, we employ this strategy to better understand multiple-object tracking (MOT; Pylyshyn & Storm, 1988). MOT is the ability to monitor the positions of a number of target items as they move among distractors. Young adults can typically track around four items at once, though there are individual differences (e.g., Trick, Mutreja, & Hunt, 2012). Pylyshyn (2001) argues that MOT requires assigning mental reference tokens, or indexes, to a small number of selected targets so that the locations of targets can be reported even if the properties and positions of targets change from moment to moment. Thus, this indexing op-

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eration serves as a form of object-based selection that can operate on up to four items at once, at least among most young adults. It permits targets to be distinguished both from distractors and from other targets, and it is therefore essential to the ability to touch or point to a specific target item among others. However, according to Pylyshyn, this ability to individuate several items at once is also necessary for deriving spatial relations and consequently would be expected to be associated with performance on visuospatial tasks.

Pylyshyn's (2001) prediction was borne out in studies on individuals with Williams syndrome (WS), a disorder associated with both intellectual disability and marked visuospatial deficits accompanied by relatively spared performance on verbal tasks (Donnai & Karmiloff-Smith, 2000; Martens, Wilson, & Reutens, 2008). For example, O'Hearn, Landau, and Hoffman (2005; see also O'Hearn, Hoffman, & Landau, 2010) found that individuals with WS also exhibited poor tracking performance and proposed that individuals with WS have fewer indexes than is typical for their mental age (MA). They concluded that this deficit originated in abnormalities in the parietal lobe, which is also implicated in MOT (Culham et al., 1998; Howe et al., 2009). However, if poor MOT performance is always associated with visuospatial deficits, and visuospatial deficits are always associated with poor MOT, then MOT should be spared in specific populations for whom visuospatial processing is an area of relative strength, as is the case for persons with Down syndrome (DS; Frenkel & Bourdin, 2009; Vicari, Belluci, & Carlesimo, 2006). In order to test this hypothesis, we compared the tracking performance of individuals with DS, who show markedly different cognitive profiles than those with WS although both groups function in the range of intellectual disability, with the performance of a group of typically developing (TD) children matched on visuospatial MA.

The cognitive profile of persons with DS provides a unique opportunity to assess the extent to which MOT is dependent on visuospatial processing, an area of strength relative to other aspects of development in this population. This strength appears to be pervasive since it is evident across a range of domains including visual–spatial memory, visual–motor integration, and visual imitation (Fidler, 2005; Reilly, Klima, & Bellugi, 1990; Silverman, 2007; Vicari, 2012). However, as is the case with virtually all areas of functioning, performance on visuospatial tasks can be compromised by the pervasive language impairments associated with DS (Jarrold & Brock, 2012). For example, difficulties on tasks of digit span and nonword repetition are due to difficulties in representing verbal information in short-term memory (Jarrold & Brock, 2012; Thorn & Frankish, 2005). Concordantly, impairments in working memory and long-term memory are linked to difficulties with verbal processing (Fidler & Daunhauer, 2011; Jarrold & Brock, 2012; Vicari, 2012), and deficits in executive function are noted on tasks that involve verbal components, such as those used to test rule use and set shifting, but not on tasks that do not involve verbal components, such as those used to assess inhibition and planning (for a review, see Russo, Dawkins, Huizinga, & Burack, 2012). Despite this deleterious impact of diminished language abilities, visuopatial abilities continue to be a relative strength among persons with DS, relative to developmental level, and should be associated with intact performance on MOT.

The comparison of tracking performance across groups is, however, complicated because performance deficits may originate from several sources, and different groups may have deficits for different reasons. For example, the beginning of the MOT task involves encoding of the positions of all of the targets as they are presented among the distractors. Difficulties in encoding targets would be manifested by a less accurate *immediate report* of the target locations after encoding, but before the items begin to move. Similarly, the reporting of the location of the targets after a gap of 5 s or more from the encoding stage (during which the item movement takes place) requires the ability to sustain attention and hold information in memory long enough for it to be reported. Deficits in these domains would be manifested in a task of simple *delayed report* of the positions of the targets. The true test of the indexing operation only occurs in the intermediate stage, during which the targets and distractors move. At the very least, this stage requires motion perception, but it also involves a form of selection that is object based, rather than just spatially based, because accurate performance is dependent on the observer maintaining item identity (target or nontarget) despite the movement of the items (Pylyshyn, 2001).

These different components of MOT may also vary in developmental trajectory. For example, the abilities necessary for immediate and delayed report develop and change in different ways across the lifespan than do those for MOT as a whole (Trick, Hollingsworth, & Brodeur, 2009). TD children improve significantly in their immediate and delayed report performance between 4 and 6 years of age, and performance reaches adultlike levels between the ages of 8 and 11 years, depending on the difficulty of the task (O'Hearn et al., 2005; Trick et al., 2009; Trick, Jaspers-Fayer, & Sethi, 2005). In contrast, the ability to track moving items develops later, with significant improvements occurring between 5 and 7 years of age, and adultlike levels of performance appearing between the ages of 11 and 13 years, again depending largely on task difficulty (O'Hearn et al., 2005; Trick et al., 2009).

The disparity in development was further highlighted by O'Hearn et al.'s (2005, 2010) finding that the delayed report performance of persons with WS with a mean MA of between 5 and 6 years was comparable to that of 5- to 6-year-old TD children, whereas their tracking performance was only comparable to that of 4-year-old TD children. This suggests that the impaired performance of persons with WS was not due to problems related to report but rather to the indexing phase of the MOT task. Since the deficit in indexing among persons with WS might be the cause of their more global problem in visuospatial processing (Donnai & Karmiloff-Smith, 2000; Martens et al., 2008), we hypothesized that persons with DS, for whom visuospatial processing was an area of relative strength (e.g., Frenkel & Bourdin, 2009; Vicari et al., 2006), should not show deficits in MOT.

In the present study, participants with DS and TD individuals matched on an MA of approximately 5.5 years were compared on an MOT task and on tasks of immediate and delayed report. A challenging version of the MOT task with 10 item displays and 10-s intervals between encoding and report was used to minimize ceiling effects in the corresponding report tasks. Consistent with the notion that groups with specific areas of strengths and weaknesses should be matched to TD persons on the domain of functioning that is relevant to the target task (e.g., Burack, 1997; Burack, Evans, Klaiman, & Iarocci, 2001; Burack, Iarocci, Flanagan, & Bowler, 2004; Russo et al., 2007), the Leiter International Performance—Revised Brief IQ Scale (Leiter-R; Roid & Miller, 1997), which provides a measure of visual–spatial MA, was used to match the groups both because persons with DS show a relative strength in this area and because the MOT task is one of visual–spatial processing. Because the average MAs of the participant groups were approximately 5.5 years, we expected that they would be able to track around two items, based on the performance of TD children in studies with tasks of comparable difficulty (Trick et al., 2005, 2009). If the individuals with DS performed as would be consistent with their chronological age, they were even expected to track up to three or four items at once. However, the persons with DS might not have been expected to perform as well as the TD individuals on MOT if they had difficulty encoding or sustaining attention for the duration of the tracking interval, as measured by report tasks (Trezise, Gray, & Sheppard, 2008). In addition, immediate and delayed report require spatial memory, and deficits in visuospatial simultaneous working memory for static items are reported among individuals with DS in some tasks (Lanfranchi, Caretti, Spano, & Cornoldi, 2009; Visu-Petra, Benga, Tincas, & Miclea, 2007). Thus, any deficits in MOT among the participants with DS would be expected to be accompanied by deficits in immediate and delayed report for static items.

Method

Participants

The participants included 13 persons (11 male) with DS with an average chronological age of 15.12 ($SD = 3.38$) years and an average visual–spatial MA of 5.42 ($SD = 0.75$) years as measured with the Leiter-R (Roid & Miller, 1997), and 13 TD children (7 male) with an average chronological age of 5.21 ($SD = 0.54$) years and an average visual–spatial MA of 5.54 ($SD = 0.76$) years. The Leiter-R is a measure of nonverbal intelligence that can be easily administered to populations with developmental disabilities and language impairments. The groups were well matched on visuospatial MA, $t\,(24) = 0.37$, $p = .72$.

The participants with DS were recruited from two centers that provide services to persons with DS, and the TD children were recruited from kindergarten, Grade 1, and Grade 2 classes in public schools. The TD children were reported to be free of any mental health-related diagnoses. All the participants had self-reported or parent-reported normal or corrected to normal vision. Although visual acuity was not measured, only significant uncorrected impairment would have made the displays difficult to see under the close viewing conditions used during experimentation.

Stimuli and apparatus

Testing was carried out on a Macintosh iBook with an external computer mouse for making responses. The participants were seated at a table, directly in front of the computer, 45 cm from the viewing screen. The stimuli were presented on a central black 22.96×17.33 degree rectangle that served as the tracking field. The pretrial central fixation point was a 0.18 degree white outline square. The stimuli used in the tracking and report tasks are presented in Figure 1; they include happy faces (1.45 degree blue circles outlined by 0.18 degree white contours) and spies (1.53 degree black squares with 0.18 degree white contours, forming faces wearing spylike fedora hats). During each trial, 10 randomly positioned stimuli were positioned on the tracking field. The only items that moved were the happy faces (the happy faces could be targets or distracters), and their movements were constrained in such a way that they could touch but never occlude. Items bounced off each other and the walls of the tracking field. Each item had its own rate of movement, and that rate changed randomly every frame (every 16.5 ms), with values somewhere between 0 and 9.35 degree visual angle per second. These items moved independently of one another. In every frame, there was a 1/100 chance that the item would spontaneously change direction even if it did not bounce off anything.

Procedure

The participants were tested in two 30-min sessions on separate days. On the first day, they completed the Leiter-R. On the second, they completed variants of the catch the spies task (Trick et al., 2005, 2009). In all variants of the task, the goal was for the participants to indicate the locations of one or more spies (targets) that had disguised themselves as regular civilians (happy-face figures) in a display of regular civilians (distractors). For each task variant, there were four or more of the following stages shown in Figure 1 in each trial. In the initialization stage, 10 randomly positioned happy-face figures were displayed on the screen for 1105 ms. Next, during the 1650 ms target encoding stage, between one and four of these items repeatedly changed back and forth from happy-face to spy form to indicate that those specific items were the targets (spies). At the end of this period, all of the items reverted to their happy-face form and remained static for 495 s (the postencoding display). In the item movement phase, all 10 of the happy-face figures (targets and distractors) moved randomly and independently of one another for 10 s. Then all item motion stopped. Then during the report phase, the participants used the computer

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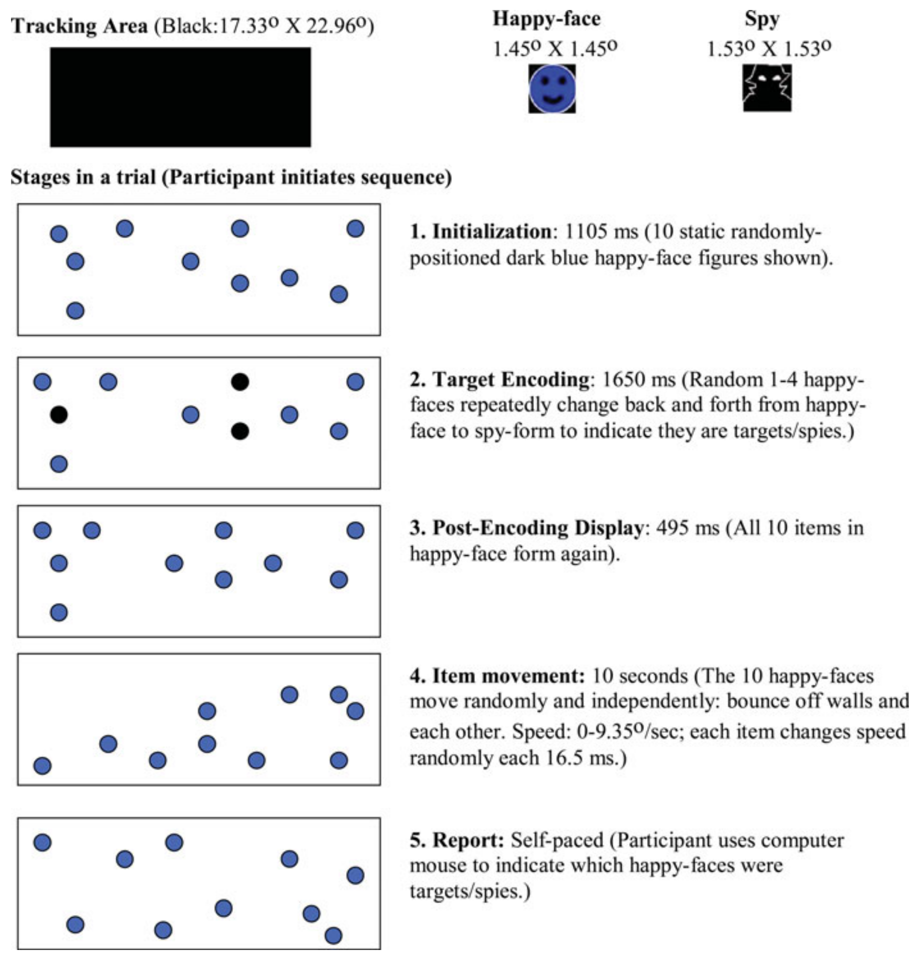

Figure 1. Stages in the catch the spies task. Note that all three variants of the catch the spies task (immediate report, delayed report, and multiple-object tracking [MOT]) went to the end of the postencoding display. However, for immediate and delayed report there were always four targets, and the participants did not experience the item movement stage. For immediate report participants went directly to report stage after the postencoding display, whereas for delayed report they waited an additional 10 s before report. For the MOT task, there were between one and four targets, and participants went through all five stages of the task. [A color version of this figure can be viewed online at http://journals.cambridge.org/dpp]

mouse to indicate the happy-face figures in the static display that were "really spies" (targets).

The three variants of the catch the spies task included immediate report, delayed report, and MOT. All involved the initialization, target encoding, postencoding, and report phases, but for immediate report, the participants completed the report stage immediately after the postencoding phase, while for delayed report, they completed the report phase that followed postencoding after a 10-s delay, during which the items remained static. The item movement phase only occurred in the MOT task (item movement occurred in the 10 s immediately after the postencoding display). The immediate and delayed report variants always involved four targets. The MOT task involved between one and four targets per trial, and the trials were presented in a random order with the number of targets varied from trial to trial. For all three variants, feedback was provided after each trial during a 1260-ms interval at which time the actual targets identified themselves as spies.

The participants completed the immediate report, delayed report, and MOT variants in that order. Practice trials were administered before each task. The immediate and delayed report variants each entailed 2 practice trials and 8 experimental trials. The MOT variant comprised 8 practice trials and 32 experimental trials. In total, the participants completed 60 trials in under 30 min. None of the participants reported difficulty completing the tasks.

Results

For all of the analyses, the dependent variable was the mean percentage of correctly identified targets (spies). Unless otherwise specified, follow-up tests were conducted using Bonferoni's test. Boxplots were used for all conditions and groups for an initial outlier check. However, because there was no evidence that outliers distorted the results, the boxplots will not be reported here.

Report tasks

The participants with DS were compared to the TD children on measures of immediate and delayed report. A 2×2 analysis of variance was performed with group as a between-group factor with two groups (DS and TD) and type of report task as a within-subject factor with two levels (immediate and delayed). No group differences emerged, $F\ (1, 24) = 0.12$, $p > .05$, but there was a main effect of task, $F\ (1, 24) = 9.88$, $p = .004$, $\eta_p^2 = 0.29$, with performance better on immediate than delayed report ($M = 87.04\%$, $SD = 10.7$ and $M = 78.68\%$, $SD = 11.6$, respectively). There was no evidence of a Group × Task interaction, $F\ (1, 24) = 0.16$, $p > .05$. Overall, the findings suggest that the participants with DS and the TD children were similar in terms of their ability to report the positions of up to four static target items (spies) in distracters. These findings are displayed in Figure 2, along with the expected outcomes (the expected percentage of correctly identified targets) if the participant guessed the positions of one or two of the four targets. These expected outcomes were calculated based on the assumption that the participants accurately remembered the positions of some of the targets and randomly guessed the rest (sampling without replacement; Freund, 1981). For example, if there were four targets and six distractors, and the participants knew the locations of three targets but were guessing the position of one, their expected percentage of accurately identified targets would be $(3 + [1 / 7]) / 4 \times 100 = 78.57\%$. Both groups performed about as well as would be expected if they were guessing the position of one of the targets in the delayed report for four items.

MOT

Group differences in tracking performance for the targets were analyzed in a 2 × 4 mixed-design analysis of variance. As is typical in tracking studies, performance dropped with increases in the number of targets, $F\ (3, 72) = 25.91$, $p < .001$, $\eta_p^2 = 0.52$. For both groups, tracking performance for four targets was significantly below delayed report for the positions of four static targets (DS: M difference = 29.96%; SD of difference = 15.5. TD M difference = 32.36%; SD of difference = 15.0; $p < .001$ for both). Thus, tracking four items was markedly more difficult than simply reporting the positions of four static items after a delay of the duration of the tracking interval.

Overall, tracking performance was marginally worse among the participants with DS than among the TD children, $F\ (1, 24) = 3.94$, $p = .059$, $\eta_p^2 = 0.14$, but this effect was superseded by a Group × Number of Targets interaction, $F\ (3, 72) = 3.83$, $p = .013$, $\eta_p^2 = 0.14$. Figure 3 indicates that the TD children displayed better tracking performance than did the participants with DS until there were four targets. Simple main effects analyses revealed significant differences between the participants with DS and the TD children for one target, $F\ (1, 72) = 15.96$, $p < .01$; two targets, $F\ (1, 72) = 9.33$, $p < .01$; and three targets, $F\ (1, 72) = 5.33$, $p =< .01$; but not four targets, $F\ (1, 72) = 0.42$, $p > .05$.

As can be seen in Figure 3, the participants with DS performed almost exactly as might be expected if they randomly guessed the position for one of the targets even when required to track only two targets at once. They also performed as would be expected if they randomly guessed the positions of two of the targets when required to track three items at once, one sample t tests, $t\ (12) < 1$ for both. Thus, the participants with DS did not appear to perform MOT but instead tracked a single target and guessed the positions of the remainder. In contrast, one sample t tests revealed that the TD children performed significantly better than would be expected if they guessed the position of one item when required to track two at once, $t\ (12) = 2.44$, $p = .031$, M difference = 15.6%, and significantly better than would be expected if they guessed two of the targets when required to track three at once, $t\ (12) = 2.29$, $p = .041$, M difference =10.83%. This suggests that the TD children were capable of tracking more than one target at a time, but their performance was still worse than would be expected if they only guessed one of the targets

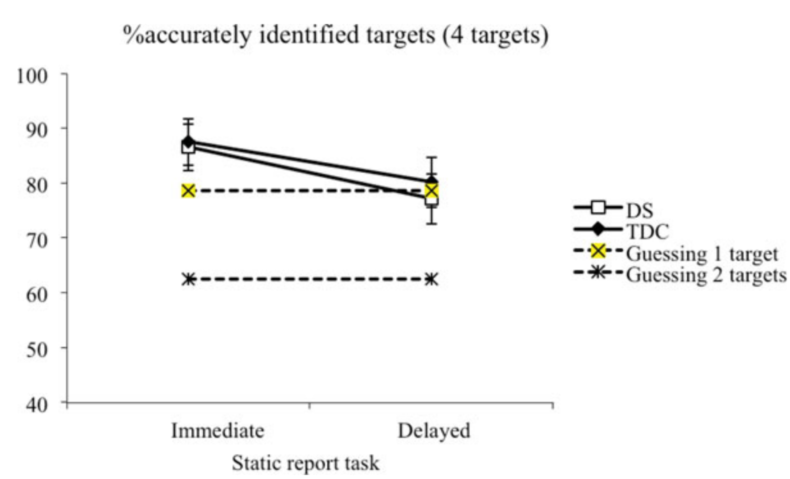

Figure 2. Mean percentages of correctly identified targets for immediate and delayed report of the positions of four static targets in the typically developing control (TD) and Down syndrome (DS) groups. The dotted lines represent the expected outcomes if participants were guessing the positions of one or two of the targets they were required to report. Standard error bars are included. [A color version of this figure can be viewed online at http://journals.cambridge.org/dpp]

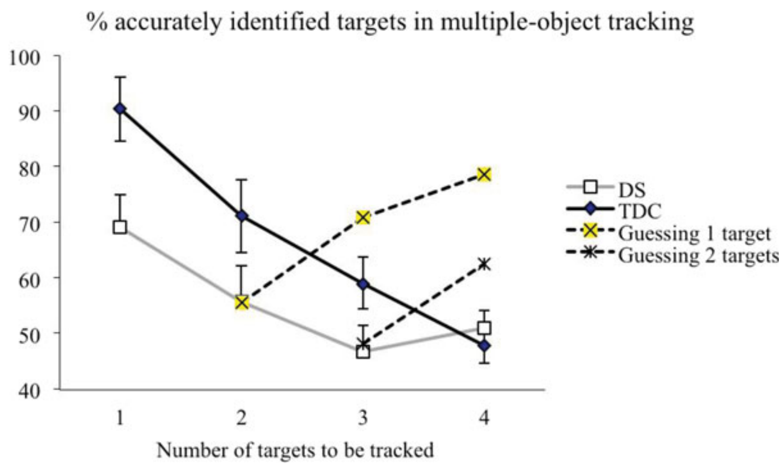

Figure 3. Mean percentages of correctly identified targets in the typically developing control (TD) and Down syndrome (DS) groups on the multiple-object tracking task. The dotted lines represent the expected outcomes if participants were guessing the positions of one or two of the targets they were required to track. Standard error bars are included. [A color version of this figure can be viewed online at http://journals.cambridge.org/dpp]

when required to track three at once, $t\ (12) = –2.52$, $p = .027$, *M* difference = 11.86%. Thus, on average, the TD children tracked between one and two items at once, which is consistent with the developmental pattern observed by Trick et al. (2005) with a similar tracking task.

Floor effects obscured group differences in the four-target tracking condition. Both groups performed significantly worse than would be expected if they guessed two of the four targets that they were required to track, one sample *t* tests: DS $t\ (12) = –3.58$, $p = .004$; TD $t\ (12) = –4.57$, $p = .001$, indicating that all guessed the positions of the majority of the targets. Since both groups performed about as well as might be expected if they guessed the position of one of the targets in delayed report for four static targets, poor tracking performance with four targets is not surprising.

In summary, the participants with DS performed about as well as would be expected if they could not track multiple items at once but could only track a single item at a time. In contrast, the matched TD children performed as would be expected if they could track between one and two targets at once.

Do differences in immediate and delayed report account for tracking performance?

In order to evaluate the impact of possible relations between the report tasks and MOT, a 2 (Group) × 4 (Number of Targets) analysis of covariance was performed with accuracies for both immediate and delayed report included as covariates. Immediate report accuracy was not a significant covariate, $F\ (1, 22) = 0.35$, $p > .05$, $\eta_p^2 = 0.02$, but delayed report accuracy was, $F\ (1, 22) = 18.40$, $p < .001$, $\eta_p^2 = 0.46$, suggesting a relationship between report and tracking performance. However, the covariance did not substantially change the overall pattern of results. The main effect for the number of targets emerged again, $F\ (3, 66) = 5.61$, $p = .002$, $\eta_p^2 = 0.20$; the marginal effect of group became significant, $F\ (1, 22) = 6.40$, $p = .019$, $\eta_p^2 = 0.22$; adjusted $M = 66.01$ for the TD and 56.77 for DS; and the Group × Number of Targets interaction remained, $F\ (3, 66) = 3.99$, $p = .011$, $\eta_p^2 = 0.15$. An analysis of covariance was carried out independently for each group and test. For both the participants with DS and the TD children, delayed report performance was a significant covariate ($p < .01$ for each), but among the TD children, immediate report performance was also a significant covariate, $F\ (1, 11) = 17.08$, $p = .002$, $\eta_p^2 = 0.61$.

Discussion

Participants with DS were compared to TD children matched on a MA of approximately 5.5 years in terms of their immediate report, delayed report, and MOT performance. Although the groups were matched on visual–spatial processing, the individuals with DS showed impairments in tracking moving objects that could not be explained by deficits in immediate and delayed report. The two groups were similar in terms of the ability to report the positions of up to four static target items (spies) in distracters, but the ability to track the target items was worse among the participants with DS as compared to the TD children for one, two, and three targets. When there were four targets, both groups performed as would be expected if they were randomly guessing more than two of the four target locations. Both groups performed as if they were randomly guessing the positions of the *majority* of the targets. Tracking performance for four targets was significantly worse than the delayed report for the positions of four static target items among both the persons with DS and the TD children. Overall, the results suggest that the participants with DS did not track multiple objects at the same time but rather tracked a single target item and guessed the positions of the remainder. Whereas the TD children (average age 5.21 years) were capable of tracking more than one target at a time, the individuals with DS were not, as calculated by

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Hulleman's (2005) estimate for high threshold guessing (Hulleman $k = 1.45$ and $k = 0.86$ for TD and DS groups, respectively, when required to track three items at once). These deficits in MOT among individuals with DS could help explain other findings in the literature. For example, if MOT is as critical for visual–motor coordination as Pylyshyn (2001) suggests, then a deficit in MOT could partly explain some of the visual–motor coordination difficulties seen among persons with DS (Virji-Babul et al., 2006).

Because the task used in this study with persons with DS was more difficult than the one used by O'Hearn et al. (2005, 2010) with individuals with WS, tracking performance in the two groups cannot be compared directly. However, the individuals with DS in this study exhibited the same dissociation displayed by persons with WS (O'Hearn et al., 2005, 2010), because performance on static memory tasks was more similar to that of the MA-matched TD children than performance on the tracking task. This supports the notion that separable mechanisms are responsible for report and tracking, and that the mechanism responsible for tracking is susceptible to disruption by atypical development. The most important difference between the two report tasks and tracking is that tracking requires item movement (in addition to encoding and report). Static spatial selection mechanisms would be adequate for immediate and delayed report, but object-based selection becomes necessary when items move.

Problems in object-based selection may emerge for a number of reasons. As suggested by O'Hearn et al. (2005, 2010) for individuals with WS, individuals with DS may not be able to select as many objects at once because they have fewer spatial indexes to assign. In addition, Pylyshyn's (2006) finding of distractor inhibition in MOT suggests that persons with DS may be deficient in object-based inhibition (cf., Lanfranchi, Jerman, Dal Pont, Alberti, & Vianelli, 2010). The observed tracking deficits may also occur because of the demands that MOT makes on executive working memory. Although individual differences in executive function do not seem to predict differences in tracking performance in TD young adults (Trick et al., 2012), they may predict performance among persons with DS, who display special deficits under dual task conditions (Kittler, Krinsky-McHale, & Devenny, 2008).

Although the above interpretations may all contribute to observed group differences, we believe one further possiblity provides the most compelling explanation. The problem may be that individuals with tracking deficits have a lower spatial or temporal resolution for object-based selection/inhibition operations than is seen among TD individuals. Intriligator and Cavanagh (2001) demonstrated that processes that require attentional selection generally have a much lower spatial resolution than do sensory processes. If the mechanisms used to update the positions of selected items were either slower or less accurate (or both) among individuals with DS, then tracking deficits could occur even though DS does not seem to have much effect on the resolution of sensory processes per se. Partial support for this contention includes evidence of spatial vision deficit among individuals with DS that is associated with cortical rather than ocular mechanisms (Courage, Adams, & Hall, 1997; John, Bromham, Woodhouse, & Candy, 2004; Suttle & Turner, 2004). Furthermore, initial evidence suggests that basic motion processing is intact in persons with DS, whereas complex motion processes that would be influenced more by the spatial and temporal resolution of cognitive systems, such as deriving form from motion, are deficient (Virji-Babul, Kerns, Zhou, Kapur, & Shiffar, 2006). Poor resolution might also explain why the deficit in performance emerged even with only a single target to track.

The present study provides a unique way of exploring the ramifications of one of the tenets of Pylyshyn's (2001) spatial indexing theory. According to Pylyshyn, the operations necessary to index and track multiple items at once in MOT are also necessary for deriving spatial relations. If that is true, then there is reason to expect an association between poor tracking performance and poor visuospatial skills, as occurs in WS (O'Hearn et al., 2005, 2010). However, we found that individuals with DS performed worse than TD children on an MOT task, even though visuospatial skills are an area of relative strength among persons with DS and even though the groups were matched closely on MA derived from a task of visuospatial reasoning. This finding calls into question the notion that MOT necessarily predicts performance in other visuospatial tasks.

The unexpected presence of MOT deficits among persons with DS suggests at least two possible interpretations. One is that the individuation operations used in MOT are not strictly necessary for the visuospatial tasks used in standard tests of spatial abilities. Many of these tasks involve static items for which a simple spatial (non-object-based) selection mechanism would be adequate to explain performance. A second interpretation is that tracking deficits occur for different reasons in persons with DS and WS. For example, compared to individuals with WS, persons with DS may display relatively intact object-based selection, but may nonetheless exhibit reduced tracking performance because the temporal resolution of their selection processes is poor, which would be especially problematic in dynamic displays. Another explanation is that object-based selection may be preserved in persons with DS, but limitations in executive function may reduce the ability to store information for later report while updating item positions. A final possibility is that all, or aspects of all, of these explanations may be true.

In conclusion, MOT is a complex task involving a number of different brain areas (e.g. Howe et al., 2009), some of which show greater activity in individuals with greater tracking skill (e.g. Drew & Vogel, 2008). Deficits may originate from a variety of different neural sources including frontal and parietal areas, both of which are found to relate to the development of visuospatial working memory in TD children (Klingberg, Forssberg, & Westerberg, 2002). Overall the evidence from individuals with unique etiological profiles is consistent with the view that tracking is most likely supported by a cortically based indexing mechanism that is independent of other memory and selection processes. However, because individuals with DS show relatively preserved visuospatial performance despite pronounced tracking deficits, the notion that deficits in MOT necessarily predict performance deficits in all visuospatial tasks needs to be reassessed.

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