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Visuo-spatial Ability in Individuals with Down Syndrome: Is it Really a Strength?

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Abstract

Down syndrome (DS) is associated with extreme difficulty in verbal skills and relatively better visuo-spatial skills. Indeed, visuo-spatial ability is often considered a strength in DS. However, it is not clear whether this strength is only relative to the poor verbal skills, or, more impressively, relative to cognitive ability in general. To answer this question, we conducted an extensive literature review of studies on visuo-spatial abilities in people with Down syndrome from January 1987 to May 2013. Based on a general taxonomy of spatial abilities patterned after Lohman, Pellegrino, Alderton, and Regian (1987) and Carroll (1993) and existing studies of DS, we included five different domains of spatial abilities – visuo-spatial memory, visuo-spatial construction, mental rotation, closure, and wayfinding. We evaluated a total of 49 studies including 127 different comparisons. Most comparisons involved a group with DS vs. a group with typical development matched on mental age and compared on a task measuring one of the five visuo-spatial abilities. Although further research is needed for firm conclusions on some visuo-spatial abilities, there was no evidence that visuo-spatial ability is a strength in DS relative to general cognitive ability. Rather, the review suggests an uneven profile of visuo-spatial abilities in DS in which some abilities are commensurate with general cognitive ability level, and others are below.

Keywords

visuo-spatial ability; Down syndrome; spatial memory; mental rotation; visuo-spatial construction; closure; wayfinding; review

1. Introduction

Down syndrome (DS) is the most common genetic cause of intellectual disability, occurring in approximately 1 in 691 US live births (Parker et al., 2010). Caused by all or part of an

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extra 21 chromosome, it is typically associated with mild to severe intellectual disability. However, DS is associated with uneven cognitive abilities and researchers have sought to describe a DS cognitive phenotype. One of the key features of the cognitive phenotype is good visuo-spatial ability relative to verbal ability (see Chapman & Hesketh, 2000; Davis, 2008; Moldavsky, Lev, & Lerman-Sagie, 2001; Silverman, 2007 for reviews). Visuo-spatial ability is the ability to process visual information that involves spatial relations, whereas verbal ability is the ability to process information that involves words and speech sounds. For example, young people with DS perform better on short term memory tasks when recalling visuo-spatial information such as sequences of block locations than when recalling verbal information such as sequences of digits or words (e.g., Jarrold & Baddeley 1997). Having a relative strength in visuo-spatial ability would be a clear advantage in certain aspects of life. It would make it easier to understand left from right, tie one's shoes, catch a ball, organize a desk or closet, or find one's way home from school or work. For those with DS, in many realms visual approaches may be more successful than verbal approaches. Indeed, visual approaches to reading and memory improvement have been promoted for this reason (e.g., Buckley, 1995; Duarte, Covre, Braga, & Macedo, 2011; Freeman & Hodapp, 2000; Hodapp & Ly, 2003). In fact, visuo-spatial ability is commonly referred to as an area of strength in DS.

1.1. Rationale

Much of the research that established visuo-spatial ability as a relative strength in DS, however, contrasted it with verbal ability. Because language is uniquely affected by DS (Abbeduto, Warren, & Conners, 2007; Silverman, 2007), verbal performance tends to be especially poor – below the level of general cognitive ability. With the exception of receptive vocabulary, people with DS typically demonstrate much poorer performance in language domains such as grammar, verbal short-term memory and, speech production than mental age matched control groups (Abbeduto et al., 2006; Caselli et al., 1998; Chapman, Schwartz, & Kay-Raining Bird, 1991; Laws & Bishop, 2003, 2004; Lemons, & Fuchs, 2010; for reviews, see Conners, Moore, Loveall, & Merrill, 2011; Kent, & Vorperian, 2013; Næss, Halaas Lyster, Hulme, & Melby-Lerväg, 2011). Thus, it is possible for visuo-spatial performance to be better than verbal performance, but still not particularly strong. Other research that identified visuo-spatial ability as a strength in DS compared participants with DS against those with Williams syndrome (WS). But visuo-spatial ability is uniquely affected by WS (Farran & Jarrold, 2003; Jarrold, Baddeley, & Hewes, 1999; Wang & Bellugi, 1994). Thus, it is possible for visuo-spatial ability in DS to be better than in WS, but still not particularly strong. The purpose of the present review is to evaluate how strong visuo-spatial ability is in DS in relation to general cognitive ability.

The current assertion that there is a relative strength in visuo-spatial ability in DS is based on a small number of tasks, particularly the Corsi block span task. However, growing evidence suggests there actually may be deficits on other visuo-spatial tasks (e.g., Hodapp, Leckman, Dykens, & Sparrow, Zelinsky, & Ort, 1992; Lanfranchi, Cornoldi, & Vianello, 2004; Pennington, Moon, Edgin, Stedron, & Nadel, 2003). Just as there are peaks and troughs within the verbal domain in DS, there very well may be peaks and troughs within the visuo-spatial domain. Thus, in the present review, we examine several aspects of visuo-spatial ability in individuals with DS to evaluate the strengths (or weaknesses) of these different aspects.

1.2. Identifying Visuo-spatial Abilities

Most researchers view visuo-spatial ability as an amalgam of several correlated factors (see Hegarty & Waller, 2005). It refers to “the ability to generate, retain, retrieve, and transform well-structured visual images” (Lohman, 1996). After an extensive literature review, Lohman, Pellegrino, Alderton, and Regian (1987) identified ten spatial factors - visualization, spatial orientation, flexibility of closure, closure speed, spatial relations, spatial scanning, perceptual speed, serial integration, visual memory, and kinesthetic. After factor analysis, Carroll (1993) identified five spatial factors - visualization, spatial relations, closure flexibility, closure speed, and perceptual speed. Spatial memory was considered separately in Carroll's taxonomy. To arrive at a set of abilities to include in the present paper, we collapsed similar abilities across Lohman's and Carroll's taxonomies and then deleted any factors that have not yet been researched in DS. This gave us four distinct visuo-spatial abilities – (1) visuo-spatial memory, (2) visuo-spatial construction, (3) mental rotation, and (4) closure. We added a fifth ability – (5) wayfinding - that appears in neither taxonomy but has been researched in DS.

Thus, the first four factors are very similar to factors that Lohman et al. and Carroll described. *Visuo-spatial memory* refers to the ability to retrieve information about objects or aspects of objects in relation to each other in space and to retrieve the locations of objects. *Visuo-spatial construction* (similar to what Lohman et al. and Carroll called visualization) refers to the ability to see parts of an object and then reconstruct the original entity based on the interpretations of the parts. *Mental rotation* refers to the ability to rotate mental representations of two and three dimensional shapes. *Closure* refers to the ability to process partial information into large wholes and to deconstruct whole objects into parts. The last factor, *wayfinding*, though not part of either Lohman's or Carroll's taxonomy, is an emerging topic in the DS literature and has important real life application. It refers to the process of determining and/or following a route from an origin to a destination. For each of these five types of visuo-spatial ability, we reviewed the empirical literature to determine whether some or all of them can be considered strengths in DS relative to their general cognitive ability.

1.3. Defining “Relative Strength”

As we have already implied, “relative strength” can be defined in different ways. It can be defined in relation to a different ability (e.g., verbal ability) within the same group of participants, or in relation to the same ability in another group of participants (e.g., WS). In the present paper, we are most interested in strength relative to one's general cognitive functioning level. There are several different types of comparisons that can be made to assess this type of relative strength. First, standard scores on spatial measures from norm-referenced tests can be compared with standard scores on general cognition (i.e., IQ) measures. One limitation of this comparison is that it requires that the visuo-spatial measure be norm-referenced and standardized, preferably on the same standardization sample as the IQ measure.

Second, for measures that are not norm-referenced and standardized, scores can be compared across groups that are similar in general cognitive functioning level. The group with DS can be compared with a group that is typically developing (TD) and performing cognitively at the same general level (i.e., mental age or MA-match design). A drawback to this type of comparison is that the group with DS will always have a higher mean *chronological* age (CA) than the typically developing group. If CA or experience in DS affords any advantage on visuo-spatial tasks, this makes interpretation of strengths complex, with the age/experience factor pulling in favor of the group with DS performing better. Alternately, the group with DS can be compared with a group that also has intellectual disability (but not DS), is similar in CA, and is performing at the same general cognitive level. The composition of the comparison group, however, is important, as it would have to rule out etiologies with known spatial impairments (e.g., WS). Possibly, the best such comparison group is one that is representative of ID in terms of etiology, and not specific to any one etiology. Finally, some designs allow for mismatching of groups but statistically covary the influence of MA and/or CA.

We included any of these types of comparisons in the present review. We excluded CA-match designs, which compare a group with DS against a TD group of the same CA. Although informative in some contexts (e.g., Atwell, Conners, & Merrill, 2003), by virtue of their lower IQ and general developmental level, the group with DS will almost always perform more poorly than the CA-match group on spatial tasks.

To evaluate a potential strength in DS relative to general cognitive level is not straightforward. General cognitive ability is often measured in terms of age-equivalence scores from comprehensive IQ tests (i.e., general MA from *Wechsler Intelligence Scale for Children* or WISC, *Stanford Binet*, *Kaufman Assessment Battery for Children* or K-ABC, etc.). However, to the extent that visuo-spatial ability is part of the measurement of general MA, using this index as a baseline for comparison is conservative and would bias toward visuo-spatial ability being consistent with general cognitive ability. On the other hand, verbal skills are also part of the measurement of general MA. To the extent that deficits in the verbal domain in DS depress general MA, the comparison would be liberal, biasing toward finding higher visuo-spatial ability compared to general MA. These two biasing influences may or may not cancel each other out; thus there is some uncertainty about the impact of using general MA as a basis of comparison. Other options are to use nonverbal-only ability measures or verbal-only ability measures as the basis of comparison. Each method has obvious disadvantages, with nonverbal-only measures biasing toward visuo-spatial ability being similar to the comparison measure or group, and verbal-only measures biasing toward visuo-spatial ability being higher than the comparison measure or group. In the DS literature, it is common to use receptive vocabulary as a basis of comparison for several types of abilities (e.g, Peabody Picture Vocabulary Test or PPVT, or British Picture Vocabulary Test or BPVT). Although receptive vocabulary is in the verbal domain, it is not as impaired in DS as are other verbal abilities such as receptive grammar and expressive vocabulary (Næss et al., 2011). Thus, as a matching variable, it is preferable to a more comprehensive verbal ability measure (Phillips, Loveall, Channell, & Conners, 2014). Still, it may be the case that receptive vocabulary biases for finding a relative strength in visuo-spatial abilities in DS. In the present review, we included a wide variety of indexes of cognitive ability so that we could judge the degree to which the exact index used influenced the outcome of the comparison.

2. Method

We conducted a systematic search of the PsychInfo database for articles published between January 1987 and May 2013. In the first step of the search we used the terms *Down syndrome* and *spatial*. In the second step we replaced the term *spatial* with other specific spatial factor names that had been used by Carroll and Lohman et al. such as *spatial visualization*, *spatial relations*, *closure speed*, *closure flexibility*, *spatial orientation*, spatial scanning, perceptual speed, serial integration, kinesthetic, and *spatial memory*. In the third step, we replaced the spatial factor names with specific task names associated with each factor using terms such as *block design*, *mental rotation*, *wayfinding*, *navigation*, *Gestalt closure*, *form board*, *paper folding*, *cube comparisons*, *snowy pictures*, *hidden figures*, identical pictures, rod and frame task, water-level task, etc. Finally, we used GoogleScholar when searching for specific spatial factors and/or their corresponding tasks if they did not yield any relevant results in PsychInfo. We included journal articles, dissertations, and theses, but not books or book chapters. This process yielded over 200 articles.

To arrive at a set of studies to review for the present paper we then excluded duplicates, articles that did not address visuo-spatial abilities in people with DS, articles that did not have any relevant comparison groups or within-group comparisons, and articles that investigated very young children (age 1-3). We did not exclude articles that provided indirect statistical comparisons (e.g., a complex MANOVA including but not limited to spatial measures), as long as enough information was provided in the report to allow us to compute t-tests.

There were 49 articles in the final set to be included in the present review. Many of these included a TD comparison group, but others included a comparison group with mixed-etiology ID or idiopathic ID (both hereafter referred to as ID), or another specific etiology of ID such as WS or fragile X syndrome (FXS). Many studies had more than one relevant comparison group (e.g., DS compared to both TD and ID) or presented comparisons within subgroups (e.g., DS compared to TD within male and female subgroups separately). We included all of these comparisons in the review. Some studies included comparison groups that, though important to those studies, were not directly relevant to the present review (e.g., DS compared to specific language impairment, autism, or siblings), and we did not include these specific comparisons in our review. Many studies included more than one visuo-spatial ability (e.g., visuo-spatial construction and spatial working memory), some included more than one measure of a particular visuo-spatial ability (e.g., two different spatial working memory tasks), and some included more than one measure from a single task (e.g., recognition and recall) or the same measure under more than one stimulus condition (e.g., abstract pictures vs. meaningful pictures). Across the 49 studies, we included 127 different comparisons. In the sections that follow we discuss the collective results of these studies, grouped into the five different types of visuo-spatial ability represented.

3. Results

3.1. Visuo-spatial memory

Visuo-spatial memory refers to the ability to retrieve information about objects or aspects of objects in relation to each other in space and to retrieve the locations of objects. Spatial memory represents the largest portion of the literature on visuo-spatial ability in DS. For the present review we have grouped studies on spatial memory into four sets—spatial sequential memory, spatial simultaneous memory, memory for location, and spatial working memory.

3.1.1. Spatial sequential memory: Corsi Block task—Spatial sequential memory refers to memory for the order of spatial information that has been presented in temporally sequential order. A good example of a spatial sequential memory task is the Corsi block task (Corsi, 1972; Milner, 1971). In this task, the examiner shows the participant a set of identical blocks, laid out in a random spatial array. The examiner then taps a sequence of blocks, approximately one per second, and the participant immediately attempts to tap the same blocks in the same order. Typically, the sequence of blocks starts off short (e.g., 2 blocks) and increases until a discontinue criterion is met. In computerized variations of the task, the blocks may be replaced by stepping stones or lily pads, with a cartoon character hopping across a path. The Corsi block task is by far the most commonly used visuo-spatial task in the DS literature, with 29 studies in the present review including this task or a similar one (see Table 1). Nearly all of the tasks listed in Table 1 involve sequential presentation of spatial information followed by sequential recall of that information, with order recall an important aspect of the task. However, in few tasks, retrieval was scored without regard to order (Carretti, Lanfranchi, & Mammarella, 2013).

Not only are the Corsi block task studies the most numerous in the DS visuo-spatial literature, they also provide the most consistent results. In the present review, there were 17 studies making 24 comparisons between groups with DS and MA-matched TD groups on Corsi-type tasks. Of the 24 comparisons, 20 showed no significant group difference. These comparisons were based on a variety of different group matching measures (general cognitive ability, receptive vocabulary, reasoning skill) with mean MA ranging from 4-7 years across studies. There were also several variations of the Corsi block task. Thus, in general, the research suggests that spatial sequential memory in DS is largely consistent with overall cognitive ability level when compared with MA-matched TD counterparts. Note that this empirical evidence is *not* consistent with spatial ability being a strength relative to general cognitive ability.

Four comparisons, however, showed differences in Corsi block performance between the group with DS and the TD group. Contrary to the visuo-spatial ability strength hypothesis, in three of the four comparisons the group with DS performed more poorly than the TD group (Duarte et al., 2011; Vicari, Bellucci, & Carlesimo, 2006; Vicari et al., 2004), though in one of these (Vicari et al., 2006) the group difference disappeared when visuo-spatial perceptual ability was covaried out. Each of these comparisons was based on a general cognitive ability matching variable (MA from WISC-III, Wechsler, 2002; WAIS-III, Wechsler, 2004; or Stanford Binet, Bozzo, & Mansueto Zecca, 1993). Duarte and colleagues (2011) included two TD comparison groups – one matched on general MA (from WISC-II and WISC-III) and the other matched on receptive vocabulary (from PPVT, Dunn & Dunn, 1997). Although the group with DS performed more poorly than the group matched on general cognitive ability, these participants performed similarly to those matched on receptive vocabulary. The single study reporting better Corsi block performance in the DS group than in the TD group (Laws, 2002) also matched on receptive vocabulary. With only one comparison out of 24 reporting better performance in the group with DS, spatial sequential memory cannot be considered a strength in DS relative to general cognitive ability. With only three comparisons reporting poorer performance in the group with DS, it cannot be considered a relative weakness either.

However, a study by Frenkel and Bourdin (2009) presented an interesting nuance. In this study the researchers performed a multiple regression analysis using Group (DS vs. TD), MA (from the K-ABC; Kaufman & Kaufman, 1993), and Group x MA as predictors of Corsi block performance. There was no main effect for Group, but there was both a main effect for MA and a Group x MA interaction. When plotted, the interaction showed that, at the lowest MA (approx. 3 years) individuals with DS outperformed TD children. But TD children's performance increased more rapidly with increasing MA, closing the gap. At the highest MA (approx. 8.5 years) children with TD outperformed individuals with DS. A slower developmental trajectory of spatial sequential memory in DS compared to typical development may mean that, though most study outcomes show comparable means, they may depend on the mean MA of the sample. In the studies we reviewed, most MA means were between 4 and 6 years corresponding to the midrange of Frenkel and Bourdin's (2009) trajectory. Further research focusing on developmental trajectories is needed to clarify this issue.

A smaller set of studies compared Corsi Block performance of groups with DS with that of groups with other ID etiologies. These studies matched on an MA measure or on a combination of age and IQ or used covariation techniques to control for these factors. Results of these studies suggest that groups with DS performed similarly in spatial sequential memory to groups with ID of unknown or mixed causes (Jarrold, & Baddeley, 1997; Jarrold et al., 1999; Jarrold, Baddeley, & Phillips, 2002; Numminen, Service, Ahonen, & Ruoppila, 2001; Rowe, Lavender, & Turk, 2006; Vicari, Carlesimo, & Caltagirone, 1995). However, they performed better than groups with WS and FXS (Crowe & Hay, 1990; Edgin, Pennington, & Mervis, 2010; Jarrold et al., 1999; Wang & Bellugi, 1994; but see Klein & Mervis, 1999; Vicari et al., 2004). Due to the known visuo-spatial impairment in WS, we expect the group with DS to outperform them; less is known about visuo-spatial abilities in FXS. Thus, these studies are consistent with the TD comparison studies in suggesting that spatial sequential memory is consistent with general ability level in DS.

3.1.2. Spatial simultaneous memory: Pattern recall task

Spatial simultaneous memory refers to memory for spatial information that has been presented simultaneously and can be retrieved in any convenient order. A good example of a simultaneous memory task is pattern recall (e.g., Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999). In the standard pattern recall task, participants see a matrix in which some of the squares are filled with a target color while the other squares are blank or with a different color. After a brief exposure to this matrix (a few seconds or less), the colors disappear and participants immediately indicate which squares had appeared just before in the target color. Note that random patterns might be more suitable for studying spatial memory because structured patterns (e.g., that form a shape) can be influenced by verbal coding, for which participants with DS might be at a disadvantage.

Results from seven studies suggest that when groups are matched on various MA measures, pattern recall is not a strength for participants with DS (see Table 2). In three studies researchers found similar performance of participants with DS to participants with TD (Hick, Botting, & Conti-Ramsden, 2005; Lanfranchi et al., 2004) or to participants with ID (Numminen, et al., 2001) when matched on nonverbal ability. Three studies showed poorer performance by the DS group than by the TD group when matched on receptive vocabulary (Carretti & Lanfranchi, 2010; Lanfranchi, Carretti, et al., 2009) or general cognitive ability (Frenkel & Bourdin, 2009). One study that matched on receptive vocabulary showed similar performance between groups with DS and TD when the patterns were random, but poorer performance by the group with DS compared to the group with TD when the patterns were structured (Carretti, Lanfranchi, & Mammarella, 2013). It is possible that the nature of the matching variable in part determined the outcome of the study, with the nonverbal matching measures being the most likely to show pattern recall to be consistent with MA. However, studies using receptive vocabulary or general cognitive ability as the matching measure were also not consistent with the spatial strength prediction. Hence, regardless of matching variable, none of the studies reported better performance in the DS group than the TD group.

Interestingly, Lanfranchi and colleagues used the same task in two different studies and obtained different outcomes (Lanfranchi et al., 2004; Lanfranchi, Carretti, Spano, & Conoldi, 2009). Whereas Lanfranchi et al. (2004) found that the group with DS performed similarly to the TD group, Lanfranchi. Carretti, et al. (2009) found that the group with DS performed more poorly than the TD group. One possible explanation is that the former study used a nonverbal matching measure (Logical Operations; Vianello & Marin, 1997), whereas the latter study used a receptive vocabulary measure (PPVT). However, the mean MA was also lower in the former study than the latter study (4.5 vs. 6, respectively). Lanfranchi, Carretti, et al (2009) suggested that pattern recall may increase more slowly with growth in MA for individuals with DS compared to TD children. Thus, when matched at an MA of 4.5, both groups may be similar in pattern recall, but when matched at an MA of 6, participants with DS may perform more poorly than TD children. This interpretation suggests different developmental trajectories in DS and TD groups, though this was not tested directly in either of the Lanfranchi studies.

Two studies did examine developmental trajectories of pattern recall tasks in groups with DS and TD. In a longitudinal study (Hick et al., 2005), participants saw pattern displays in which half of the cells were occupied by identical sharks. At the first time of testing, participants with DS and MA-matched TD participants were at 4.5 and 4.3 years of nonverbal MA, respectively, as measured by the Leiter International Performance Test-Revised (Leiter, 1969). Although participants with DS did not differ as a group from their TD counterparts at the first testing point, their disadvantage in pattern recall became prominent when retested 6 months and 12 months later. However, at the two retests the groups were no longer matched on MA. Frenkel and Bourdin's (2009) cross-sectional developmental trajectory analysis, mentioned earlier in the spatial sequential memory section, included a pattern recall test. In their version of the task, after the pattern matrix was presented, a second pattern matrix was presented, with one previously filled cell now unfilled. Participants pointed to the cell that changed. As for other pattern recall tasks, participants needed to process the entire pattern in a brief time (e.g., 2 seconds); however, their response reduced the demand on memory because they only pointed to one square rather than two or three squares. As a group, participants with DS detected fewer locations correctly compared with their MA-matched TD counterparts (matched on general MA). Although there was also a main effect of MA, there was no Group x MA interaction. Thus, contrary to the suggestion of Lanfranchi, Carretti, et al. (2009), the two groups showed similar rates of progress in pattern recall performance with the increase of MA. However, it is worth noting that the task in Frenkel and Bourdin's study was slightly different from that in other pattern studies. Regardless, to date there is no empirical evidence of a slower developmental trajectory over MA in DS compared to TD and the present evidence suggests that for those with DS, pattern recall is either consistent with or lower than developmental level, but not higher.

3.1.3. Memory for locations—Location memory tasks require participants to view a set of different items and some time later (a few minutes or more) to recall the spatial locations of those items. These tasks are different from pattern recall tasks in which participants view a matrix of filled and unfilled cells for just a few seconds and immediately report the filled cells. Location information is often encoded automatically, without intention (Hasher & Zacks, 1979), and in many location memory tasks participants are not informed that they will be tested on the location of items until the time of the test. For example, Ellis, Woodley-Zanthos, and Dulaney (1989) showed participants 15 pages, each displaying four different pictures. After the participants had viewed all 60 pictures, they were shown each picture and asked to say which quadrant of the page it had appeared in earlier. Participants with DS performed below the level of their chronological age peers (see also Dulaney, Raz, & Devine, 1996; Munir, Cornish & Wilding, 2000; Simon, Watson, & Elliott, 2005).

More relevant to the present review, however, are the studies that compared participants with DS to TD participants of similar MA, or to participants with other forms of ID of similar age and IQ (see Table 3). Two studies made MA-match comparisons between groups with DS and TD groups on location memory measures. Contrary to the visuo-spatial strength hypothesis, the group with DS did not outperform the TD group in either of these studies. When common pictures were used, both studies showed that the two groups were similar in location memory (Vicari, Bellucci, & Carlesimo, 2005; Zucco, Tessari, & Soresi, 1995). Zucco et al. (1995) also compared groups using different types of stimuli – “nonsense” pictures, concrete words, and abstract words. For these types of stimuli, participants with DS performed more poorly than TD participants. Also, two studies compared groups with DS against groups with ID, both finding no difference between groups (Dulaney, et al., 1996; Simon, et al., 2005). Although in Dulaney et al. the exact IQ matching measure was not reported and in Simon et al. groups were not well matched (on receptive vocabulary), the results of these studies are consistent with those of the TD match studies, indicating no particular strength in location memory for participants with DS.

A somewhat different way of measuring location memory is to show an array of pictures that are randomly placed on a page, take it away, and ask participants to locate each picture on a blank page. The Spatial Memory subtest of the K-ABC is such a task (Kaufman & Kaufman, 2004). In this task, participants are told explicitly to try to remember the locations of pictures and recall where the pictures were after a few seconds. The number of locations they had to recall increases across trials. This task might be more difficult than the tasks in the studies discussed above because there are more stimuli to view at one time, more possible locations, and less spatial structure for guidance. On the other hand, participants know that they will be asked to recall the location and there is less time between encoding and retrieval.

Four different studies in our review compared performance on this task between a group with DS and an MA-matched group. Participants with DS performed more poorly than MA-matched TD participants (Cornish, Munir, & Cross, 1999; 2001; Munir, Cornish, & Wilding, 2000) and similarly to MA-matched participants with ID (Hodapp, et al., 1992). Results in comparison to participants with FXS were mixed, with two studies showing similar performance in the two groups (Cornish et al., 2001; Hodapp et al., 1992), one showing better performance by the group with DS (Munir et al., 2000), and one showing better performance by the group with FXS (Cornish et al., 1999). Overall, the evidence suggests that spatial location memory is either consistent with or lower than developmental level in DS.

3.1.4. Spatial working memory—Working memory refers to a memory system that maintains and manipulates information in order to process complex thought and learning (Baddeley & Jarrold, 2007). Thus, the present section of our review focuses on studies that used spatial working memory tasks that required both storage and processing of spatial information. In total, 18 comparisons from 10 separate studies were included (see Table 4).

One of the simplest measures of spatial working memory is the backwards Corsi block task, in which participants view a sequence of blocks tapped by the experimenter, and then immediately tap it backwards. Compared to the forward Corsi block task, this requires not only storage of spatial sequential information, but also processing requirements associated with reversing the sequence. Using the backward version of the traditional Corsi block task, Vicari et al. (1995) found that participants with DS performed more poorly than TD participants matched on nonverbal MA. However, Lanfranchi and colleagues (2004) used a variation of this task in which a frog jumps across a chessboard and found no difference between groups with DS and TD matched on logical operations. Possibly, the frog-jumping task was more engaging than the traditional Corsi block task for participants with DS, and this is why they performed relatively better in the Lanfranchi et al. (2004) study. It could also be that a significant lag relative to MA occurs in youth with DS as MA increases, as Frenkel and Bourdin (2009) demonstrated for forward Corsi task performance. Lanfranchi's participants were about a year behind in developmental level compared to Vicari's. When compared with participants with WS, those with DS performed similarly (Edgin, Pennington, & Mervis, 2010).

Three studies used the CANTAB spatial working memory task (Fray, Robbins, & Sahakian, 1996). In this task, participants search among 3-8 colored boxes to locate a token. They touch each box to find out if the token is there. When touched, the box reveals its contents (if any), and then closes up again. During this process, participants are instructed not to return to the boxes they have already searched because tokens will not be in the same box more than once. This task thus requires participants to retain the spatial locations they have searched, update such information, and inhibit incorrect responses of searching the old locations. A common measure of spatial working memory from this task is the number of errors made by returning to previously searched locations. Fewer errors correspond to better spatial working memory. Pennington, and colleagues (2003) found no difference between the group with DS and TD counterparts matched on general MA. Using some of the same participants, Cardoso-Martins, Peterson, Olson, and Pennington (2009) also reported similar performance of participants with DS and general MA-matched TD participants, in separate sets of good and poor readers. In contrast, Visu-Petra, Benga, Ţincaş, and Miclea (2007) found that individuals with DS made more errors than TD children matched on general MA, indicating poorer spatial working memory in the DS group. However, the developmental level was slightly higher in Visu-Petra's study (MA 5.8 rather than MA 4.5 in Pennington et al., 2003). Such discrepant results could be another reflection of different developmental trajectories in DS group and TD group. This has yet to be tested directly.

In addition to the backwards Corsi block task and the CANTAB spatial working memory task, there are also other approaches to investigating spatial working memory. Lanfranchi and colleagues (2004) studied visuo-spatial working memory on a continuum of *control*. Those tasks that require more control are also those that place more demand on simultaneous storage and processing. One task on this continuum of control that requires more control than the basic Corsi block task is the backward Corsi block task derivative or *pathway backwards* task that Lanfranchi et al. (2004) labeled a medium-low control task. Next up in the continuum was *starting position selection* which the authors identified as a medium-high control task. In this task, participants were shown one or two frogs’ step-by-step paths through a 4 × 4 chessboard, and asked to remember the frog's starting position. The task began with one path with three steps and progressed to two paths each with four steps. Participants tried to remember the first position(s) of the path(s) while processing the rest of the path(s). Highest in the continuum of control was the *dual request selective task* (a high control task). This task was similar to *starting position selection* except that, in addition to remembering the starting position of the path, participants had to tap the table every time the frog jumped onto the red square.

Whereas Lanfranchi and colleagues (2004) found that their group with DS performed similarly to their TD group on the medium-low control task (*pathway backwards*), differences between groups began to emerge when higher level control tasks were used. In that same study, they found that their group with DS performed more poorly on the *starting position selection* task than did their TD group. However, this result was not replicated in two later studies where no difference between groups was found (Lanfranchi, Baddeley, Gathercole, & Vianello, 2012; Lanfranchi, Jerman, & Vianelli, 2009). The discrepancy could be attributable in part to different matching measures – both Lanfranchi, Jerman et al.

(2009) and Lanfranchi et al. (2012) matched on verbal measures (either receptive vocabulary or broader verbal skills from the Wechsler Preschool and Primary Scale of Intelligence or WPPSI; Wechsler, 1967), whereas Lanfranchi et al. (2004) matched on logical thinking. The verbal matching measures would be expected to produce the better relative outcome for the DS group on nonverbal tasks. Consistent with this possibility, Carney, Brown, and Henry (2013) found that their group with DS performed more poorly than their TD group on an "executive loaded" spatial working memory task that was structured similarly to the *starting position selection task* after controlling for general rather than verbal MA.

Interestingly, all four studies that employed the *dual request selective task* (Lanfranchi, et al., 2012; Lanfranchi et al., 2004; Lanfranchi, Jerman, Dal Pont, Alberti, & Vianello, 2010; Lanfranchi, Jerman et al., 2009) showed that the group with DS performed significantly more poorly than the TD group regardless of whether the matching measure was receptive vocabulary or nonverbal reasoning. In general the results across studies agree with Lanfranchi and colleagues' claim that the more control a working memory task requires, the more likely it is that participants with DS will show an impairment. In general the research on spatial working memory suggests that there might in fact be an impairment, particularly when processing demand is high.

3.1.5. Visuo-spatial memory summary—Spatial sequential memory appears to be consistent with general ability level, as indicated by studies using the Corsi block task. There is some evidence of a flatter trajectory of Corsi block performance over MA, compared with TD children in the 3 - 8.5 range of MA, with an advantage for DS over TD groups at lower MAs and a disadvantage at higher MAs (Frenkel & Bourdin, 2009). Both pattern recall and location memory appear to be either consistent with or lower than developmental level in DS. Spatial working memory is the most likely aspect of spatial memory to be impaired in DS, especially for tasks requiring a high level of cognitive control.

3.2. Visuo-spatial construction

Visuo-spatial construction refers to the ability to see parts of an object and then reconstruct the original entity based on the interpretations of the parts (see Mervis, Robinson, & Pani, 1999). One common visuo-spatial construction task is the block design subtest of the Wechsler IQ tests. We describe the research in DS using this and similar tasks in the following section. In addition, we include drawing tasks that measure the ability to construct or reproduce visuo-spatial relations.

3.2.1. Block Design and its derivatives—Block design is not only one form of visuo-spatial construction ability but also a task that reflects spatial visualization--the most general spatial factor according to Lohman et al. (1987) and Carroll (1993). To successfully accomplish block design, participants must mentally rotate some block objects/pictures and then rearrange them to make a predetermined pattern. Block design is incorporated as a subtest of many standardized tests including, for example, the Block Design subtest in the Wechsler Intelligence Scales (e.g., WISC-IV; Wechsler, 2003; WAIS-IV; Wechsler, 2008), the Pattern Analysis subtest in the Stanford Binet Intelligence Scales (Roid, 2003), the

Pattern Construction subtest in the Differential Ability Scale (DAS; Elliott 1990), and the Block Building subtest in the McCarthy Scales of Children's Abilities (MSCA; McCarthy, 1972). In the Wechsler Block Design subtest, for example, participants see blocks for which some sides are all white sides, some sides are all red, and some sides are half red and half white. They try to arrange from 2 to 9 blocks to form two-dimensional patterns that match the models given.

Nine studies making 16 comparisons on block design tasks between a group with DS and a comparison group were included in the present review (see Table 5). Five of these studies compared groups with DS and TD. Two reported no significant difference between groups, with one study matching on general MA (Vicari et al., 2004) and the other matching on receptive vocabulary (Lee, Pennington, & Keenan, 2010). Two found the group with DS performed more poorly than the TD group when matched on general MA (Bihrle, 1990) or receptive vocabulary (Cornish et al., 1999). The Bihrle (1990) study, however, did not report MA means or statistical comparisons for the groups with DS and TD, so it is unclear how well the groups were matched. In the Cornish et al. (1999) study, MA was a full year lower in the DS group than the TD group, though the authors reported that the difference in MA between groups was not significant. This difference may have disadvantaged the group with DS on the two block design tasks used in this study. The final study in this set showed that the group with DS performed better than the TD group (Lanfranchi, et al., 2012). Matching groups on receptive vocabulary, Lanfranchi and colleagues (2012) reported a very wide range of block design performance in the group with DS (1-18 years in MA units). The best conclusion might be that block design performance is fairly consistent with general cognitive ability level in DS.

However, as evidenced by the Lanfranchi et al. (2012) study, it seems that there may be more variability in block-design performance of participants with DS compared with TD participants. A group of Australian researchers assessed over 200 individuals with DS over 17 years using the subtests from Stanford-Binet Intelligence Scale, one of which is Pattern Analysis (Couzens, Cuskelly, & Haynes, 2011). The researchers found that among all the subtests (e.g., vocabulary, quantitative, bead memory, memory for sentences), the one with the largest within-group variance was Pattern Analysis.

There might also be differences between DS and other groups regarding the developmental trajectory of block design skill. Couzens and colleagues (2011) reported that the performance of participants with DS group grew rapidly from 4 to about 8 years old and then continued to grow gradually until adulthood (30yrs). By contrast, the performance of TD individuals begins to decline in the early adult years. In addition, cross-sectional results of Gibson, Groeneweg, Jerry, and Harris (1988) suggested that individuals with DS decline rapidly in Wechsler Block Design performance during the 4th decade, which was not the case for individuals with ID (see also Jozsvai, Kartakis, & Collings, 2002).

In addition to the studies that compared groups with DS to groups with TD, there were two comparisons between groups with DS and groups with ID (Hodapp, et al., 1992; Kittler, Krinsky-McHale, & Devenny, 2004) and two comparisons between groups with DS and groups with FXS (Cornish et al., 1999; Hodapp et al., 1992). None of these comparisons showed a significant difference between groups. Finally, four studies made comparisons between a group with DS and a group with WS, with all but one showing better performance in the group with DS than the group with WS (Bihrle, 1990; Edgin, Pennington, & Mervis, 2010; Klein & Mervis, 1999; Vicari et al., 2004). The one study showing no difference had floor effects for both groups (Bihrle, 1990). The better performance by participants with DS compared to participants with WS, however, can be attributed to the well-known impairment in visuo-spatial construction ability in WS (see Farran & Jarrold, 2003; Mervis & Klein-Tasman, 2000; Mervis et al., 1999 for reviews). Thus, the studies using block design and similar tasks do not argue strongly for a strength relative to mental age level in DS.

3.2.2. Figure-copying measures—Visuo-spatial construction abilities can also be studied in terms of how well participants reconstruct spatial relations or patterns by drawing. For instance, both the Test of Visual-Motor Integration (VMI, Beery, 1982; Beery, Buktenica, & Beery, 2010) and the Rey Complex Figure Test (Myers & Myers, 1995) require participants to copy drawings of geometric forms. The Rey test also includes a retention test. Compared to the block building measures of visuo-spatial construction, drawing tasks are more demanding in terms of fine motor control. The results from the available studies are not consistent (see Table 5). Vicari et al. (2004) found that individuals with DS scored similarly to general MA-matched TD individuals on the VMI but Dykens, Rosner, and Ly (2001) found that individuals with DS scored higher on the VMI relative to their own IQ as measured the Kaufman Brief Intelligence Test (Kaufman & Kaufman, 1990), and Carlesimo, Marotta, and Vicari (1997) found that participants with DS performed more poorly than general MA-matched participants on Rey's Figure Form B (both on copying and 15-minute delay measures). In a different type of drawing task, Laws and Lawrence (2001) asked participants with DS and TD participants matched for receptive vocabulary to draw a toy bear placed beside, inside, or behind a pot. Like Dykens et al. (2001) they also found that the group with DS performed well – they outperformed their TD peers. In comparison to individuals with ID, Carlesimo and colleagues found that participants with DS performed more poorly on the copy measure of the Rey's Figure Form B, but similarly on the recall measure. And as expected, the three studies that compared a group with DS to a group with WS on figure copying tasks all reported that the WS group performed more poorly (Klein & Mervis, 1999; Vicari et al., 2004; Wang, Dougherty, Rourke, & Bellugi, 1995).

Aside from the comparison to participants with WS, the figure copying results are mixed. Possibly the different findings have to do with the complexity of the experimental materials or the developmental level of the participants. The only study that reported any impairment in figure drawing (Carlesimo et al., 1997) used Rey's Figure Form B, which requires more complicated drawing skills than the VMI or the bear-and-pot tasks. The participants in this study also had an unusually high mean MA for a group with DS (mean 9.1 years), quite a bit higher than that in the other studies (most about 5 years). More research is necessary to determine whether visuo-spatial construction as measured by figure copying, is a strength in DS relative to general cognitive level or not.

3.3. Mental Rotation

Without a doubt, mental rotation is one of the most classic spatial abilities (Carroll, 1993; Lohman, et al., 1987). However, we found only three studies involving DS in our search and only two of them met our inclusion criteria (see Table 6). Possibly, the reason that mental rotation has not often been studied in DS is that it is a very complex spatial skill. Successful rotation strategies are not evident until 4-6 years in TD children (Estes, 1998; Frick, Daum, Walser, & Mast, 2009; Frick, Ferrara, & Newcombe, 2013), although the more basic ability of distinguishing between a figure and its mirror image is observed even in infants as indicated by measures of looking-time (Frick & Möhring, 2013; Moore & Johnson, 2011; Quinn, & Liben, 2008). In a typical mental rotation task the participant looks at an upright figure (e.g., a letter or a design) and then looks at the same figure rotated to different degrees. For each rotation trial, the participant indicates whether the figure is the same as the original or its mirror image. Most of the time, the task is speeded and reaction time (RT) corresponds with angle of rotation. More specifically, RT increases from upright to 180 degrees and then decreases from 180 degrees to 315 degrees (see Cooper & Shepard, 1973; Shepard & Metzler, 1971, for early demonstrations).

The first study of mental rotation by individuals with DS was done by Uecker, Obrzut, and Nadel (1994). Their participants with DS averaged only 3.1 years MA and had very low accuracy in deciding which side of a stick figure was holding a ball (overall 55%). The low accuracy made interpreting the reaction time data difficult. However, accuracy decreased with angle of rotation, a pattern that parallels that typically seen in reaction time. This is perhaps some evidence of mental rotation in DS. Though two comparison groups were included in this study, they were much higher in MA than the group with DS, and thus this study did not meet our inclusion criteria.

Two subsequent studies included participants with DS whose MA level was higher and who were matched on MA with TD comparison groups. Hinnell and Virji-Babul (2004) tested 7 participants with DS and 9 TD children matched on receptive vocabulary at a mean MA level of 8.2. In their mental rotation task, participants judged whether a rotated letter “F” was reversed or non-reversed. Individuals with DS made more errors than those with TD. However, statistically, both groups showed increased RT with increased angle of rotation, thus demonstrating the usual mental rotation pattern. There was no group effect for RT or group x angle interaction. With twice the sample size, Vicari, et al. (2006) also found similar performance on two different mental rotation tasks in groups with DS and TD matched on general MA. In this study both mental rotation tasks used multiple choice response formats, and therefore focused on accuracy rather than RT. Thus, the two MA-match studies on mental rotation of individuals with DS agree in showing performance commensurate with MA level. However, there are several reasons to be cautious in interpreting these studies’ results. Hinnell and Virji-Babul (2004) had a very small sample size, their participants with DS were unusually high-functioning, and they had only a small number of trials. Vicari et al. (2006) had a floor effect on one of the two tasks (the “Stick” task), and did not report data as a function of angle of rotation. Thus, more research is needed employing larger samples, including more representative participants with DS, and testing diverse versions of rotation tasks. Use of materials that are developmentally appropriate for people with intellectual disabilities (e.g., Stinton, Farran, & Courbois, 2008) will also be important if researchers are to understand mental rotation skills in DS.

3.4. Closure

Both Lohman et al. (1987) and Carroll (1993) referred to closure in their taxonomy of spatial abilities. Closure refers to the ability to process information into larger wholes and deconstruct larger wholes into smaller parts. One aspect of closure (closure speed) is the ability to interpret incomplete visuo-spatial information, or to perceptually “fill in” the gaps to find a whole, using information from long-term memory. The K-ABC Gestalt Closure subtest (Kaufman & Kaufman, 1983; 2004) is a good example of this aspect of closure. It requires examinees to look at partially completed pictures and name the objects or actions pictured. Another aspect of closure (closure flexibility) is the ability to break away from one whole to identify another smaller form within the whole. This aspect of closure is usually measured by tasks that require finding a simple figure within a complex figure or a small object within a larger scene. Because they are related conceptually we discuss them together here (see Table 7 for study results).

Three studies used the K-ABC Gestalt Closure subtest to compare participants with DS against MA-matched TD participants, with two of the three studies reporting poorer performance by participants with DS (Cornish et al., 1999; Pueschel, Gallagher, Zartler, & Pezzullo, 1987). Both of these studies matched groups on receptive vocabulary. The third study (Bihrle, 1990) reported no significant difference, but for this study it is unclear how good the DS-TD matching was. In addition to performing more poorly than TD participants in most studies, participants with DS also performed more poorly than participants with ID and FXS (Cornish et al., 1999; Hodapp et al., 1992). They performed similar to participants with WS, however, on K-ABC Getsalt Closure as well as two other closure speed tasks (Bihrle, 1990; Wang et al., 1995). Thus, the evidence is fairly strong for an impairment in closure speed in participants with DS, relative to their developmental level.

Closure flexibility was examined in five comparisons across three studies in our review. All comparisons showed poorer performance by the participants with DS. For example, Vicari et al. (2006) employed the Visual Perception Test – Subtest 4 (Hammill, Pearson, & Voress, 1993), in which participants first look at a geometric shape and then pick up the same shape from a group of other shapes that are overlapped with each other. They found that individuals with DS performed significantly more poorly than TD children matched on general MA. In a recent dissertation, Kuschner (2009) used both the Preschool Embedded Figures Test (Coates, 1972) and the Figure Ground Test from the Leiter-R (Roid & Miller, 1997). In the former task, children try to find a triangle in a picture (e.g., a rabbit holding a block with a triangle in it). In the latter task, children try to identify a specific object/shape in a context (e.g., hairbrush in a crowded garage). Children with DS performed more poorly than TD children on the Embedded Figures Test, with both nonverbal ability and receptive vocabulary covaried, though the difference fell just short of statistical significance ($p = .06$). Figure Ground Test performance was expressed as a deviation from overall nonverbal IQ. The group with DS had a mean deviation score that was negative, suggesting they performed below their nonverbal level as measured by overall Leiter performance. In contrast, the TD group showed the opposite pattern and the two groups were significantly different. Finally, Cornish et al. (2001) compared groups on how many restaurant symbols (fork and knife) they could find on a map in a prescribed time. The group with DS found fewer restaurant symbols than both groups with TD and with FXS. As a whole, it appears that individuals with DS demonstrated deficits in closure, with similar results from tasks measuring closure speed and closure flexibility.

3.5. Wayfinding

Although wayfinding was not included in either taxonomy proposed by Carroll (1993) or Lohman et al. (1987), we included it in the present review as a real-life application of visuo-spatial cognition. Wayfinding is a process of determining and following a route or path from an origin to a destination and is an outcome of a collection of skills such as route memory, landmark use, and survey knowledge (Wiener, Büchner, & Hölscher, 2009). Correlational studies have shown that wayfinding performance is positively, albeit somewhat weakly, associated with spatial memory (Nori, Grandicelli, & Giusberti, 2009; Taillade et al., 2013), mental rotation (Kozhevnikov, Motes, Rasch, & Blajenkova, 2006; Malinowski, 2001), and closure (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006; Kirasic, 2000; Meneghetti, Fiore, Borella, & De Beni, 2011). On the other hand, wayfinding, as a task on geographic large-scale environment, is also unique in its own form and distinguished from the four spatial abilities as reviewed here, which are mostly measured by psychometric tasks (for a review and discussion, see Allen, 1999; but see Hegarty et al., 2006). At the neurological level, spatial navigation has been closely linked to the hippocampus (Kolb, & Whishaw, 2009), which is known to be reduced in volume in DS as shown in both animal-model (Fernandez & Garner, 2008; Fernandez et al., 2007) and human studies (Pinter et al., 2001).

We found four behavioral studies that explored wayfinding skills in individuals with DS, and together they suggest a possible impairment (see Table 8). Pennington et al. (2003) and Edgin, Mason, et al. (2010) administered a computerized version of the Morris water maze task called Computer-Generated Arena (C-G Arena; Thomas, Hsu, Laurance, Nadel, & Jacobs, 2001) to a group of participants with DS and MA-matched TD children. The Morris water maze is commonly used to investigate spatial memory and navigation skills in rodents. A rodent is placed in a tank of water and swims around searching for a submerged platform that will allow them to escape from swimming. A landmark, or cue to the platform's location is placed outside of the water tank within view of the rodent. Of interest is how quickly and accurately the rodent can find the platform a second (or third) time after finding it through exploration the first time. In the C-G Arena used by Pennington et al. (2003) and Edgin, Mason, et al (2010), a target (i.e., a blue rug) is hidden on the floor of a circular arena that is set within a rectangular room. The walls of the room contain landmarks (e.g., door, picture frame, leaf, globe) to help participants orient and navigate. Participants use a joystick to move around the arena virtually in first person perspective, trying to find the target. At first the target is visible and participants move to the target. Then the target disappears, and participants must find the invisible target from memory. Participants completed five such trials, and in the fifth “probe” trial, the target was taken away unbeknownst to the participants, who were forced to continue looking for the target for the imposed 90 second time period (see Pennington, et al., 2003 for details). The percent of time the participant spent in the correct quadrant of the arena was the key measure used.

Pennington and colleagues (2003) found that participants with DS spent less time in the correct quadrant after initial learning relative their MA-matched TD counterparts. Using the exact same task, however, Edgin, Mason, et al. (2010) found no difference between DS and MA-matched TD groups. Both studies matched groups on general ability (DAS and KBIT-II, respectively), so the matching variable is probably not the explanation of the discrepant findings. In the Edgin, Mason, et al. (2010) study, the means for the groups with DS and TD were both at about chance (26.73% and 20.69% time in the correct quadrant, respectively), whereas in the Pennington et al. (2003) study, mean group performance was at chance only for the group with DS (17% vs. 30% for the TD group). Edgin, Mason, et al. (2010) suggested that their TD participants may have had more difficulty manipulating the joystick than their participants with DS, negatively impacting their performance to a level similar to that of participants with DS. A comparison of MA level across these studies is difficult because MAs were not reported for the reduced samples that were able to complete the task. In addition, the percent of time measure may be difficult to interpret - some participants might try creative solutions when they find out that the target is not where they know it to be, rather than keep searching the same location for 90 seconds.

Two other wayfinding studies used a different measurement paradigm, in which participants move through a set of virtual hallways to find a target. Benson's (2010) study included 16 landmarks and 8 choice points along the route. At each choice point, the participant could go left, right, or forward by pressing keys on the keyboard. Like the C-G Arena, participants viewed the environment from a first-person perspective. In the first run, participants were guided through the route by following the green lights at each choice point, and were told to remember the route. In the next run, participants were to follow the same the route on their own without the green lights. Benson (2010) reported that young adults with DS made significantly more errors when trying to reproduce the route relative to the nonverbal MA-matched TD children as well as young adults with mixed ID. However, the groups were not well matched on MA so this finding is difficult to interpret. Benson (2010) did report that the difference between groups with DS vs. ID was still significant after MA was covaried; however she did not report the same comparison for groups with DS vs TD.

Courbois and colleagues (2013) also examined route learning by participants with DS using a virtual environment. Their environment was a set of city blocks that included 3 buildings and 17 realistic landmarks (e.g., bench, road sign, traffic light), thus a more complex environment than the one used by Benson (2010). They showed each participant two routes in this environment (A→B and A→C, e.g., Railway Station→Store and Railway Station→Apartment Building) and gave them multiple trials to learn each path to a criterion of 3 times correct in a row. Participants with DS required more trials to learn the two routes compared to MA-matched TD participants, though the difference was only marginally significant. Those who learned the initial routes to criterion were then asked to find a new route (B→C, e.g., Store→Apartment Building). Although the participants with DS seemed less able to find a shortcut compared to TD participants, the difference was not significant. One limitation of this study is the very small sample size – only 10 per group reducing down to 7-9 per group for the new route test. With more power, the differences might have been statistically supported.

In addition to being small in number, the studies examining wayfinding abilities in DS are limited methodologically by floor effects, mismatched groups, and small sample sizes. Nevertheless, there are strong indications that wayfinding abilities might be particularly poor in individuals with DS. As this is an important skill for community inclusion, more research is warranted that resolves the methodological issues.

3.6. Summary of Results

We reviewed five domains of visuo-spatial abilities in DS – visuo-spatial memory, closure, visual-spatial construction, mental rotation, and wayfinding. There is no clear empirical support for a strength in any of these abilities relative to general cognitive ability. However, there is support for a profile of uneven visuo-spatial abilities across and within different aspects of visuo-spatial function. Specifically, spatial sequential memory seems to be commensurate with general ability level. Spatial simultaneous memory and memory for locations are either consistent with or lower than general cognitive ability. In contrast, spatial working memory may be a particular weakness in people with DS, especially with increased demand of cognitive control. Closure speed and closure flexibility also seem to be impaired in people with DS. Finally, for visuo-spatial construction, mental rotation and wayfinding the current evidence is mixed or/and insufficient, and only tentative conclusions can be drawn before more future investigation.

4. Discussion

4.1. Overview of findings

Researchers have commonly commented on the visuo-spatial strengths of individuals with DS. Indeed, relative to verbal abilities or to individuals with WS, there do appear to be visuo-spatial strengths in DS. However, the present review systematically analyzed whether visuo-spatial performance in people with DS is strong (or perhaps weak for some visuo-spatial abilities) relative to their general ability level. The task of evaluating whether people with DS perform above, at, or below their MA in a variety of visuo-spatial abilities proved to be challenging, for three main reasons. First, although many distinct visuo-spatial factors have been identified (Carroll, 1993; Lohman et al., 1987), the extant studies involving participants with DS are so unevenly distributed that several of these factors have not been researched at all. We could only address a portion of the possible visuo-spatial abilities, and at that, for some abilities conclusions are premature because the base of research is too thin. Second, studies of the same factors often have been approached in very different ways by different researchers. Third, many of the extant studies have their own methodological issues and matching concerns. Nevertheless, we attempted to synthesize and integrate these results based on careful evaluations of each study considering aspects such as the characteristics of the DS sample (e.g., sample size, CA, MA), the characteristics of the control sample, the specific matching variable, and the nature of the tasks.

At least two general conclusions can be drawn. First, contrary to the popular perception that people with DS are especially good at visuo-spatial skills, our review reveals that they actually show no particular “strength” in any visuo-spatial ability that has been researched in this population, relative to overall cognitive ability. Participants with DS do not consistently perform above the level expected for their general ability level on any of the visuo-spatial factors that have been studied. Instead, they perform either at or below the level of their younger MA-matched TD counterparts, in spite of any advantage they may have due to being chronologically older and in some ways more experienced. Second, DS is associated with an uneven profile across and within the different aspects of visuo-spatial function. There are both peaks and troughs within the visuo-spatial domain.

Overall, visuo-spatial memory seems to be a particularly weak area in DS (see also Conners, et al., 2011). In the present review, impairments were often found in spatial simultaneous memory where there are multiple to-be-learned locations within each single encounter, and also in location memory where these multiple locations are associated with objects with distinctive features, although occasionally differences were not found. The most significant weakness in spatial memory, however, is in spatial working memory, which requires actively updating, maintaining, and inhibiting spatial information. Weaknesses in spatial working memory are particularly apparent under a high processing load (e.g., Voyer, Voyer, & Bryden, 1995).

Although there are aspects of visuo-spatial memory that appear especially weak in DS, a clear exception is spatial sequential memory (as measured by the Corsi block task and its derivatives), which in general is commensurate with overall cognitive ability level. The Corsi block task is perhaps the simplest of the spatial memory tasks involving only one location at a time with object identity being irrelevant to the task. The processing load is rather low and the task is relatively simple. Perhaps it is for these reasons that spatial sequential memory is not as impaired as some other aspects of spatial memory. However, Frenkel and Bourdin (2009) showed that there may be very different developmental trajectories of spatial sequential memory for those with DS and those with TD. At very low MA (3 years) those with DS outperform those with TD; in the midrange (MA 4-6) the two groups perform similarly; and at higher MA (7-9) those with DS perform below those with TD. This intriguing finding should prompt future research examining developmental trajectories across many aspects of spatial abilities.

In addition to visuo-spatial memory per se, deficits may also occur in tasks that rely on visuo-spatial memory. For instance, in closure flexibility, people with DS did not perform as well as their MA matched peers. This may be because people with DS have difficulty actively maintaining the spatial relationships of the image while searching for the exact match. People with DS also have difficulty in closure speed, which requires the participants to retrieve information of the spatial image from long-term memory. These memory deficits are also consistent with the neurological evidence that people with DS have neuroanatomical and functional abnormalities in regions such as the medial temporal lobes and the prefrontal lobes, which support various memory processes (Beacher et al., 2010; Carducci et al., 2013; Jacola et al., 2011; Krasuski, Alexander, Horwitz, Rapoport, & Schapiro, 2002; Lorenzi &

Reeves, 2006; Menghini, Costanzo, & Vicari, 2011; Nelson, Orme, Osann, & Lott, 2001; Teipel et al., 2003).

In contrast to spatial memory, we do not have definitive conclusions regarding other spatial factors such as visuo-spatial construction, mental rotation and wayfinding due to the limited number of the studies on these topics. Visuo-spatial construction and mental rotation both reflect spatial visualization, which is the ability to understand and manipulate the structures of elements within a visual stimulus. The results of studies on visuo-spatial construction are rather mixed. Studies on mental rotation are not only scarce but they also have methodological flaws that need to be addressed. Hence, although the review of both of these domains implies a possibility that these spatial abilities are on par with developmental level in DS, more methodologically rigorous studies in these areas are needed before firm conclusions can be made.

The final spatial domain is wayfinding. The extant studies suggest that people with DS may perform more poorly than their general ability level in utilizing landmarks and establishing route/survey knowledge, Wayfinding encompasses a complex set of cognitive processes such as spatial memory, landmark usage, route integration, route planning and the coordination of these different processes. From a neurological perspective, the hippocampus is one of the most important contributors to navigation skills and the hippocampal regions have also been found to be affected in people with DS and the mouse model of DS (e.g., Carducci, et al., 2013; Fernandez & Garner, 2008; Fernandez et al., 2007; Lorenzi & Reeves, 2006; Menghini et al., 2011; Pinter et al., 2001). Thus, we also call for further research in wayfinding in DS. Not only is this an adaptive skill that allows for independence and integration, but also, it is quite possible it is significantly impaired in DS.

Taken as a whole, our current review of the spatial profile in people with DS may be a little bit surprising to some scholars. Many researchers (including ourselves prior to this review) assume people with DS have an advantage in the spatial domain. The rationale is simple: if two groups are matched on overall ability level and one group is poor in verbal ability (as is the case in DS), then this group should in turn be good in visuo-spatial ability. Otherwise, two groups would not be matched on overall ability level, which presumably is the combination of verbal and visuo-spatial abilities. Our review of the literature challenges this perspective and suggests that people with DS also have specific deficits in visuo-spatial processing in addition to verbal processing, though perhaps not to the same extent. Moreover, from a psychometric perspective, the notion that general ability as measured by standard IQ test is the composite of verbal and spatial abilities may be rather too simplified. An intelligence test may incorporate other abilities as well such as reasoning, attention, and memory, which do not belong specifically to either verbal or visuo-spatial domain. Yet, we are at present unaware of any specific cognitive abilities *of any kind* that appear strong relative to overall ability in DS. If there are many that appear weak, there must be some that appear strong. Future research will be necessary to sort this out.

4.2. Future Directions

Although research on development of visuo-spatial abilities is currently picking up pace (e.g., Huttenlocher, & Newcombe, 1984; Hegarty & Waller, 2005; Hyde et al., 2011;

Newcombe, 1982; Newcombe, & Sluzenski, 2004; Waller, & Nadel, 2013), there is still much to be learned about how infants and children acquire spatial representations and manipulate, interpret, and execute spatial information (e.g., Hermer, & Spelke, 1996; Newcombe, & Huttenlocher, 2006; Shutts, Ornkloo, von Hofsten, Keen, & Spelke, 2009; Spelke, von Hofsten, & Kestenbaum, 1989). Future well-structured basic research studies involving typically developing children would greatly benefit research in DS by laying the groundwork not only in theory but also in methodology. For example, there is a need for better designed wayfinding and mental rotation tasks for developmentally young individuals. Rather than directly borrowing tasks from the adult literature, employing developmentally sensitive measures is more likely to reveal the true capabilities of those with DS.

Our review highlights the paucity of research on visuo-spatial skills of people with DS. Further, the literature base is piecemeal, with measures of different spatial abilities coming from different studies. Large sample DS studies that include the wide variety of visuo-spatial abilities discussed by Lohman and colleagues (1987) and Carroll (1993) would be especially helpful in advancing knowledge on this topic. There are still several types of visuo-spatial abilities that have yet to be investigated in this population, such as spatial orientation (e.g. water-level task, rod and frame taks) and contextual cueing (Chun & Jiang, 1998). In addition, it would be beneficial for researchers to probe more deeply into certain aspects of spatial ability. For example, mental rotation studies could look into 3-dimensional rotation in addition to 2-dimensional rotation. Also, various aspects of wayfinding could also be further investigated in people with DS, such as route reversing, map usage, direction usage, route planning and wayfinding strategies.

Future studies should not only include more visuo-spatial topics, but also employ more sound methodologies. Most of the studies in the current review had fairly small sample sizes, many fewer than 15 participants per group, and most of the samples included a wide range of age. Considering the wide inter-individual variation in both general intelligence and domain-specific abilities (Couzens, Cuskelly, & Jobling, 2004; Silverman, 2007; Thomas, Annaz, Ansari, Scerif, Jarrold, & Karmiloff-Smith, 2009; Tsao, & Kindelberger, 2009), a larger sample that allows analysis in narrower age bands would be more generalizable and thus yield more reliable results (Klein & Mervis, 1999; Klein-Tasman, & Mervis, 2003). In addition, many researchers did not provide information regarding how well the group with DS and the control group were matched. To establish that two groups are equivalent on a matching variable requires more than showing that the groups are not significantly different from one another. More stringent standards have been recommended, such as requiring $p > .50$ as well as highly similar means and variances (Kover & Atwood, 2013; Mervis & Klein-Tasman, 2004). When groups are not well matched, results are more likely to be biased, with contradictory findings in a set of similar studies. There are also other issues that future studies should be aware of such as the different choice of matching variables (see Phillips, et al., 2014), which should align with purpose of the specific study.

As noted earlier in this paper, the field also needs more studies that examine developmental trajectories. Of course longitudinal studies are ideal, but not always possible. Cross-sectional studies are also very valuable (e.g., Frenkel & Bourdin, 2009; Thomas et al., 2009) and more expedient. Developmental trajectory analyses can help illustrate the course of visuo-spatial development in people with DS. For instance, Couzens and colleagues' (2011) longitudinal study suggested that people with DS showed the greatest variability in visuo-spatial construction among all the Stanford-Binet subscales. Frenkel and Bourdin's (2009) cross-sectional study on Corsi task and pattern recall illustrated an interesting contrast of the developmental trajectories between the DS and the TD groups for one but not the other task. Despite the emerging recognition of the importance of developmental trajectory analysis, however, there are in fact very few studies in the DS literature that have employed these methods. According to a recent review (Patterson, Rapsey, & Glue, 2013), from 1990 to 2011 only four studies have tested visuo-spatial processing in people with DS longitudinally (Chapman, Hesketh, & Kistler, 2002; Couzens et al., 2011; Hick et al., 2005; Laws, Buckley, Bird, & MacDonald, 1995). More studies that reveal the pattern of spatial development over a wide range of mental or chronological age would be tremendously helpful in furthering our understanding of cognitive development in those with DS.

4.3. Implications

We want to once again highlight the importance of studying spatial abilities in people with DS. Many adults with DS live in the community semi-independently with appropriate supports. Their ability to move freely and find their way in their environment depends in part on their visuo-spatial abilities. For example, those with adequate spatial abilities may be able to remember where things are kept, walk to the store or the bus stop, and follow a map. They would be less likely to get lost, but if lost, they would have a better chance of finding their way. In spite of their importance to independent living, however, visuo-spatial skills may never be explicitly taught to youth with DS in either regular or special education classrooms. According to a recent meta-analysis of typical developing children and adults, though, visuo-spatial skills are highly trainable and malleable (Uttal, Meadow, et al., 2013; see also Uttal, Miller, & Newcombe, 2013). Effective training in visuo-spatial processing can last for a relatively long period of time and can even be successfully transferred into other similar tasks. We also hope that this review will motivate more researchers in the field to investigate visuo-spatial competences in people with intellectual disabilities and ultimately improve their ability to live in the community.

4.4. Conclusion

We systematically reviewed empirical articles over the last 15 years on spatial abilities in people with DS. People with DS demonstrated uneven profiles across and within five different visuo-spatial abilities – visuo-spatial memory, visuo-spatial construction, closure, mental rotation and wayfinding. However, no visuo-spatial strength relative to mental age was found in any of these areas. We anticipate and hope that future studies will help unveil a more comprehensive profile of spatial abilities in people with DS.

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Highlights

Research on five visuo-spatial abilities in people with Down syndrome was reviewed.

Spatial sequential memory is commensurate with general ability in people with Down syndrome.

Spatial working memory and closure are particular weaknesses in people with Down syndrome.

Visuo-spatial construction and mental rotation results are mixed and inconclusive.

Wayfinding may be a particular weakness in people with Down syndrome.

Table 1

Studies comparing group with Down syndrome (DS) to MA-matched control group in spatial sequential memory

Authors and Year of Publication	Task	Matching					Results	Notes	Cohen's d
		Matching Measure	Group with DS		Comparison Group				
			Mean (SD)	N	Mean (SD)	N			
Brock & Jarrold, 2005	Corsi Derivative – Frog jumping on lily pads	BPVS-MA	7.1 (1.8)	26	7.4 (1.6)	33	DS=TD	BPVS scores were covaried in analyses.	NA[a]
Cardoso-Martins, Peterson, Olson, & Pennington, 2009	CANTAB Spatial Span	DAS	nr	6	nr	6	DS=TD-Good	DS and TD all compared among Good readers and Poor readers separately.	0.50
				7		7	DS=TD-Poor		0.71
Carretti, Lanfranchi, & Mammarella 2013	Look at a matrix with squares flashing on and off in sequence. Recall locations of filled cells without regard to order– Random patterns	PPVT-MA	5.2 (1.8)	20	5.1 (1.7)	20	DS=TD	Both all completed 2 versions of the task, one with random patterns and one with structured patterns.	NA
	Same task with structured patterns						DS = TD		NA
Crowe & Hay, 1990	Traditional Corsi block task	PPVT-MA & CA	7.1 (2.1)	8	8.6 (3.1)	8	DS>FXS	All participants were male. Also measured supraspan, same results.	0.91
Duarte, Covre, Braga, & de Macedo, 2011	Traditional Corsi block task	WISC IQ*CA/100	6.8 (2.4)	25	6.8 (0.7)	25	DS<TD	One group with DS was matched to 2 separate TD all – one on general MA and one on receptive vocabulary. Participants completed a traditional Corsi block task and a derivative.	−2.136[b]
		PPVT-Raw	51.1 (7.8)		49.3 (8.0)	25	DS=TD		−0.345[b]
	Corsi Derivative - 3 × 3 grid with pictures	WISC IQ*CA/100	6.8 (2.4)		6.8 (0.7)	25	DS=TD		−0.58[b]
		PPVT-Raw	51.1 (7.8)		49.3 (8.0)	25	DS=TD		0.56[b]
Edgin et al., 2010	CANTAB Spatial Span	KBIT-Raw	Verbal 26.4 (10.3) NonVerbal 13.7 (4.5)	55	Verbal 27.4 (5.5) Nonverbal 14.0 (3.4)	36	DS=TD	Of 74 DS tested, 8 could not complete this task; of those remaining, 33% performed at floor.	−0.26

Authors and Year of Publication	Task	Matching					Results	Notes	Cohen's d
		Matching Measure	Group with DS		Comparison Group				
			Mean (SD)	N	Mean (SD)	N			
Edgin, Pennington, & Mervis, 2010	Traditional Corsi block task	WASI IQ & CA	IQ 59.3 (6.1) CA 17.4 (2.9)	18	IQ 59.6 (6.2) CA 17.4 (3.2)	18	DS>WS		0.70
Frenkel & Bourdin, 2009	Traditional Corsi block task	K-ABC-MA	5.0 (1.5)	54	5.0 (1.5)	54	DS=TD	Also matched on sex and SES. Also included a trajectory analysis.	0.02
Jarrold & Baddeley, 1997	Corsi derivative – Monty Mouse popping out of holes in cheese	BPVS-MA	4.1 (1.0)	15	4.1 (0.9)	15	DS=TD		NA
					4.0 (1.0)	15	DS=ID		NA
Jarrold, Baddeley, & Hewes,1999 (Exp 1)	Corsi derivative – circles flashed on an off making a spatial sequence	No matching; covariate analyses instead	BPVS: 4.8 (1.5) NVMA: 4.3 (0.5)	25	BPVS: 6.9 (1.6) NVMA: 6.2 (2.6)	17	DS=ID	Results are with VMA and NVMA covaried. NVMA was based on DAS pattern construction	NA
					BPVS: 8.8 (3.8); NVMA 5.2 (1.7)	16	DS>WS		NA
Jarrold, Baddeley, & Phillips, 2002	Traditional Corsi block task	BPVS-MA	5.1 (1.3)	19	5.1 (1.3)	19	DS = TD+ID	A group with DS was matched to a TD group and a group with ID. Participants completed a traditional Corsi block task and a recognition version. DS was compared with the combined group of TD+ID	NA
					5.1 (1.3)	19			
	Corsi recognition	5.1 (1.3)		5.1 (1.3)	19	DS = TD+ID			NA
				5.1 (1.3)	19				
Klein & Mervis, 1999	McCarthy Tapping Sequences –sequences of keys on a xylophone	MSCA-MA	4.9 (nr)	13	4.9 (nr)	13	DS=WS	All participants were 9-10 years old.	−0.14
Lanfranchi, Carretti, Spano, & Cornoldi, 2009	Corsi Derivative, - Frog jumping on a 3×3 or 4×4 chessboard	PPVT-R-MA	6.0 (1.5)	34	5.8 (1.5)	34	DS=TD	All were matched on both PPVT and Raven CPM	NA
		Raven CPM-MA	5.8 (1.0)		5.5 (1.3)				
Lanfranchi, Cornoldi, & Vianello, 2004	Corsi Derivative - Frog jumping on a 3×3 or 4×4 chessboard	Logical Operation Test-MA	4.5 (0.6)	22	4.5 (nr)	22	DS=TD		0.11

Authors and Year of Publication	Task	Matching					Results	Notes	Cohen's d
		Matching Measure	Group with DS		Comparison Group				
			Mean (SD)	N	Mean (SD)	N			
Lanfranchi, Jerman, & Vianello, 2009	Corsi Derivative - Frog jumping on a 3×3 or 4×4 chessboard	PPVT-R-MA	4.1 (0.9)	20	4.1 (1.6)	20	DS=TD	One group with DS was matched with two different TD all – one on PPVT and one on WPPSI Verbal.	0.05[c]
		WPPSI Verbal-MA	4.3 (0.6)	4.5 (0.6)	20	DS=TD			0.05[c]
Laws (2002)	Traditional Corsi block task	BPVS-MA	4.0 (1.4)	16	4.0 (1.4)	16	DS>TD		1.43
Numminen, Service, Ahonen, & Ruoppila, 2001	Traditional Corsi block task	Raven CPM-MA	5.0 (1.4)	15	5.23 (1.1)	15	DS=ID		0.40
Pennington, Moon, Edgin, Stedron, & Nadel, 2003	CANTAB Spatial Span	DAS-MA	4.5 (nr)	28	4.5 (nr)	28	DS=TD		0.14
Rowe, Lavender, & Turk, 2006	WMS-III Spatial Span	BPVS-raw & CA	BPVS 14.5 (3.8) CA 33.3 (5.3)	26	BPVS 15.6 (4.1) CA 33.5 (9.7)	26	DS=ID		0.06
Vicari, Bellucci, & Carlesimo, 2006	Corsi Derivative – a shape appears sequentially in 2 or more locations on the screen. Then the locations appear and P must show the order in which they appeared.	Stanford-Binet-MA	5.2 (0.7)	18	5.2 (0.7)	18	DS<TD	Group difference eliminated when visuo-spatial perceptual factors were controlled.	NA
Vicari, Carlesimo & Caltagirone, 1995	Traditional Corsi block task	Leiter-MA	5.3 (1.2)	15	5.5 (1.8)	24	DS=TD		NA
					5.1 (1.3)	14	DS=ID		NA
Vicari et al, 2004	Traditional Corsi block task	Stanford-Binet-MA	5.2 (1.0)	56	5.4 (1.2)	46	DS<TD	Z scores were analyzed - computed using the mean and SD of the TD group. Also, IQ was covaried in analyses. Age breakdown (Study 2) suggested DS > WS in the young group (< 9 years)	between 0.44-1.1[c]
					5.2 (1.2)	69	DS=WS		NA between 0.44-1.1[c]

Authors and Year of Publication	Task	Matching					Results	Notes	Cohen's d
		Matching Measure	Group with DS		Comparison Group				
			Mean (SD)	N	Mean (SD)	N			
								but DS=WS in the older group (> 11 years) but DS=WS in the older group (> 11 years) but DS=WS in the older group (> 11 years)	
Visu-Petra, Benga, Tincas, & Miclea, 2007	CANTAB Spatial Span	Stanford-Binet-MA	5.8 (1.1)	25	5.2 (1.2) 5.5 (1.2)	69 25	DS=WS DS=TD	Also matched on CANTAB psychomotor speed & accuracy. The difference was marginally significant, with DS<TD	NA −0.56
Wang & Bellugi, 1994	Traditional Corsi block task	WISC IQ & CA	IQ 47.8 (7.6) CA 15.4 (4.5)	9	IQ 51.3 (7.1) CA 13.4 (2.1)	9	DS>WS		0.85

Note. MA = mental age; VMA = verbal mental age; NVMA = nonverbal mental age; nr = not reported; CA = chronological age; SD = standard deviation; TD = typically developing; FXS = fragile × syndrome; ID = intellectual disability; WS = Williams syndrome; CANTAB = Cambridge Neuropsychological Test Automated Battery; BPVS = British Picture Vocabulary Scale; DAS = Differential Ability Scales; PPVT = Peabody Picture Vocabulary Test; WISC = Wechsler Intelligence Scale for Children; KBIT = Kaufman Brief Intelligence Test; WASI = Wechsler Abbreviated Scale of Intelligence; K-ABC = Kaufman Assessment Battery for Children; MSCA = McCarthy Scales of Children's Abilities; Raven CPM = Raven Colored Progressive Matrices; WPPSI: Wechsler Preschool and Primary Scale of Intelligence; WMS = Wechsler Memory Scale. For Cohen's d, positive sign indicates DS group outperforms control group while negative sign indicates control group outperforms DS group.

[a] no adjusted means available

[b] converted from effect size r

[c] reported by author

Table 2

Studies comparing group with DS to MA-matched control group in spatial simultaneous memory

Authors and Year of Publication	Task	Matching					Results	Notes	Cohen's d
		Matching Measure	Group with DS		Comparison Group				
			Mean (SD)	N	Mean (SD)	N			
Carretti & Lanfranchi, 2010	Look at a matrix with some squares filled. Recall locations of filled cells – Random patterns	PPVT-MA	5.2 (1.2)	20	5.3 (1.3)	20	DS<=TD *p*=.051		0.54[a]
	Same task with structured patterns						DS<TD		1.88[a]
Carretti, Lanfranchi, & Mammarella 2013	Look at a matrix with some squares filled. Recall locations of filled cells–Random patterns	PPVT-MA	5.2 (1.8)	20	5.1 (1.7)	20	DS=TD		NA
	Same task with structured patterns						DS<TD		−0.93[b]
Frenkel and Bourdin, 2009	Look at a matrix with half the squares filled. Then look again. Find the filled square that is now unfilled	K-ABC-MA	5.0 (1.5)	54	5.0 (1.5)	54	DS<TD	All were also matched on sex and SES. Also included a developmental trajectory analysis	−0.40
Hick, Botting, & Conti-Ramsden, 2005	Look at a paper grid with half the squares filled with sharks. Recall the locations of the sharks	Leiter-MA	4.5 (0.5)	12	4.3 (0.5)	12	DS=TD	Results here are for Time 1 of this longitudinal study, when all were MA-matched.	−0.24
Lanfranchi, Carretti, Spano, & Cornoldi, 2009	Recall the locations of green cells in 3×3 or 4×4 chessboards.	PPVT-MA	6.0 (1.5)	15	5.8 (1.5)	20	DS<TD		0.49[a]
Lanfranchi, Cornoldi, & Vianello, 2004	Recall the locations of green cells in 3×3 or 4×4 chessboards.	Logical Operations Test-MA	4.5 (0.6)	22	4.5 (nr)	22	DS=TD		0.13
Numminen, Service, Ahonen, & Ruoppila, 2001	Recall the locations of filled cells in matrices.	Raven CPM-MA	5.0 (1.4)	15	5.23 (1.1)	15	DS=ID		−0.36

Note: MA = mental age; SD = standard deviation; nr = Not Reported; TD = typically developing; ID = intellectual disability; PPVT = Peabody Picture Vocabulary Test; K-ABC = Kaufman Assessment Battery for Children; Raven CPM = Raven Colored Progressive Matrices. For Cohen's d, positive sign indicates DS group outperforms control group while negative sign indicates control group outperforms DS group.

[a] reported by author

[b] converted from eta squared

Table 3

Studies comparing group with Down syndrome (DS) to MA-matched control group in location memory

Authors and Year of Publication	Task	Matching					Results	Notes	Cohen's d
		Matching Measure	Group with DS		Comparison Group				
			Mean (SD)	N	Mean (SD)	N			
Cornish, Munir, & Cross, 2001	K-ABC Spatial Memory	Verbal MA	nr	15	nr	15	DS<TD	Authors reported no significant difference in MA across all.	−2.29
					nr	15	DS=FXS		-0.82^a
Cornish, Munir, & Cross, 1999	K-ABC Spatial Memory	BPVS-MA	5.1 (1.2)	14	6.2 (1.4)	15	DS<TD	Authors reported no significant difference in MA across all. The researchers have also conducted analysis with MA covaried. Also included a TD-CA match, DS<CA	-1.90^b
					5.7 (0.9)	15	DS<FXS		-1.19^b
Dulaney, Raz, & Devine,1996	Look at 4 pictures located in 4 different quadrants on poster boards. After 25 poster boards of different pictures, recall the location of each picture.	IQ & CA	IQ 44.1 (10.4) CA 33.6 (6.8)	24	IQ 49.2 (9.3) CA 35.0 (6.3)	22	DS=ID	MA not reported. IQ test used was not reported. Also included a TD-CA match, DS<CA. Participants were tested twice in two days.	Day 1: 0.53; Day 2: 0.36
Hodapp, Leckman, Dykens, Sparrow, Zellnsk, & Ort, 1992	K-ABC Spatial Memory	K-ABC-MA	4.5 (nr)	10	4.8 (nr)	10	DS=ID	All participants were male. Also matched on age.	NA
					4.1 (nr)	10	DS=FXS		NA
Munir, Cornish, & Wilding, 2000	K-ABC Spatial Memory	BPVS-MA covaried	6.1 (1.5)	25	7.0 (1.4)	25	DS<TD	All participants were male. Also included a TD-CA match, DS<TD-CA.	−1.33
					6.8 (1.6)	25	DS>FX S		2.04
Simon, Watson, & Elliott, 2005	Look at a grid with 5 different objects in different locations. After each trial, recall the locations of the 5 objects.	PPVT-MA covaried	7.8 (1.3)	14	9.3 (1.4)	13	DS=ID	Also included a TD-CA match, DS<CA. Included 4 stimulus types (everyday objects, printed words, colored blocks, nonsense shapes) but did not report cross-group comparisons separately.	NA
Vicari, Bellucci, & Carlesimo, 2005	Look at sequentially presented pictures of 15 common objects. Then recall the location of each. Repeat 2 times.	Stanford-Binet-MA	5.3 (0.7)	15	CA proxy 5.5 (0.6)	15	DS=TD	Both all improved in the 2nd & 3rd trial over the 1st trial.	NA
Zucco, Tessari, & Soresi, 1995	Look at 16 pictures presented sequentially in one of 4 possible locations on a card. Recall the location of each picture.	WAIS-MA	11.6 (1.0)	15	11.5 (nr)	15	DS=TD	Both all were tested using 4 different stimuli. Overall DS<TD.	−0.57
	Same task using nonsense pictures						DS<TD		−1.54
	Same task using concrete words						DS<TD		−1.33

Authors and Year of Publication	Task	Matching					Results	Notes	Cohen's d
		Matching Measure	Group with DS		Comparison Group				
			Mean (SD)	N	Mean (SD)	N			
	Same task using abstract words						DS<TD		−0.89

Note: MA = mental age; CA = chronological age; SD = standard deviation; nr = Not Reported; TD = typically developing; FXS = fragile X syndrome; ID = intellectual disability; K-ABC = Kaufman Assessment Battery for Children; BPVS = British Picture Vocabulary Scale; PPVT = Peabody Picture Vocabulary Test; WAIS = Wechsler Adult Intelligence Scale. For Cohen's d, positive sign indicates DS group outperforms control group while negative sign indicates control group outperforms DS group.

[a] They used a Bonferroni correction of 0.005 alpha level. In this corrected alpha, DS and FXS do not differ

[b] based on original means – adjusted means were unavailable, but because all were still matched, the original means were meaningful as well.

Table 4

Studies comparing group with Down syndrome (DS) to MA-matched control group in spatial working memory

Authors and Year of Publication	Task	Matching					Results	Notes	Cohen's d
		Matching Measure	Group with DS		Comparison Group				
			Mean (SD)	N	Mean (SD)	N			
Carney, Brown & Henry, 2013	Modified Odd-One-Out test. Look at a row of abstract figures and identify the "odd one out." Then recall its location. Do this for 1 up to 4 rows.	Stanford Binet Abbrev.-MA	6.0 (2.6)	25	6.5 (1.2)	26	DS<TD	Also included a group with WS, but direct comparison was not made with the group with DS. MA & CA covaried.	NA[a]
Cardoso-Martins, Peterson, Olson, & Pennington, 2009	CANTAB Spatial Working Memory	DAS	nr	6	nr	6	DS=TD-Good	Some participants were from Pennington et al. (2003). DS and TD compared for Good readers and for Poor readers.	−0.44
				7	nr	7	DS=TD-Poor		0.69
Edgin, Pennington, & Mervis, 2010	Backward Traditional Corsi block task	WASI IQ & CA	IQ 59.3 (6.1) CA 17.4 (2.9)	18	IQ 59.6 (6.2) CA 17.4 (3.2)	18	DS=WS	11% of DS performed at floor on backward Corsi span, the same as WS participants.	0.22
Lanfranchi, Baddeley, Gatherocole, & Vianello, 2012	Recall the starting positions of a frog jumping on path(s) on a chessboard	PPVT-MA	5.3 (1.8)	45	5.3 (1.6)	45	DS=TD	A single group with DS was compared with a single TD group on 2 spatial working memory tasks.	0.1[b]
	Recall the starting positions of a frog jumping on path(s) on a chessboard, while tapping when the frog lands on a red square						DS<TD		0.5[b]
Lanfranchi, Cornoldi, & Vianello, 2004	Backward Corsi Derivative - frog jumping on a 3 × 3 or 4 × 4 chessboard	Logical Operation Test-MA	4.5 (0.6)	22	4.5 (nr)	22	DS=TD	A single group with DS was compared with a single TD group on 3 spatial working memory tasks.	−0.24
	Recall the starting positions of a frog jumping on path(s) on a chessboard						DS<TD		−0.68
	Recall the starting positions of a frog jumping on path(s) on a chessboard, while tapping when the frog lands on a red square						DS<TD		−0.86

Authors and Year of Publication	Task	Matching					Results	Notes	Cohen's d
		Matching Measure	Group with DS		Comparison Group				
			Mean (SD)	N	Mean (SD)	N			
Lanfranchi, Jerman, Dal Pont, Alberti, & Vianello, 2010	Recall the starting positions of a frog jumping on path(s) on a chessboard, while tapping when the frog lands on a red square	Logical Operation test-MA	5.8 (0.7)	15	5.8 (0.7)	15	DS<TD		−0.95
Lanfranchi, Jerman, & Vianello, 2009	Recall the starting positions of a frog jumping on path(s) on a chessboard	PPVT-MA	4.1 (1.6) 4.3 (0.6)	20	4.1 (1.6)	20 per group	DS=TD	A single group with DS was compared to 2 different TD all – one matched on PPVT and the other on WPPSI Verbal.	0.4
		WPPSI Verbal-MA			4.5 (0.6)		DS=TD		0.09
	Recall the starting positions of a frog jumping on path(s) on a chessboard, while tapping when the frog lands on a red square	PPVT-MA	4.8 (1.5)		4.1 (1.6)		DS<TD		−1.2
		WPPSI Verbal-MA	4.3 (0.6)		4.5 (0.6)		DS<TD		−1.0
Pennington, Moon, Edgin, Stedron, & Nadel, 2003	CANTAB Spatial Working Memory	DAS-MA	4.5 (nr)	28	4.5 (nr)	28	DS=TD		0.20
Vicari, Carlesimo & Caltagirone, (1995)	Backward Traditional Corsi block task	Leiter-MA	5.3 (1.2)	15	5.5 (1.8)	24	DS<TD		−0.96[c]
					5.1 (1.3)	14	DS<ID		−0.95[c]
Visu-Petra, Benga, Tincas, & Miclea, 2007	CANTAB Spatial Working Memory	Stanford-Binet-MA	5.8 (1.1)	25	5.5 (1.2)	25	DS<TD	Also matched on CANTAB psychomotor speed & accuracy.	−0.73

Note: MA = mental age; SD = standard deviation; TD = typically developing; nr = Not Reported; WS = Williams syndrome; ID = intellectual disability; CANTAB = Cambridge Neurolopsychological Test Automated Battery; DAS = Differential Ability Scales; WASI = Wechsler Abbreviated Scale of Intelligence; PPVT = Peabody Picture Vocabulary Test; WPPSI: Wechsler Preschool and Primary Scale of Intelligence. For Cohen's d, positive sign indicates DS group outperforms control group while negative sign indicates control group outperforms DS group.

[a] no adjusted means available

[b] reported by author

[c] converted from F test statistics.

Table 5

Studies comparing group with DS to MA-matched control group in visuo-spatial construction

Authors and Year of Publication	Task	Matching					Results	Notes	Cohen's d
		Matching Measure	Group with DS		Comparison Group				
			Mean (SD)	N	Mean (SD)	N			
Block Design Tasks									
Bihrle, 1990	WISC Block design	WISC MA for TD match; IQ & CA for WS match	MA not reported; IQ 53.4 (SD nr) Age 15.2 (SD nr)	10	Not reported but CA 7.4 (SD nr)	10	DS<TD	Unclear how good DS-TD matching was. DS constructed the outer square configurations well while WS constructed the inner configurations better. Also matched for sex; also included a CA match group, DS<CA. Floor effects were observed for DS and WS all.	NA
					IQ 53.7 (SD nr) CA 16.1 (SD nr)	10	DS=WS		NA
Cornish, Munir, & Cross, 1999	WISC Block Design	BPVS-MA	5.1 (1.2)	14	6.2 (1.4)	15	DS<TD	A single group with DS was compared on 2 different tasks with a single group with TD and a single group with FXS. Authors reported no significant difference in MA across all. The researchers have also conducted analysis with MA covaried. Also included a TD-CA match, for both tasks DS<CA	-2.91^a
					5.7 (0.9)	15	DS=FXS		-0.15^a
	K-ABC Triangles				6.2 (1.4)	15	DS<TD		-1.83^a
					5.7 (0.9)	15	DS=FXS		0.43^a
Edgin, Pennington, & Mervis, 2010	WISC Block design	WASI IQ & CA	IQ 59.3 (6.1) CA 17.4 (2.9)	18	IQ 59.6 (6.2) CA 17.4 (3.2)	18	DS>WS		0.85
Hodapp, Leckman, Dykens, Sparrow, Zellnsky, & Ort, 1992	K-ABC Triangles	K-ABC-MA	4.5 (nr)	10	4.8 (nr)	10	DS=ID	All participants were male. Also matched on age.	NA
					4.1 (nr)	10	DS=FXS		NA
Kittler, Krinsky-McHale, & Devenny, 2004	WISC Block Design	IQ & CA	Female IQ 51.6 CA 37.9	21	Female IQ 59.3 CA 40.5	Female 18	Female DS=ID	Participants were tested twice. Only Time 1 data are included here. Had to be 55 years or younger at Time 1 to be included.	0.39
			Male IQ 54.3 CA 40.3	21	Male IQ 59.4 CA 42.4	Male 10	Male DS=ID		−0.28

Authors and Year of Publication	Task	Matching					Results	Notes	Cohen's d
		Matching Measure	Group with DS		Comparison Group				
			Mean (SD)	N	Mean (SD)	N			
Klein & Mervis, 1999	MSCA Block Building - copy 4 block arrangements of increasing difficulty	MSCA-MA	4.9 (nr)	13	4.9 (nr)	13	DS>WS	Participants were also matched on age. All participants were 9-10 years old.	1.32
Lanfranchi, Baddeley, Gatherocole, & Vianello, 2012	WPPSI Block design	PPVT-MA	5.3 (1.8)	45	5.3 (1.6)	45	DS>TD		0.52
Lee, Pennington, & Keenan, 2010	DAS Pattern construction	PPVT-MA	7.0 (2.3)	18	7.0 (2.5)	18	DS=TD	Also matched on sex	−0.49
Vicari et al., 2004	WISC Block design	Stanford-Binet-MA	5.2 (1.0)	56	5.4 (1.2)	46	DS=TD	Z scores were analyzed - computed using the mean and SD of the TD group. Also, IQ was covaried in analyses. CA breakdown (Study 2) suggested DS=WS in the younger group (<9 years), DS>WS in the older group (>11 years).	NA
					5.2 (1.2)	69	DS>WS		NA[b]
Drawing Tasks									
Carlesimo, Marotta, & Vicari, 1997	Rey's Figure Form B – copy a figure; then recall it immediately and after 15 mins.	WISC or WAIS-MA	9.1 (2.5)	15	nr	30	DS<TD copy	Recall was adjusted for initial copying ability. Specific information about CA and MA of TD group not provided.	NA
							DS<TD recall		−0.854[c]
					9.7 (2.1)	15	DS<ID copy		−0.967[c]
							DS=ID recall		NA
Dykens, Rosner, & Ly, 2001	Test of Visual–Motor Integration (VMI) - copy drawings	KBIT-MA (not matched)	5.1 (1.3)	20	6.5 (1.7)	24	DS vs ID NA	Compared VMI standard score to IQ. For DS, VMI>IQ; for ID, VMI=IQ; for WS VMI<IQ	For DS, VMI > IQ, d=1.03 For ID, VMI=IQ, d=.35; for WS, VMI <IQ, d= −0.64
					6.5 (1.7)	19	DS vs WS NA		
Klein & Mervis, 1999	McCarthy Draw-A-Design – Copy 9 geometrical designs of increasing difficulty	MSCA-MA	4.9 (nr)	13	4.9 (nr)	13	DS>WS	Participants were also matched on age. All participants were 9-10 years old.	1.02
Laws & Lawrence, 2001	Look at a bear and a pot. Draw the bear beside/ inside/	BPVS-MA	5.2 (1.5)	17	5.1 (1.1)	17	DS>TD	DS group produced more mature drawing than DS	For opaque Pot 0.74

Authors and Year of Publication	Task	Matching					Results	Notes	Cohen's d
		Matching Measure	Group with DS		Comparison Group				
			Mean (SD)	N	Mean (SD)	N			
	behind the pot. The pot is transparent or opaque. behind the pot. The pot is transparent or opaque.							group and have better drawing skills.	For transparent Pot 0.65
Vicari et al., 2004	Test of Visual–Motor Integration - copy drawings	Stanford-Binet-MA	5.2 (1.0)	56	5.4 (1.2)	46	DS=TD	Z scores were analyzed - computed using the mean and SD of the TD group. Also, IQ was covaried in analyses. Age breakdown (Study 2) suggested DS>WS in both younger (<9 years) and older (>11 years) all.	NA
					5.2 (1.2)	69	DS>WS		NA[b]
Wang, Doherty, Rourke, & Bellugi, 1995	Test of Visual–Motor Integration – copy drawings	IQ and CA	IQ 50.0 (7.9) CA 15.0 (2.6)	9	IQ 48.9 (7.1) CA 15.7 (3.1)	10	DS>WS		1.96

Note: MA = mental age; CA = chronological age; SD = standard deviation; nr = Not Reported; TD = typically developing; WS = Williams syndrome; FXS = fragile X syndrome; ID = intellectual disability; WISC = Wechsler Intelligence Scale for Children; BPVS = British Picture Vocabulary Scale; K-ABC = Kaufman Assessment Battery for Children; WASI = Wechsler Abbreviated Scale of Intelligence; MSCA = McCarthy Scales of Children's Abilities; WPPSI: Wechsler Preschool and Primary Scale of Intelligence; PPVT = Peabody Picture Vocabulary Test; WAIS = Wechsler Adult Intelligence Scale; KBIT = Kaufman Brief Intelligence Test. For Cohen's d, positive sign indicates DS group outperforms control group while negative sign indicates control group outperforms DS group.

[a] based on original means; adjusted means unavailable. Since all were still matched, original means were meaningful as well.

[b] when Block design and visual-motor integration combined, d=0.60.

[c] based on F test statistics.

Table 6

Studies comparing group with Down syndrome (DS) to MA-matched control group in mental rotation

Authors and Year of Publication	Task	Matching					Results	Notes	Cohen's d
		Measure	Group with DS		Comparison Group				
			Mean (SD)	N	Mean (SD)	N			
Hinnell, & Virji-Babul, 2004	Judge whether a rotated letter “F” was reversed or not	PPVT-MA	8.2 (2.7)	7	8.4 (1.7)	9	DS=TD	Both all showed increased RT with increased angular disparity. Those with DS made more overall errors than TD group.	NA
Vicari, Bellucci, & Carlesimo, 2006	Stick Test - participants mentally rotate an L- or S-shaped stick. Choose from 4 alternatives.	Stanford-Binet-MA	5.2 (0.7)	18	5.2 (0.7)	18	DS=TD	Only accuracy data were reported and not broken down by angle of rotation. On the Stick Test there was a floor effect for both all, with performance below chance.	−0.40
	Spatial Rotation Test - mentally rotate geometric drawings. Choose from 6 alternatives						DS=TD		−0.12

Note. MA = mental age; SD = standard deviation; TD = typically developing; PPVT = Peabody Picture Vocabulary Test.

Table 7

Studies comparing group with Down syndrome (DS) to MA-matched control group in closure speed and flexibility

Authors and Year of Publication	Task	Matching					Results	Notes	Cohen's d
		Matching Measure	Group with DS		Comparison Group				
			Mean (SD)	N	Mean (SD)	N			
Closure Speed									
Bihrle, 1990	K-ABC Gestalt Closure	WISCMA for TD match; IQ & CA for WS match	MA not reported; IQ 53.4 (SD nr) CA 15.2 (SD nr)	10	Not reported but CA 7.4 (SD nr)	10	DS=TD	Unclear how good DS-TD matching was. DS constructed the outer square configurations well while WS constructed the inner configurations better. Also matched for sex; also included a CA match group, DS<CA.	NA
					IQ 53.7 (SD nr) CA 16.1 (SD nr)	10	DS=WS		NA
Cornish, Munir, & Cross, 1999	K-ABC Gestalt Closure	BPVS-MA	5.1 (1.2)	14	6.2 (1.4)	15	DS<TD	Authors reported no significant difference in MA across all. The researchers have also conducted analysis with MA covaried. Also included a TD-CA match, DS< CA	−1.25[a]
					5.7 (0.9)	15	DS< FXS		−0.76[a]
Hodapp, Leckman, Dykens, Sparrow, Zelinsky, & Ort, 1992	K-ABC Gestalt Closure	K-ABC-MA	4.5 (nr)	10	4.8 (nr)	10	DS< ID	All participants were male. Also matched on age.	NA
					4.1 (nr)	10	DS<FXS		NA
Pueschel, Gallagher, Zartler, & Pezzullo, 1987	K-ABC Gestalt Closure	PPVT-MA	5.1 (1.4)	20	5.2 (1.3)	20	DS<TD	Also included a group of TD-siblings composed of younger TD siblings of children with DS, DS<Sibs	−1.50
Wang, Doherty, Rourke, & Bellugi (1995)	K-ABC Gestalt Closure	IQ & CA (specific test not reported)	IQ 50.0 (7.9) CA 15.0 (2.6)	9	IQ 48.9 (7.1) CA 15.7 (3.1)	10	DS=WS		−0.55
	Mooney Closure Faces – identify gender and age of faces from shadowy pictures						DS=WS		−0.45
	Anomalous Contours – identify figures with illusory contours created by forms of other figures						DS=WS		0.74
Closure Flexibility									
Cornish, Munir, & Cross, 2001	Find the restaurant symbol (knife & fork) on a map	Verbal MA (specific test not reported)	nr	15	nr	15	DS<TD	Authors reported no significant difference in MA across all, though TD group mean CA was 13.41 years. All participants were male.	−3.66
					nr	15	DS<FXS		−1.48

Authors and Year of Publication	Task	Matching					Results	Notes	Cohen's d
		Matching Measure	Group with DS		Comparison Group				
			Mean (SD)	N	Mean (SD)	N			
Kuschner, 2009	Preschool Embedded Figures Test - find the triangle in the complex picture	Leiter-MA & PPVT-MA covaried	Leiter 3.9 (0.7) PPVT 4.1 (1.1)	18	Leiter 4.5 (0.8) PPVT 4.9 (1.3)	18	DS<=TD *p* = .06	A single group with DS was compared with a single TD group on 2 tasks. Also included an ASD group matched on CA.	−0.68
	Leiter Figure Ground - find the target picture in a complex picture						DS<TD		−3.39
Vicari, Bellucci & Carlesimo, 2006	Visual Perception Test – Subtest 4 Find a target geometric shape from overlapping shapes	Stanford-Binet-MA	5.2 (0.7)	18	5.2 (0.7)	18	DS<TD		−0.76

Note: MA = mental age; CA = chronological age; SD = standard deviation; nr = Not Reported; TD = typically developing; WS = Williams syndrome; FXS = fragile X syndrome; ID = intellectual disability; K-ABC = Kaufman Assessment Battery for Children; WISC = Wechsler Intelligence Scale for Children; BPVS = British Picture Vocabulary Scale; PPVT = Peabody Picture Vocabulary Test. For Cohen's d, positive sign indicates DS group outperforms control group while negative sign indicates control group outperforms DS group.

[a] based on original means; adjusted means unavailable. Since all were still matched, original means were meaningful as well

Table 8

Studies comparing group with Down syndrome (DS) to MA-matched control group in wayfinding

Authors and Year of Publication	Task	Matching					Results	Notes	Cohen's d
		Matching Measure	Group with DS		Comparison Group				
			Mean (SD)	N	Mean (SD)	N			
Benson (2010)	Route learning	KBIT-Matrices-MA (covaried)	5.6 (1.6)	17	6.4 (1.9)	16	DS<ID	Results with MA covaried. Also included a TD group that was higher in MA; MA was not covaried in the DS-TD comparison	NA[a]
Courbois, et al., 2013	Route learning	NEMI-2-MA	7.7 (1.0)	10	CA proxy 7.7 (1.1)	10	DS<=TD	Also had a CA match, DS<CA on both measures. Those who met criterion in route learning participated in the survey knowledge test	NA
	Shortcut test of survey knowledge		nr	7	nr	9	DS=TD but in the expected direction		NA
Pennington, Moon, Edgin, Stedron, & Nadel, 2003	Computer-Generated Arena task	DAS-MA	4.5 (nr)	28	4.5 (nr)	28	DS<TD	DS mean was at chance. Only 18 pairs of the original 28 were included in the comparison. MA for these 18 pairs was not reported.	−0.80
Edgin et al., 2010	Computer-Generated Arena task	KBIT-Raw	Verbal 26.4 (10.3) Nonverbal 13.7 (4.5)	55	Verbal 27.4 (5.5) Nonverbal 14.0 (3.4)	36	DS=TD	Both DS and TD means were at chance. MAs were not reported.	0.30

Note: MA = mental age; CA = chronological age; SD = standard deviation; nr = Not Reported; TD = typically developing; KBIT = Kaufman Brief Intelligence Test; DAS = Differential Ability Scales. NEMI-2= Nouvelle Echelle Me'trique de l'Intelligence, a French intelligence test. For Cohen's d, positive sign indicates DS group outperforms control group while negative sign indicates control group outperforms DS group.

[a] no adjusted means available.