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Lexical decision performance using the divided visual field technique following training in adults with intellectual disabilities with and without Down syndrome

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ABSTRACT

Studies of brain lateralization in individuals with non-specific intellectual disability and Down syndrome suggest atypical brain lateralization to speech perception. According to the biological dissociation model, the right hemisphere (RH) mediates speech perception and the left hemisphere (LH) mediates motor control in Down syndrome. The current study aimed to test, for the first time, brain lateralization in both non-specific intellectual disability and Down syndrome, compared to individuals with typical development. Furthermore, bilateral word presentation was utilized to assess interhemispheric communication. Twenty adults with non-specific intellectual disability, 14 adults with Down syndrome, and 30 adults with typical development participated in the study. Participants in the non-specific intellectual disability and Down syndrome groups were trained to perform the task prior to the experiment. The results showed that whereas hemispheric lateralization did not differ between individuals with non-specific intellectual disability and typical development, individuals with DS showed reduced brain lateralization in comparison to adults with typical development. All three groups showed no significant difference between words presented to the LH and bilaterally. Our results also show that individuals with intellectual disabilities can benefit from training programmes and that they may perform equally as fast as their typically developing peers.

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KEYWORDS Down syndrome; lateralization; hemispheres; intellectual disability; lexical decision

Introduction

Individuals with intellectual disabilities constitute a heterogeneous group with regard to IQ level, etiology, and accompanying disorders. The current study focuses on adults with mild and moderate intellectual disabilities (IQ = 40–70) with either non-specific intellectual disabilities or Down

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syndrome. Individuals with non-specific intellectual disability exhibit linguistic delays, poor language competence (Aitchison, 2003; Fink & Cegelka, 1982), limited vocabulary (Borkowski & Büchel, 1983; Cornoldi, Giofre, Orsini, & Pezzuti, 2014), limited syntax, lack of verbal rehearsal, and low ability to actively retrieve coded information (Hulme & Mackenzie, 1992). They also exhibit difficulties in semantic relation classification, deficits in lexical development (Van der Schuit, Segers, Van Balkom, & Verhoeven, 2011), and poorer comprehension of abstract relations between pairs of objects (Paour, 1992). Individuals with non-specific intellectual disabilities, as well as persons with Down syndrome, frequently exhibit slower and more variable response times associated with deficient top-down attentional and/or control-related processes relative to age-matched controls (Heath et al., 2005).

Down syndrome is a genetic disorder caused by an extra copy of chromosome 21 (trisomy 21), with an incidence of 1 in 700 live births. The cognitive profile of individuals with Down syndrome resembles the cognitive profile of individuals with non-specific intellectual disabilities, although some abilities are better preserved than others in Down syndrome. Individuals with Down syndrome exhibit a remarkable deficit in language abilities compared to their non-linguistic visual-spatial abilities (Gunn & Crombie, 1996; Vicari, Bellucci, & Carlesimo, 2005), particularly in expressive vocabulary and grammar. Furthermore, individuals with Down syndrome exhibit difficulties in executive functioning, in particular: working memory, planning (Costanzo et al., 2013; Lanfranchi, Baddeley, Gathercole, & Vianello, 2012), and analogical problem solving (Natsopoulos, Christou, Koutselini, Raftopoulos, & Karefillidou, 2002). Volumetric neuroimaging studies in this population have consistently reported smaller overall brain volumes, with disproportionately smaller cerebellum, brainstem, frontal lobe, and hippocampus volumes (e.g., Pinter, Eliez, Schmitt, Capone, & Reiss, 2001).

One possible explanation for the poor verbal competence in Down syndrome has been linked to morphological callosal deficiencies observed, such as a thinner corpus callosum (e.g., Wang, Doherty, Hesselink, & Bellugi, 1992). A thinner corpus callosum may cause poor interhemispheric communication, and may explain the verbal difficulties observed in Down syndrome (Heath, Grierson, Binsted, & Elliott, 2007). Thus, unlike typically developed individuals who manifest a typical left brain asymmetry, those with Down syndrome exhibit right hemisphere (RH) asymmetry and weak interhemispheric collaboration (Wang et al., 1992); this may cause isolation of the functions of the two cerebral hemispheres (Welsh, Elliott, & Simon, 2003).

Data obtained from brain lesion studies and neuroimaging studies technique suggest that the left hemisphere (LH) is predominant for processing language in most right-handed adults with typical development (e.g., Perrone-Bertolotti, Lemonnier, & Baciu, 2013). Whereas most right-handed individuals with typical development (97%) exhibit the typical LH lateralization for language, the remaining 3% of right-handed individuals exhibit bilateral or right hemisphere lateralization for language (Bishop, 1990). Studies using the divided visual field (DVF) technique are also used to assess the laterality of cognitive functions. They are based on the fact that visual stimuli presented in the left visual field (LVF) are initially projected to the right cerebral hemisphere, whereas stimuli shown in the right visual field (RVF) are projected to the left cerebral hemisphere. This anatomical feature supports the argument that LVF-RVF differences are an index of asymmetric functioning within the two cerebral hemispheres. Thus, the consistent finding that words are recognized more easily in the RVF than in the LVF reflects LH dominance for language processing. In support of this position, evidence suggests that individuals with left hand preference show a reduced RVF superiority for word recognition relative to persons with right hand preference (e.g., Kim, 1994).

In contrast to the visual modality data obtained from DVF studies in participants with typical development, most of the data in respect to brain lateralization in individuals with intellectual disabilities comes from auditory speech perception studies (i.e., dichotic listening) and handedness. To the best of our knowledge, there have been no DVF studies of brain lateralization in intellectual disability using a lexical decision task. It is possible that the expectation of slower response times and potential difficulty in coordinating responses with flashed words on the screen have impeded researchers from conducting such studies in people with intellectual disability. Heath et al. (2007) argued that individuals with Down syndrome, in particular, are not capable of performing perceptual-motor tasks because they may not possess adequate skills to respond to externally paced stimuli. In the current study, we explored the possibility that individuals with Down syndrome and non-specific intellectual disability may be capable of doing so, given adequate training. Therefore, in the current study we sought to gradually train participants with Down syndrome and non-specific intellectual disability to perform a lexical decision task combined with the DVF technique.

Studies of brain lateralization in individuals with intellectual disabilities, including studies of handedness, provide insight into the functioning and representation of cognitive systems in the two cerebral hemispheres. Studies using dichotic listening technique for assessing brain lateralization for language in individuals with intellectual disabilities indicate atypical brain lateralization for individuals with Down syndrome and typical brain lateralization for individuals with non-specific intellectual disabilities and typical development (Giencke & Lewandowski, 1989; Pipe, 1983, 1988). For instance, Giencke and Lewandowski (1989) examined ear advantages of young adults with non-specific intellectual disability and with Down syndrome compared to individuals with typical development with the same mental age. Participants with non-specific intellectual disability and the typical development group demonstrated typical right ear advantage (left hemisphere dominance), whereas the Down syndrome group showed a significant left ear advantage (right hemisphere dominance). The atypical brain lateralization in Down syndrome was further supported by a meta-analysis (Elliott, Weeks, & Chua, 1994) in which a reversed cerebral specialization for speech perception (but not speech production) was observed. This observed left-ear advantage in Down syndrome is suggestive of a link between severe language-related disabilities and RH specialization.

Based on dichotic listening and manual asymmetry studies, the biological dissociation model (Elliott & Weeks, 1990) has been proposed to explain cerebral laterality and deficient cognitive performance in Down syndrome. This model argues that speech perception and control of movements are separated in Down syndrome: the RH mediates speech perception, and the LH, similar to individuals with typical development, mediates motor control. According to a core feature of this model, individuals with Down syndrome perceive speech with the RH but organize complex movement control, including speech production, with the LH. This model has practical implications for language processing in Down syndrome: language deficits may be related to the biological dissociation of the structures responsible for speech perception and speech production. Thus, whereas these language systems typically overlap in the typically developed population, their dissociation may contribute to the language-related deficits exhibited by individuals with Down syndrome. However, to date, this model has not been tested in studies that used written word identification.

Given the evidence for corpus callosum morphological abnormalities in Down syndrome, a delayed interhemispheric transmission is expected in this population. A simple behavioural paradigm to examine interhemispheric communication is the Poffenberger paradigm in which participants respond with either their contralateral hand (i.e., cross condition) or ipsilateral hand (uncrossed condition) to a visual stimulus presented to either the left or right visual field. Thus, in the crossed condition, participants see a visual stimulus presented to the opposite visual field of the responding hand, whereas in the uncrossed condition, the visual stimulus and the hand are on the same side. The time difference between the crossed and the uncrossed condition (CUD) provides a measure of the interhemispheric transmission time and is directly related to the structural integrity of the corpus callosum (Iacoboni & Zaidel, 2003). In particular, this difference typically manifests as a 4-ms advantage in favour of the uncrossed condition over the crossed condition, and presumably reflects the time required for between-hemisphere callosal communication. However, contrary to the expectations, the study of Heath et al. (2007) did not find evidence for this time difference (crossed–uncrossed) in adults with Down syndrome. Thus, whereas adults with typical development showed, as expected, faster RTs as compared to adults with Down syndrome and, more notably, slower responses to the crossed condition than the uncrossed condition, adults with Down syndrome did not demonstrate the expected CUD. The authors concluded that this paradigm is probably not sensitive enough to examine corresponding brain–behaviour relations in the Down syndrome population owing to inherent variability in speeded executive-motor processes. Thus, it is still unclear whether interhemispheric transmission in Down syndrome is deficient. To the best of our knowledge, there are no studies that have tested interhemispheric communication among individuals with non-specific intellectual disability; doing so, in both individuals with Down syndrome and non-specific intellectual disability, would allow comparison of the pattern of cerebral organization among these groups.

A well-established technique to assess hemispheric communication, and to assess which hemisphere exerts control over the other hemisphere, is to present the same visual stimulus to both visual fields simultaneously (bilateral presentation). Faster response times and more accurate responses to a bilateral presentation (as compared to a unilateral presentation), also called bilateral gain (BG), indicate interhemispheric facilitation and cooperation. If the response time following bilateral presentation is identical to the pattern of results elicited from RVF/LH presentation, but differs from the pattern observed following LVF/RH presentation, it can be concluded that the LH exerts control over the RH (Mohr, Pulvermüller, Mittelstädt, & Rayman, 1996; Mohr, Pulvermüller, Rayman, & Zaidel, 1994). It has been shown that bilateral presentation of concrete words (but not pseudo-words) lead to more accurate (and a tendency toward faster) lexical decisions compared to unilateral modes of presentation in individuals with typical development (Mohr et al., 1996). A putative explanation of this finding is based on the neurobiological model of word representation (Pulvermiiller, 1992) according to which words are represented in widely distributed cortical regions in both hemispheres. When the visually presented words stimulate the corresponding neural representation (assembly), the entire assembly is activated. Furthermore, bilateral word stimulation leads to summation of activity via interhemispheric connection, resulting in faster activation.

Studies that tested bilateral presentation in tasks involving word reading indicate that more complex judgment tasks benefit from bilateral presentation. However, when a task involves a process that only one hemisphere can perform effectively, the bilateral advantage is decreased. For instance, Belger and Banich (1998) did not find a bilateral advantage for rhyme judgments. This finding was interpreted in light of split-brain studies suggesting that only the left hemisphere is specialized in the phonological processing necessary for rhyme judgment (Rayman & Zaidel, 1991), such that right hemisphere involvement in this task may be more harmful than helpful. Thus, if one hemisphere is more dominant (i.e., exerts control over the other), then response times to bilateral trials should equal the faster of the two unilateral trial responses (Hellige, 1987). This notion, describing the case in which one hemisphere consistently dominates processing, is related to the concept of meta-control. Meta-control refers to the neural mechanism that determines which hemisphere will attempt to control cognitive processing (Hellige, 1987).

The current study aims to examine, for the first time, brain lateralization in both individuals with non-specific intellectual disability and Down syndrome, compared to adults with typical development, using a lexical decision task combined with the DVF technique. Furthermore, we aimed to test hemispheric cooperation in these etiologies by testing bilateral gain using a bilateral word presentation. Based on the biological dissociation model (Elliott & Weeks, 1990), we expected a reversal pattern of hemispheric lateralization in adults with Down syndrome. Based on dichotic listening studies (Giencke & Lewandowski, 1989; Pipe, 1983) we expected a typical brain lateralization in the non-specific intellectual disability group. Based on the anatomical alteration of the corpus callosum, we hypothesized that adults with Down syndrome would demonstrate reduced bilateral gain. Whereas faster and more accurate responses to words presented bilaterally are expected in the typically developed group, compared with unilateral presentation, a different pattern of results was predicted for the Down syndrome group.

Method

Participants

Sixty-four native Hebrew speaking volunteers, 34 of whom were participants with intellectual disabilities (ID) and 30 of whom were typically developed (TD) participants (14 females) were recruited for the study. All participants were right-handed and had normal or corrected-to-normal vision.

The ID sample, comprised of participants with mild and moderate ID (IQ = 40–70), was divided into two etiology groups: 20 participants (seven females) with non-specific intellectual disability (NSID) and 14 participants (eight females) with Down syndrome. All of the participants met the study criteria: individuals with mild/moderate ID according to the traditional AAMR definition (Grossman & Begab, 1983), independent in terms of Activities of Daily Living (ADL) skills, and without maladaptive behaviour.

All participants performed the Vocabulary and Similarities subtests from the shortened Adult Intelligence Scale (WAIS–IV, Wechsler, 2001). The Vocabulary subtest measures word knowledge and verbal concept formation, while the Similarities subtest assesses abstract reasoning and the power to conceptualize dissimilarity. All participants were also assessed by a reading test (Schiff & Kahta, 2009a, 2009b): The participants were asked to read accurately as many words and non-words as they could in 45 s from three lists (Hebrew words without vowel marks, Hebrew non-words with vowel marks, and Hebrew words with vowel marks). The differences between the groups on the reading test were analyzed with a one way ANOVA.

As can be seen in Table 1, the typically developed group outperformed non-specific intellectual disability and the Down syndrome groups in all tests. The Down syndrome and the non-specific intellectual disability groups read significantly fewer words and non-words than the typically developed group, and had been matched according to age, Vocabulary and Similarities subtests, and three reading tests. Participants had no history of learning disorders, psychiatric disturbances, neurological disease, or head trauma (according to self-report).

Authorizations to conduct the study were obtained from the University Ethics Committee and the Division of Individuals with Intellectual Disabilities in the Ministry of Welfare. Adults with intellectual disabilities were recruited through the employment venues and hostels currently accommodating this population. Consent for participation of participants with Down syndrome and non-specific intellectual disability was obtained from the participants' parents/guardians. The study's aims and procedures were explained to the participants, who signed an adapted informed consent form for participation of individuals with ID in scientific research. Participants with Down syndrome and non-specific intellectual disability received 50 new Israel shekels (the equivalent of approximately U.S. $15) for their participation. Adults with typical development were recruited through Bar Ilan University and other places.

Stimuli

Stimuli construction – the experiment included 120 stimuli, half being real words and half being non-words, all in Hebrew. The non-words were created by replacing the first letter and another additional letter among the real words. The length of the non-words was equal to the real words. All words were highly familiar concrete nouns (e.g., body, moon), and were 3–4 letters long. The 60 words were divided into three lists of 20 words each,

Table 1. Demographic characteristics and performance on screening tests and performance on the reading tests, by group.

	TD (1) $N = 30$	ID (2) $N = 20$	DS (3) $N = 14$	F	Adjusted T-test
Age	33.83 (6.44)	(9.58) 33.80	(5.07) 32.93	0.081	1 = 2 = 3
Vocabulary	(5.46) 53.	(11.75) 20.60	(6.62) 14.71	90.01***	1 > 2, 1 > 3, 2 = 3
Similarities	(5.12) 25.53	(3.76) 14.25	(2.58) 14.29	90.01***	1 > 2, 1 > 3, 2 = 3
Reading fluency	98.05 (12.55)	45.80 (21.89)	38.79 (17.82)	47.82***	1 > 2, 1 > 3, 2 = 3
Reading non-words	18.65 (1.79)	9.15 (5.83)	10.21 (5.38)	47.82***	1 > 2, 1 > 3, 2 = 3
Reading words	58.40 (1.35)	36.70 (16.74)	35.43 (13.17)	47.82***	1 > 2, 1 > 3, 2 = 3

***$p < .001$.

presented to either the LVF/RH, the RVF/LH, or the bilateral VF. These three lists (conditions) were counterbalanced according to word frequency and length. In order to assess word frequency, a questionnaire was given to 10 typically developed students, native Hebrew speakers ($M = 28.8$, $SD = 3.64$). They were presented with the list of all the words and asked to rate their degree of frequency on a seven point frequency scale ranging from 1 (highly non-frequent) to 7 (highly frequent). The average rates on the frequency scale for the words presented to each of the three conditions were identical ($M = 6.93$, $SD = 0.08$). No significant difference was found for the words between the three conditions, $F(2, 57) = 0.00$, $p > .99$, $\eta_p^2 < .001$. Furthermore, word frequency based on Linzen (2009) was matched across the three experimental conditions, $F(2, 57) = .9$, $p = .36$. In addition, in order to assert that these words would be familiar to individuals with Down syndrome and non-specific intellectual disability, five adults with intellectual disabilities who did not participate in the experiment were asked to read the words and indicate whether these words were familiar to them. They replied that all the words were familiar to them. In addition, they successfully explained the meanings of a sample of five words selected from the list. Finally, a one-way ANOVA found no significant difference between the three lists in word length $F(2, 57) = 0.00$, $p > .99$, $\eta_p^2 < .001$.

Procedure

Experiment process – Each participant was presented with all 120 word and non-words, randomly presented either to the right visual field, the left visual field, or both. The experiment started with a " + " presented to the centre of a white screen for 3,000 ms. The "+" remained on the screen throughout the experiment in order to maintain the gaze at the centre of the screen. Next, the words/non-words appeared in the right/left/bilateral field of vision for 180 ms (Bourne, 2006) and were displayed at 2.8° (centre of lateralized word to centre of fixation) to the right or to the left of fixation. Participants were instructed to maintain central fixation. The stimuli were written in the "David" font, size 36, throughout the experiment. The participants sat 60 cm away from the screen and were asked to make a lexical decision for each word by clicking "yes" (by pressing the N key) with their right hand for a stimulus that represented a real word in the language, or "no" (by pressing the B key) for a stimulus that represented a non-word. The participants were instructed to respond as rapidly and accurately as possible within 3,000 ms until the next word appeared. In addition, during the experiment the experimenter sat in front of the participants in order to observe the participants' focus on the centre of the screen. Less than 2% of all trials involved deviation of gaze from the fixation point. Due to the very minimal percent of deviation, these trials were not excluded from further data analyses. The stimuli were displayed via Super-Lab-Pro 5.0 installed on a laptop. The experiment started with a practice session using four real words and two non-words.

Training programme

Each participant with intellectual disability took part in a training programme, aimed at preparing the participants for the experiment to use the keys correctly and to coordinate their response as fast as possible. Before conducting the study, we tested whether the participants in both etiology groups were able to perform the task. We found that all participants were unable to attend the stimuli *at all*, even at a 1000 ms presentation rate, indicating a complete inability to perform the task (it should be noted that stimuli were ultimately presented for 180 ms in the live experiment). Furthermore, 82% of the participants with intellectual disability were unable to perform the task at 2000ms presentation rate. During the training programme, the words were presented in same font and size as in the live experiment. The training programme was comprised of six stages in increasing difficulty, so each stage increased the speed of the stimuli display on the screen. In the first stage, the stimuli were displayed for 2,000 ms to either the RVF, LFV, or bilaterally, in a random fashion. In the second stage, the stimuli were displayed for 1,500 ms, in the third stage for 1,000 ms, in the fourth stage for 750 ms, and in the fifth stage for 500 ms. In the sixth stage, the stimuli were presented for 180 ms, the same duration as in the experiment. During the training, participants were taught to press the N button (coloured in green) for a real word and the B button (coloured in red) for a non-word, and were presented with different words than those used in the experiment. The criteria we used for moving a participant to the next training level was based on the accuracy of their performance: If participants were able to identify the stimuli with at least a 70% accuracy rate, they moved to the next stage. After completing the sixth stage of training, participants were ready to begin the experiment (all participants successfully completed the training programme).

The training meetings were held once a week in a quiet, stimuli-free environment that encouraged maximum concentration with minimum distractions. The length of each meeting was 20 min on average. The number of meetings was adapted to the personal abilities of each participant with ID. Participants who performed better were able to accelerate to the more advanced stages of the training programme and therefore attended less training meetings.

Results

Reaction time

After omitting outliers (responses ± 2 SD from the mean), we computed mean reaction times (RT) for correct responses for each participant in each condition. Before conducting the analyses we computed the correlations between performance on the reading tests (Reading fluency, Reading non-words, Reading words) and both the RTs and the accuracy rates in each condition within each group. No significant correlations were found (except a negative correlation in the typically developed group between the bilateral presentation RTs and the Reading words task, $r = -.51$, $p < .01$). Therefore, reading fluency was not controlled in the RT and accuracy analyses. Analyses were performed with both subjects treated as the random variable (F1) and with items treated as the random variable (F2).

RT analysis: A two-way 3 (RVF/LH, LVF/RH, Bilateral) × 3 (TD, NSID, DS) mixed analysis of variance (ANOVA) was conducted on RTs, with visual field as the within-subject factor, and group as the between-subjects factor. See Figure 1 for raw data in all conditions.

This analysis yielded a significant main effect of visual field, $F1(2, 122) = 32.85$, $p < .001$, $\eta_p^2 = .35$; $F2(2, 57) = 27.95$, $p < .001$, $\eta_p^2 = .49$. Bonferroni adjusted t-testing revealed, in both analyses, that responses to words presented to the RVF/LH were significantly faster than to the LVF/RH, $ps < 0.001$, and responses to words presented bilaterally were significantly faster than to words presented to the LVF/RH, $ps < .001$. No significant difference was found between the bilateral and the RVF/LH presentation. The main effect of group was non-significant, $F1(2,61) = 0.10$, $p = .900$, $\eta_p^2 = 0.00$; $F2(1.78, 101.85) = 1.22$, $p = .29$, $\eta_p^2 = 0.02$.

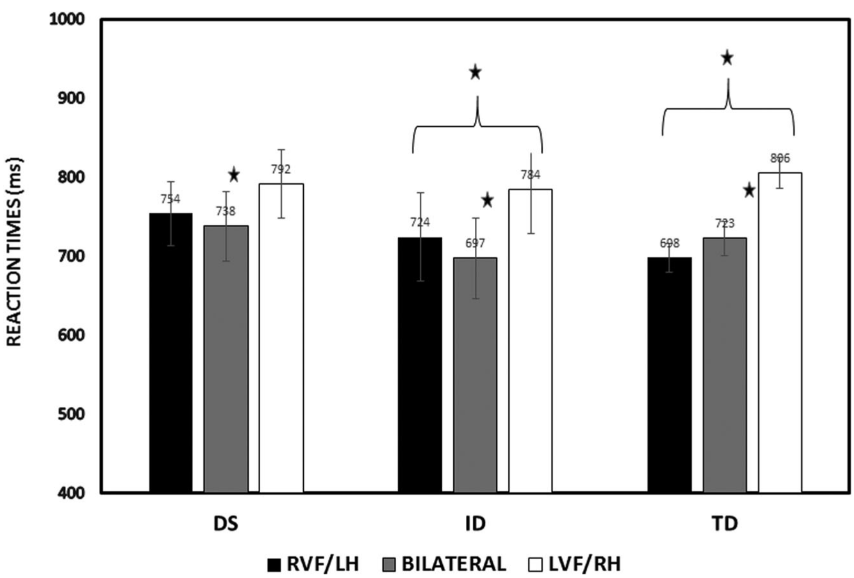

Figure 1. Mean reaction times (in milliseconds) and SEs by visual field and group.

The two-way Visual Field X Group interaction was significant, $F1(4, 122) = 2.81$, $p = .028$, $\eta_p^2 = .00$; $F2(3.57, 101.85) = 1.64$, $p = .18$, $\eta_p^2 = .05$. Bonferroni adjusted t-testing conducted on each group separately revealed that, within the non-specific intellectual disability group, RTs were faster in the RVF/LH than the LVF/RH, $p < .001$. No significant difference was observed between the RVF/LH and the bilateral presentation, $p = .29$. However, adults with non-specific intellectual disability responded faster to words presented bilaterally than to words presented to the LVF/RH, $p < .001$. Similar to the non-specific intellectual disability group, adults with typical development responded faster to words presented to the RVF/LH than to LVF/RH, $p < .001$; RTs were faster to words presented bilaterally than to LVF/RH, $p < .001$. However, no significant difference among the adults with typical development was observed between words presented bilaterally and to the RVF/LH, $p > .99$. In contrast, in the Down syndrome group, significant differences were observed neither between the two visual fields, $p = .25$, nor between the bilateral presentation and the RFV/LH, $p = .78$. However, faster RTs were observed for words presented bilaterally than to the LVF/RH among those with Down syndrome, $p < .05$.

In sum, adults with non-specific intellectual disability (but not adults with Down syndrome) demonstrated a typical LH lateralization similar to the adults with typical development. All groups showed faster RTs to words presented bilaterally, as compared to words presented to the RH, suggesting a bilateral gain as compared with the RH. Furthermore, no difference was observed between words presented bilaterally and words presented to the RVF/LH, in all groups.

Accuracy

Accuracy analysis: A two-way 3 (RVF/LH, LVF/RH, Bilateral) × 3 (TD, NSID, DS) mixed analysis of variance (ANOVA) was conducted on the percentage of correct responses, with visual field as the within-subject factor, and group as the between-subjects factor. See Table 2 for the accuracy rates.

This analysis yielded a significant main effect of Visual Field, $F(1.56, 95.19) = 39.01$, $p < .001$, $\eta_p^2 = 0.39$; $F2(2, 57) = 23.74$, $p < .001$, $\eta_p^2 = .45$. Bonferroni

Table 2. Mean percentage of correct responses by group.

	TD (1) $N = 30$	ID (2) $N = 20$	DS (3) $N = 14$	Total $N = 64$
RVF/LH	97.00	78.25	83.57	88.20
	(5.66)	(14.35)	(9.69)	(13.01)
LVF/RH	90.00	66.50	61.07	76.33
	(8.51)	(20.39)	(23.46)	(21.06)
Bilaterally	97.33	80.25	81.43	88.52
	(3.88)	(17.05)	(11.33)	(13.82)

adjusted t-testing revealed that, in both analyses, responses to words presented to the RVF/LH were significantly more accurate than to words presented to the LVF/RH, *ps* $< .001$, and responses to words presented bilaterally were significantly more accurate than to words presented to the LVF/RH, *ps* $< .001$. No significant difference was found between the bilateral and the RVF/LH presentation, *ps* $> .99$. The main effect of group was significant, $F1(2, 61) = 29.05$, $p < .001$, $\eta_p^2 = .48$; $F2(1.81, 103.38) = 114.95$, $p < .001$, $\eta_p^2 = .66$. Bonferroni adjusted t-testing revealed that, in both analyses, the typical developed group responded more accurately than both the non-specific intellectual disability group and the Down syndrome group, *ps* $< .001$. No significant difference was observed between the two etiology groups, *ps* $> .99$.

The two-way Visual Field X Group interaction was significant, $F1(3.12, 95.12) = 3.64$, $p < .05$, $\eta_p^2 = .1$; $F2(3,62,103.38) = 6.00$, $p < .001$, $\eta_p^2 = .17$. Bonferroni adjusted t-testing conducted in each group separately revealed that, within the non-specific intellectual disability group, responses were more accurate to words presented to the RVF/LH than the LVF/RH, $p < .001$, $p < .05$, respectively, and to words presented bilaterally than to the LVF/RH, *ps* $< .001$. No significant difference in accuracy rate was found between words presented bilaterally and words presented to the RVF/LH, $p = 1.0$, $p = .73$, respectively. In the typically developed group, no difference was observed between words presented to the RVF/LH and the LVF/RH, $p = .07$ (however, this difference was significant in the item analysis, $p < .01$), and no difference was observed to words presented bilaterally and to the RVF/LH, *ps* $> .99$. However, a significant difference was observed between words presented bilaterally and words presented to the LVF/RH, $p < .05$, $p < .001$, respectively. In contrast, similar to the non-specific intellectual disability group, adults with Down syndrome demonstrated more accurate responses to words presented to the RVF/LH than to the LVF/RH, *ps* $< .01$, and to words presented bilaterally than to the LFV/RH, *ps* $< .001$. In addition, no difference was observed for words presented bilaterally and to the RVF/LH, *ps* $> .99$.

In sum, adults with non-specific intellectual disability and Down syndrome demonstrated typical LH lateralization. Adults with typical development showed, although not significant, a tendency toward LH lateralization. All groups showed increased accuracy rates to words presented bilaterally as compared to words presented to the LVF/RH, demonstrating a bilateral gain over the RH. Similar to the RT analyses, no difference was observed between words presented bilaterally and words presented to the RVF/LH, in all groups, suggesting left hemisphere meta-control (Hellige, 1987).

Hemispheric lateralization

In order to measure hemispheric lateralization in each group we assessed the index of lateralization. The index of hemispheric lateralization was calculated by subtracting LH performance from RH performance for RTs, and RH performance from LH performance for accuracy rates. Higher scores indicate greater left hemisphere lateralization (faster or more accurate responses in the LH). Next, we performed one way ANOVAs on lateralization index (LI) scores separately for RT and accuracy rate. The analysis for RTs revealed a significant effect, $F(2, 61) = 4.34$, $p < .05$. Bonferroni adjusted t-testing revealed greater LI for the typically developed group than the Down syndrome group ($p < .05$) with no significant difference between the typical development and the non-specific intellectual disability group ($p = .13$) and between the non-specific intellectual disability and the Down syndrome group ($p > .99$) (see Figure 2). A one way ANOVA on LI accuracy scores revealed a significant effect, $F(2, 61) = 4.18$, $p < .05$. Bonferroni adjusted t-testing revealed greater LI for the typically developed group than the Down syndrome group ($p < .05$) with no significant difference between the typically developed and the non-specific intellectual disability group ($p = .97$) and between the non-specific intellectual disability and the Down syndrome group ($p = .21$).

Comparing response times to correct "yes" responses and correct "no" responses

Because response-buttons were not counterbalanced across participants we analyzed the RTs to correct "yes" responses (N key, for words) and to correct "no" responses (B key, for non-words) for each group separately. We therefore performed a series of paired t-tests comparing the correct "yes" and "no" responses within each hemisphere. Our results revealed that for

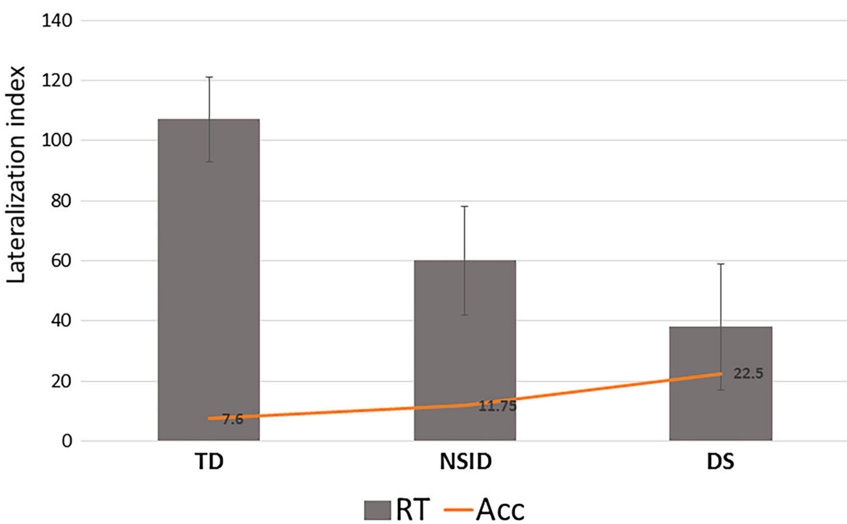

Figure 2. Lateralization index (LI) scores for RT and accuracy rate by group.

both the typically developed and the non-specific intellectual disability groups no difference was observed between the two types of responses in the LVF/RH ($t(29) = -.41$, $p = .69$; $t(19) = .28$, $p = .19$, respectively). For the Down syndrome group a significant effect was found between the two types of responses, $t(13) = 2.28$, $p < .05$. For stimuli presented to the RVF/LH we found a significant effect in all groups (ps $< .05$). The significant difference between the correct "yes" and "no" responses in the LH might result from the relative specialization in processing words in the LH as compared to the RH.

Discussion

The present study demonstrated, for the first time, typical brain lateralization in adults with non-specific intellectual disability. Adults with non-specific intellectual disability showed faster and more accurate responses to words presented to the RVF/LH than to the LVF/RH. Adults with Down Syndrome, similar to participants with non-specific intellectual disability, showed more accurate responses to words presented to the RVF/LH than to the LVF/RH. Thus, contrary to our hypotheses, the current results did not find evidence of reversed brain lateralization for language in adults with Down syndrome. Nevertheless, whereas hemispheric lateralization (as assessed by the lateralization index) did not differ between individuals with non-specific intellectual disability and typical development, individuals with Down syndrome showed reduced brain lateralization in comparison to adults with typical development.

In contrast to the biological dissociation model (Elliott & Weeks, 1990), our findings point to typical (i.e., left lateralized) brain lateralization in adults with intellectual disability, at least for a task of receptive language. These apparently contradictory findings may result from the different techniques used to assess lateralization. Most of the previous studies with intellectual disability used the dichotic listening procedure that indicated a left ear/RH advantage for the perception of speech sounds in Down syndrome, implying RH dominance for speech perception (Elliott et al., 1994). The current findings cannot dispute the assertion that auditory speech perception is lateralized to the RH in ID. However, our findings refine the biological dissociation model, and suggest that visual word identification is lateralized to the LH, as observed in most right-handed adults with typical development. It should be noted that this finding is another illustration of the fact that right-to-left reading direction (Hebrew) does not eradicate the RVF-advantage for visual word processing.

The typical left-lateralized responses demonstrated in the present study in both etiology groups find support from previous neuroanatomical findings. An MRI study, although reporting overall smaller brain volumes in Down syndrome, nevertheless indicated no aberrant pattern of anatomical brain asymmetry, in particular in the overall temporal lobe volumes (Pinter et al., 2001).

Because it has been shown that individuals with intellectual disability, with and without Down syndrome, process visual information more easily than auditory information (Grieco, Pulsifer, Seligsohn, Skotko, & Schwartz, 2015) future studies should use neuroimaging techniques to further assess whether the typical lateralization observed in our intellectual disability sample is linked to the modality of stimulus presentation. More specifically, it is important to further assess whether individuals with intellectual disability, with or without Down syndrome, rely on their LH to process visual linguistic stimuli, and utilize their RH to perceive speech.

Another finding that emerged from the current study is the RH bilateral gain (RHBG) obtained in the three groups. All groups showed faster and more accurate responses for words presented bilaterally compared to LVF/RH presentation. However, no LH bilateral gain (LHBG) was obtained for any group, indicating similar performance with words presented bilaterally and words presented to the RVF/LH. These findings are indicative of LH dominance over the RH in both non-specific intellectual disability and Down syndrome, similar to adults with typical development. In other words, the results are indicative of the left hemisphere controlling visual word identification (Hellige, 1987). Mohr et al. (1996) found more accurate lexical decisions for words presented bilaterally compared to RVF presentation in adults with typical development. The current results, unlike Mohr et al.'s findings, demonstrated similar performance in the bilateral VF and the RVF. Analyzing the percentage of correct responses in Mohr et al.'s study reveals less than 90%, 80%, and 70% correct responses in the bilateral VF, RVF/LH and LVF/RH, respectively. Thus, it is plausible to conclude that because our participants with typical development performed at ceiling level (97% in both the RVF/LH and the bilateral VF) they did not demonstrate the expected bilateral gain (i.e., better performance in respect to both unilateral presentations). Therefore, our results cannot point to interhemispheric cooperation and excitatory trans-callosal connections in the typically developed group, as no LHBG was obtained, probably because the words were highly familiar and very easy to process.

Participants in both etiology groups, like the typically developed group, did not show a significant difference between RVF/LH and bilateral VF presentation (no LHBG). A similar pattern of results was found in a split brain patient (i.e., severed corpus callosum): no RT differences were found between bilateral presentation and unilateral presentation in the RVF/LH. Because our adults with non-specific intellectual disability and Down syndrome performed similarly to our participants with typical development, it is unclear whether they performed at relatively ceiling level and therefore no BG could be detected. Another possible interpretation for this pattern of results is that there is no interhemispheric communication during the lexical decision task in both etiology groups, as observed in the split-brain patient study. A parsimonious conclusion, based on the current findings, is that we can exclude the possibility that the hemispheres interact in an inhibitory fashion. If this was the case, a worse performance of the bilateral presentation, compared to the unilateral presentations, would be expected. Moreover, we can reasonably conclude that the LH is the dominant hemisphere for word identification in both non-specific intellectual disability and Down syndrome. Future studies using this paradigm with, for example, less frequent words, might avoid a ceiling effect in TD and may reveal how the two hemispheres communicate during a lexical decision task.

One surprising finding that emerged from the current study is the non-significant differences in response times between both etiology groups and the typical development group, as manifested by the non-significant group effect. In terms of response time (RT) to words presented bilaterally, the participants with non-specific intellectual disability and Down syndrome responded as fast as the participants with typical development (697, 738, and 722 ms, respectively). Previous studies have consistently reported longer response times in the Down syndrome group compared to age-matched typical development controls (e.g., Heath et al., 2007), slower motoric movements, and difficulties in executing manual movements (Welsh & Elliott, 2001). Neuroanatomical studies have suggested that the reduced cerebellar gray matter evident in Down syndrome is associated with hypotonia and motor coordination difficulties, as well as articulatory speech deficits (Frith & Frith, 1974). We believe that the training programme that preceded our experiment revealed perhaps surprisingly adept improvement among the non-specific intellectual disability and Down syndrome groups. The stimulus presentation rate was 180 ms in the live experiment, and it was discovered that *82%* of the participants from the etiology groups were unable to adequately attend to the stimulus even at a 1000 ms presentation rate. Only after the experimenter made sure that the participant could coordinate her/his manual response with the ongoing brief stimulus presentation with at least 70% correct responses, did the experimenter move to the next stage with a decreased time of stimulus presentation. Out of six stages of training, the sixth stage mimicked the presentation duration of the actual experiment (180 ms); when participants succeeded in completing this stage (with at least a 70% accuracy rate) they were allowed begin the experiment. Participants varied in the number of meetings (5–20) required to complete the training, but all completed the training and went on to participate in the live experiment. Our findings may suggest that with the right programme, individuals with intellectual disabilities can be trained to perform equally as fast as their age-matched typically developed peers. Further, our findings indicate that despite possible structural anomalies, individuals with Down syndrome can show flexible behaviour in the context of individually-tailored training.

Notwithstanding the fact that there were no significant differences between the groups on reaction times but there were differences in accuracy that could indicate that both etiology groups may be more prone to demand characteristics and thereby respond faster (but less accurately) due to having learned what the experimenters expect. Future studies should test whether their fairly high level of performance (above 80% accuracy in the bilateral condition) indicates a ceiling effect or a result of demand characteristics.

The current study opens the door for future studies that are needed to deepen the understanding of the neural substrates of language functioning in non-specific intellectual disability and Down syndrome. Although our results show typical brain lateralization in word identification, the cause and understanding of the RH advantage for speech sounds and LH advantage for written words, as was evident in the current study, is unclear. It is evident that individuals with intellectual disability, with and without Down syndrome, exhibit more difficulties in processing auditory than visual information (Grieco et al., 2015). Furthermore, a series of meta-analyses and reviews of long-term and working memory performance (Lifshitz, Kilberg, & Vakil, 2016) found equal performance between participants with intellectual disability and typical development when auditory stimuli was accompanied by visual scaffolding (pictures cards or written words). Thus, future studies should test whether using the visual modality rather than auditory modality would reveal different pattern of brain lateralization for participants with Down syndrome and with non-specific intellectual disability. Therefore, future studies that directly compare brain processing of visual vs. auditory linguistic stimuli are necessary.

Further future studies emerged from the current study. As the current results did not provide clear-cut evidence for deficient lexical information transmission between the two hemispheres in intellectual disabilities, future studies need to investigate this topic using other methods that will shed light on the quality of interhemispheric communication in ID. Finally, our participants showed remarkable improvement in their ability to coordinate their motor-behaviour response during the lexical decision task. Thus, despite accumulating evidence pointing to slow responses and deficient motor-behaviour coordination, our findings show that following a short training intervention, participants from both etiology groups performed as fast as their age-matched typically developed peers. These findings are in line with a previous study that tested the effects of intervention on acquiring visual metaphor comprehension in individuals with non-specific intellectual disability or Down syndrome (Shnitzer-Meirovich, Lifshitz, & Mashal, 2018). The results showed a significant improvement in both etiology groups, with greater improvement among individuals who underwent an extensive intervention programme that enhanced analogical thinking. Thus, there is evidence that individuals with non-specific intellectual disability and Down syndrome can benefit from training and intervention programmes. However, we are unable to conclude whether their behavioural performance is accompanied by neural changes. The extent to which individuals with intellectual disabilities demonstrate brain plasticity should be further tested with brain imaging techniques.

The current study also has some limitations. Because the response-buttons in the lexical decision task were not counterbalanced across participants (participants always pressed the "N" button for "yes" response and the "B" button for "no" response) future studies should balance the response buttons across participants in order to exclude the possibility that faster response times to the RVF/LH are related to a right-side affirmative response. Another limitation of the current study that should be mentioned is the experimenter sitting in front of the participants in order to observe participants' focus on the screen. This might have interfered with participant performance and future study should test its impacts on the results.

Conclusion

In summary, our results provide new evidence in respect to language lateralization in non-specific intellectual disability and Down syndrome. The current findings revealed typical brain lateralization in both etiologies, with reduced left lateralization in the Down syndrome group as compared to adults with typical development. However, we could not conclude whether the two cerebral hemispheres in these populations are, in fact, cross-transmitting information during the lexical decision task. Future studies with different methods are needed to address this topic. The current study emphasizes the importance of a gradual training programme tailored for each individual with intellectual disability to foster hidden capabilities that may lead to typical functioning in other cognitive domains.

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References

Aitchison, J. (2003). *Words in the mind: An introduction to the mental lexicon* (3rd ed.). Walden, MA: Blackwell Publishing.

Belger, A., & Banich, M. T. (1998). Costs and benefits of integrating information between the cerebral hemispheres: A computational perspective. *Neuropsychology*, *12*(3), 380–398.
Bishop, D. V. M. (1990). *Handedness and developmental disorders*. Philadelphia, PA: J.B. Lippincott.
Borkowski, J. G., & Büchel, F. P. (1983). Learning and memory strategies in the mentally retarded. In M. Pressley & J. R. Levin (Eds.), *Cognitive strategy research: Psychological foundations* (pp. 103–128). New York: Springer.
Bourne, V. J. (2006). The divided visual field paradigm: Methodological considerations. *Laterality: Asymmetries of Body, Brain and Cognition*, *11*(4), 373–393. doi:10.1080/13576500600633982
Cornoldi, C., Giofre, D., Orsini, A., & Pezzuti, L. (2014). Differences in the intellectual profile of children with intellectual vs. learning disability. *Research in Developmental Disabilities*, *35*, 2224–2230. doi:10.1016/j.ridd.2014.05.013
Costanzo, F., Varuzza, C., Menghini, D., Addona, F., Gianesini, T., & Vicari, S. (2013). Executive functions in intellectual disabilities: A comparison between William's syndrome and Down syndrome. *Research in Developmental Disabilities*, *34*, 1770–1780. doi:10.1016/j.ridd.2013.01.024
Elliott, D., & Weeks, D. J. (1990). Cerebral specialization and the control of oral and limb movements for individuals with Down's syndrome. *Journal of Motor Behavior*, *22*, 6–18. doi:10.1080/00222895.1990.10735499
Elliott, D., Weeks, D. J., & Chua, R. (1994). Anomalous cerebral lateralization and Down syndrome. *Brain and Cognition*, *26*, 191–195. doi:10.1006/brcg.1994.1050
Fink, W., & Cegelka, P. T. (1982). Characteristics of the moderately and severely mentally retarded. In P. T. Cegelka & H. Y. Prehm (Eds.), *Mental retardation: From categories to people* (pp. 231–259). Columbus, OH: Merrill.
Frith, U., & Frith, C. D. (1974). Specific motor disabilities in Down's syndrome. *Journal of Child Psychology and Psychiatry*, *15*, 293–301. doi:10.1111/j.1469-7610.1974.tb01253.x
Giencke, S., & Lewandowski, L. (1989). Anomalous dominance in Down syndrome young adults. *Cortex*, *25*, 93–102. doi:10.1016/S0010-9452(89)80009-7
Grieco, J., Pulsifer, M., Seligsohn, K., Skotko, B., & Schwartz, A. (2015). Down syndrome: Cognitive and behavioral functioning across the lifespan. *American Journal of Medical Genetics Part C: Seminars in Medical Genetics*, *169*(2), 135–149. doi:10.1002/ajmg.c.31439
Grossman, H. J., & Begab, M. J. (1983). *Classification in mental retardation*. Washington, DC: American Association on Mental Deficiency.
Gunn, P., & Crombie, M. (1996). Language and speech. In B. Stratford & P. Gunn (Eds.), *New approaches to Down syndrome* (pp. 249–267). London: Cassell.
Heath, M., Grierson, L., Binsted, G., & Elliott, D. (2007). Interhemispheric transmission time in persons with Down syndrome. *Journal of Intellectual Disability Research*, *51*(12), 972–981. doi:10.1111/j.1365-2788.2007.01009.x
Heath, M., Welsh, T. N., Simon, D. A., Tremblay, L., Elliott, D., & Roy, E. A. (2005). Relative processing demands influence cerebral laterality for verbal-motor integration in persons with Down syndrome. *Cortex*, *41*, 61–66. doi:10.1016/S0010-9452(08)70178-3
Hellige, J. B. (1987). Interhemispheric interaction: Models, paradigms and recent findings. In D. Ottoson (Ed.), *Duality and unity of the brain. Wenner-Gren center international symposium series, vol 47*. Boston, MA: Springer. doi:10.1007/978-1-4613-1949-8_27

Hulme, C., & Mackenzie, S. (1992). *Working memory and sever learning difficulties*. Hillsdale, NJ: Erlbaum.

Iacoboni, M., & Zaidel, E. (2003). Stable and variable aspects of callosal channels: Lessons from partial disconnection. In E. Zaidel & M. Iacoboni (Eds.), *The parallel brain. The cognitive neuroscience of the corpus callosum* (pp. 301–306). Cambridge, MA: MIT Press.

Kim, H. (1994). Distributions of hemispheric asymmetry in lefthanders and right-handers: Data from perceptual asymmetry studies. *Neuropsychology*, *8*, 148–159.

Lanfranchi, S., Baddeley, A., Gathercole, S., & Vianello, R. (2012). Working memory in Down syndrome: Is there a dual task deficit? *Journal of Intellectual Disability Research*, *56*(2), 157–166. doi:10.1111/j.1365-2788.2011.01444.x

Lifshitz, H., Kilberg, E., & Vakil, E. (2016). Working memory studies among individuals with intellectual disability: An integrative research review. *Research in Developmental Disabilities*, *59*, 147–165. doi:10.1016/j.ridd.2016.08.001

Linzen, T. (2009). *Corpus of blog postings collected from the Israblog website*. Tel Aviv: Tel Aviv University.

Mohr, B., Pulvermüller, F., Mittelstädt, K., & Rayman, J. (1996). Multiple simultaneous stimulus presentation facilitates lexical processing. *Neuropsychologia*, *34*(10), 1003–1013. doi:10.1016/0028-3932(96)00006-1

Mohr, B., Pulvermüller, F., Rayman, J., & Zaidel, E. (1994). Interhemispheric cooperation during lexical processing is mediated by the corpus callosum: Evidence from the split-brain. *Neuroscience Letters*, *181*(1-2), 17–21. doi:10.1016/0304-3940(94)90550-9

Natsopoulos, D., Christou, C., Koutselini, M., Raftopoulos, A., & Karefillidou, C. (2002). Structure and coherence of reasoning ability in Down syndrome adults and typically developing children. *Research in Developmental Disabilities*, *23*, 297–307. doi:10.1016/S0891-4222(02)00088-4

Paour, J. L. (1992). Induction of logic structures in the mentally retarded: An assessment and intervention instrument. In H. C. Haywood & D. Tzuriel (Eds.), *Interactive assessment* (pp. 119–166). New York: Springer.

Perrone-Bertolotti, M., Lemonnier, S., & Baciu, M. (2013). Behavioral evidence for inter-hemispheric cooperation during a lexical decision task: A divided visual field experiment. *Frontiers in Human Neuroscience*, *7*, 316. doi:10.3389/fnhum.2013.00316

Pinter, J. D., Eliez, S., Schmitt, J. E., Capone, G. T., & Reiss, A. L. (2001). Neuroanatomy of Down's syndrome: A high-resolution MRI study⍰. *American Journal of Psychiatry*, *158*, 1659–1665. doi:10.1176/appi.ajp.158.10.1659

Pipe, M. E. (1983). Dichotic-listening performance following auditory discrimination training in Down's syndrome and developmentally retarded children. *Cortex*, *19*, 481–491.

Pipe, M. E. (1988). Atypical laterality and retardation. *Psychological Bulletin*, *104*, 343–347. doi:10.1016/S0010-9452(83)80030-6

Pulvermiiller, F. (1992). Constituents of a neurological theory of language. *Concepts in Neuroscience*, *3*, 157–200.

Rayman, J., & Zaidel, E. (1991). Rhyming and the right hemisphere. *Brain and Language*, *40*(1), 89–105.

Schiff, R., & Kahta, S. (2009a). *Phonological awareness test battery* (Unpublished manuscript). Hadad Center, Bar-Ilan University, Ramat Gan, Israel.

Schiff, R., & Kahta, S. (2009b). *Single word reading test: Pointed and unpointed word reading* (Unpublished manuscript). Hadad Center, Bar-Ilan University, Ramat Gan, Israel.

Shnitzer-Meirovich, S., Lifshitz, H., & Mashal, N. (2018). Enhancing the comprehension of visual metaphors in individuals with intellectual disability with or without Down syndrome. *Research in Developmental Disabilities*, *74*, 113–123. doi:10.1016/j.ridd.2018.01.010

Van der Schuit, M., Segers, E., Van Balkom, H., & Verhoeven, L. (2011). How cognitive factors affect language development in children with intellectual disabilities. *Research in Developmental Disabilities*, *32*(5), 1884–1894. doi:10.1016/j.ridd.2011.03.015

Vicari, S., Bellucci, S., & Carlesimo, G. A. (2005). Visual and spatial long term memory: Differential pattern of impairments in Williams and Down syndromes. *Developmental Medicine and Child Neurology*, *47*(5), 305–311. doi:10.1017/S0012162205000599

Wang, P. P., Doherty, S., Hesselink, J. R., & Bellugi, U. (1992). Callosal morphology concurs With neurobehavioral and neuropathological findings in two neurodevelopmental disorders. *Archives of Neurology*, *49*, 407–411. doi:10.1001/archneur.1992.00530280101029

Wechsler, D. (2001). *Wechsler adult intelligence scale* (3rd edn). San Antonio, TX: Psychological Corporation.

Welsh, T. N., & Elliott, D. (2001). The processing speed of visual and verbal movement information by adults with and without Down syndrome. *Adapted Physical Activity Quarterly*, *18*, 156–167. doi:10.1123/apaq.18.2.156

Welsh, T. N., Elliott, D., & Simon, D. A. (2003). Cerebral specialization and verbal-motor integration in adults with and without Down syndrome. *Brain and Language*, *84*, 152–169. doi:10.1016/S0093-934X(02)00511-4