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Counting Ability in Down Syndrome: The Comprehension of the One-to-One Correspondence Principle and the Role of Receptive Vocabulary

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Objective: The authors investigated whether children with Down's syndrome (DS) who have not started to produce number words understand the one-to-one correspondence principle (Experiment 1), and they looked at the relationship between number word knowledge and receptive vocabulary (Experiment 2). ***Method:*** Sixteen children with DS who did not recite the count list participated in Experiment 1, along with 2 comparison groups: 1 of 16 children with DS who recited up to 10, paired by chronological age, and another of 16 typically developing children paired by their ability to recite the list. The understanding of the principle was evaluated by a preferential looking task. Children saw 1 of 2 conditions. In the number condition, they heard number words and in the beep condition they heard computerized beeps. In both conditions, children saw videos depicting counting events that were principle-consistent or principle-inconsistent. Experiment 2 evaluated 25 children with DS using the Give-a-Number task and the Receptive Vocabulary subtest of the Wechsler Preschool and Primary Scale of Intelligence-III. ***Results:*** In Experiment 1, children in the number condition preferred principle-consistent videos, independent of their ability to recite the count list. Experiment 2 showed a strong correlation between number word knowledge and receptive vocabulary scores, independent of chronological age. ***Conclusions:*** The results suggest that the difficulty of children with DS in acquiring counting ability might not reflect a lack of understanding of the one-to-one correspondence principle, but might instead be related to vocabulary development.

General Scientific Summary
This study shows that children with DS, independent of their ability to recite the count list, preferred to watch videos that are principle-consistent over those that are not consistent, suggesting that they understand the one-to-one correspondence principle. It also shows a strong link between the number word knowledge of children with DS and their receptive vocabulary scores, independent of chronological age.

Keywords: Down's syndrome, counting, one-to-one correspondence, receptive vocabulary, preferential looking task

Children with Down's syndrome (DS) have difficulty learning several numerical and mathematical abilities (Brigstocke, Hulme, & Nye, 2008), including counting (Gelman & Cohen, 1988; Nye, Fluck, & Buckley, 2001). To explain this phenomenon, researchers have explored the possibility of a deficit in one of the core cognition systems of number (e.g., Sella, Lanfranchi, & Zorzi, 2013) that results in impaired numerical abilities in typically developing children (Mazzocco, Feigenson, & Halberda, 2011; Schleifer & Landerl, 2011). Alternatively, children with DS may have difficulty understanding the so-called how-to-count principles, which guide counting acquisition (Gelman & Cohen, 1988; Nye et al., 2001; Porter, 1999). One other possibility is that these difficulties might result from affected linguistic abilities (Nye, Clibbens, & Bird, 1995), an explanation that finds support in recent studies showing a close relationship in typical development between different aspects of language (e.g., receptive vocabulary or morphological abilities) and counting (Almoammer et al., 2013; Carey, 2009; Le Corre, Li, Huang, Jia, & Carey, 2016; Negen & Sarnecka, 2012).

The current study aimed to investigate the latter two possibilities, which have received less attention than the first. In Experiment 1, we evaluated whether children with DS who have not

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started to produce number words understand the how-to-count principle that appears earliest in development: the one-to-one correspondence principle. In Experiment 2, we explored the possible contribution of receptive vocabulary to number word knowledge in children with DS.

Core Cognition Systems of Number in DS

A working hypothesis explaining the difficulty in learning to count and other numerical difficulties of children with DS focuses on a deficit in the core cognition systems for number representation (Paterson, Girelli, Butterworth, & Karmiloff-Smith, 2006; Sella et al., 2013). According to some authors, these cognitive systems are shared with nonhuman animals, are innate (i.e., not learned), are present throughout development, and are present in all cultures, independent of formal education (Carey, 2009; Spelke & Kinzler, 2007). These systems are the object tracking system (OTS), which allows tracking of up to four objects, and the approximate number system (ANS), which allows for the approximate comparison and estimation of numerosities larger than four (Feigenson, Dehaene, & Spelke, 2004; Mou & vanMarle, 2014; Piazza, 2010).

To evaluate whether these systems are preserved in DS, a host of studies have looked at children's ability to compare numerical quantities and other indices of the accuracy of the ANS and OTS (Abreu-Mendoza & Arias-Trejo, 2015; Belacchi et al., 2014; Camos, 2009; Lanfranchi, Berteletti, Torrisi, Vianello, & Zorzi, 2015; Paterson et al., 2006; Sella et al., 2013). Studies have reported that children with DS show the same performance comparing large numerosities (larger than four) as typically developing children with the same mental age (Abreu-Mendoza & Arias-Trejo, 2015; Camos, 2009; Sella et al., 2013). However, children with DS have difficulty comparing numerosities within the range of the object tracking system (Paterson et al., 2006; Sella et al., 2013). Paterson et al. (2006) reported that infants with DS with a mental age of 15 months could not discriminate changes in small numerosities. However, two groups of typically developing children, one matched by mental age and the other by chronological age, in addition to a group of infants with Williams syndrome, could successfully discriminate such changes. This difficulty has an impact on later development: In childhood, individuals with DS who have lower performance on a task that consists of matching two collections of one to four dots each, based on numerosity, have lower scores on a standardized test of numerical abilities than children with DS who have higher scores on the matching task (Sella et al., 2013). These studies suggest that although their ability to compare small and large numerosities is greatly delayed in comparison with typically developing children, the capacity of children with DS to compare large numerosities is appropriate to their mental age, while their ability to compare small numerosities is greatly impaired.

The Acquisition of the Counting Principles in DS

According to Gelman and Gallistel (1978), typically developing children acquire counting guided by the how-to-count principles: the one-to-one correspondence principle, which states that one distinct number word must be assigned to each object to be counted; the stable order principle, which holds that number words must have a fixed order; and the cardinality principle, which requires that the last number word in a counting routine equals the number of items in a set. If children follow these principles during a counting routine, they arrive at an accurate count.

Typically developing children follow a developmental pattern to acquire these principles. Eighteen-month-olds distinguish between counting events that are consistent with the one-to-one correspondence principle and those that are not (Slaughter, Itakura, Kutsuki, & Siegal, 2011). Around two years of age, children produce the count list in a stable manner, but they do not know the meaning of number words. During the next year and a half, children give meaning to *one*, *two*, *three*, and *four*, one by one. Finally, between three and a half and four years of age, children learn the cardinality principle (Le Corre, Van de Walle, Brannon, & Carey, 2006; Wynn, 1990, 1992). This developmental pattern has been replicated in children from different cultures and with different languages (Almoammer et al., 2013; Le Corre et al., 2016; Sarnecka, Kamenskaya, Yamana, Ogura, & Yudovina, 2007).

Children with DS have difficulty in learning the how-to-count principles. In an early study, Gelman and Cohen (1988) suggested that children with DS might learn to count using rote learning instead of these principles. Porter (1999) evaluated whether children with DS adhere to the principles during their counting routines using a simple count task and an error detection task. In the first task, children with DS were more likely to adhere to the one-to-one correspondence principle (i.e., tagging each object once) than to the other two principles. Surprisingly, in the error detection task, only three of the 16 children with DS were able to verbally report whether a puppet followed the how-to-count principles in its counting routine. Nye et al. (2001) found that children with DS also produced shorter count lists than typically developing children matched by nonverbal mental age.

These studies suggest that children with DS may be able to use the one-to-one correspondence principle, but not the stable order or the cardinality principle. Nevertheless, it is still unclear whether, like typically developing children, they understand this principle before producing number words. In the study by Porter (1999), the simple counting task simultaneously evaluated the three principles. Although in a previous article, Porter (1998) argued that the error detection task might facilitate children's assessment by removing performance demands, this task might not have been appropriate for children with DS because of its linguistic demands.

More recently, Slaughter et al. (2011) used a preferential looking task to evaluate typically developing infants' comprehension of the one-to-one correspondence principle. Unlike error detection tasks, this task did not require a verbal response. The authors evaluated 15- and 18-month-olds by showing videos that were either consistent or inconsistent with the principle. They found that 18-month-olds preferred to watch videos in which a hand counted to six, pointing to all six objects (principle-consistent videos) over those that showed a hand counting up to six, but pointing only to two objects (principle-inconsistent videos). To rule out the possibility that this preference might be a general preference for a hand pointing to all objects or a preference for a nonnumerical one-to-one correspondence, the authors evaluated two additional groups of 18-month-olds in two conditions: one in which number words were replaced by a beep sound, and another in which the number words were replaced by number words from another language. Under these conditions, 18-month-olds did not show a preference for the principle-consistent videos, suggesting that their preference is not a perceptual one.

Receptive Vocabulary and Number Word Knowledge

Several aspects of language contribute to number development. As early as 12 months of age, typically developing infants can use lexical information (e.g., contrasting one vs. two pseudowords) to infer whether there is more than one object hidden in a box (Xu, Cote, & Baker, 2005). Children can also use morphological cues to distinguish between singular and plural sets: 2-year-olds orient their attention to a collection of more than one object when they hear the plural morpheme (Arias-Trejo, Cantrell, Smith, & Alva Canto, 2014; Kouider, Halberda, Wood, & Carey, 2006).

With respect to counting acquisition, recent evidence has suggested a strong link between children's vocabulary and their number word knowledge. Negen and Sarnecka (2012) found a relation between children's receptive and expressive vocabulary scores and their number word knowledge as measured by the give-a-number task. Children who understood and produced more words were those who knew the meaning of more number words as well. This relationship has been found not only in typically developing children, but also in children with genetic syndromes. Ansari et al. (2003) reported that mental verbal age, measured by a receptive vocabulary test, predicted the performance of children with Williams syndrome in the give-a-number task, even after controlling for chronological age and for visuospatial abilities.

There is indirect evidence that suggests that receptive vocabulary also makes a contribution to number word knowledge in children with DS. Nye et al. (1995) found a statistical correlation between the composite score of children with DS on a numerical abilities test including several counting tasks and their scores on the Test for Reception of Grammar (Bishop, 1983). Porter (1999) reported a correlation, independent of chronological age, between the performance of children with DS on a counting task and their receptive vocabulary scores.

The Current Study

To shed light on the difficulty of children with DS with counting acquisition, the current study presents two experiments. In Experiment 1, we investigated whether children with DS who do not produce number words understand the one-to-one correspondence principle. For this goal, we used the preferential looking task proposed by Slaughter et al. (2011) to evaluate the comprehension of the one-to-one correspondence principle of a group of children with DS who did not recite the count list. As in Experiments 1 and 2 of Slaughter et al., children with DS saw a condition in which they heard number words or saw a control condition in which they heard a beep sound. For the sake of simplicity, however, we used only one of their two control conditions—the beep but not the Japanese number word. We also contrasted the looking times of children with DS with those of two comparison groups: (a) a group of typically developing children paired by their ability to recite the count list; and (b) a group of children with DS, paired by chronological age, who recited the count list up to 10. We included this second group under the hypothesis that these children with DS, like the typically developing children, would understand the one-to-one correspondence principle. In this way, we could determine whether the task was appropriate for children with DS.

In Experiment 2, we investigated the relation between the receptive vocabulary of children with DS and their number word knowledge. To achieve this goal, we evaluated children with DS using the give-a-number task and the Receptive Vocabulary subtest of the Wechsler Preschool and Primary Scale of Intelligence-III (Wechsler, 2011).

Experiment 1

Method

Participants. The noncounting group with DS consisted of 16 children (four girls) who did not recite any number word (median count list length = 0; mean chronological age = 7.39 years [*SD* = 2.22]; and mental age = 3.03 years [*SD* = 0.54]). Their performance was contrasted with a counting group of 16 children with DS (9 girls) who counted up to 10 (median count list length = 10), matched by chronological age, and a noncounting typically developing group of 16 children (8 girls) matched by their ability to recite the count list (median count list length = 0). For the noncounting group with DS, the criteria included (a) not to count beyond three, (b) chronological age between 4.0 and 11.9 years, and (c) normal or corrected vision. For the counting group of children with DS, the criteria were the same as that of the noncounting group, except that children counted beyond the highest number word mentioned in the preferential looking task, that is, that they counted up to at least seven. Inclusion criteria for the noncounting group of typically developing children were (a) not to count beyond three, (b) chronological age between 2.5 and 3 years, and (c) IQ ≥85.

Table 1 shows the detailed statistics for the comparison between the noncounting group with DS and the two other groups. As suggested for comparison groups (Kover & Atwood, 2013;

Table 1
Group Characteristics

Characteristic	NC group *M* (*SD*)	C group *M* (*SD*)	TD group *M* (*SD*)	*p*	Cohen's *d*	Variance ratios
Chronological age (years)	7.39 (2.22)	7.84 (2.35)	2.59 (.13)	.579	.198	1.12[a]
Mental age (years)	3.04 (.54)	3.7 (.81)	*n.a.*			
Count list	.81 (1.28)	9.68 (.79)	1.06 (1.34)	.593	.191	1.10[b]

[a] *p* value for the *t*-test between noncounting (NC) group and counting (C) group. [b] *p* value for the *t*-test between NC group and typically developing (TD) group.

Steiner, Cook, Shadish, & Clark, 2010), p values for the control variables (chronological age and reciting abilities) were larger than .5, Cohen's d values were small ($d < 2$), and the variance ratios were within the acceptable range (0.8–1.25). There were no significant differences in the female/male ratios across groups, $\chi^2(2, N = 48) = 3.56$, $p = .17$.

Ten additional children were evaluated but excluded: three children with DS who recited the count list beyond three but not up to seven, and seven typically developing children who counted up to 10.

Instruments and procedures.

Abbreviated version of the Wechsler Preschool and Primary Scale of Intelligence-III. The mental age of children with DS and the IQ of typically developing children were determined with an abbreviated version of the Mexican adaptation of the Wechsler Preschool and Primary Scale of Intelligence-III (WPPSI-III; Wechsler, 2011), which included the following subtests: Receptive Vocabulary, Block Design, and Object Assembly. This abbreviated version, as reported by Sattler (2010), has high reliability (.93) and validity scores (.74). Within our sample of children with DS ($n = 32$) it was highly reliable (72 items; $\alpha = .933$).

Receptive vocabulary. In this subtest children are shown four images and asked to point to the image that corresponds to the one named by the experimenter. This subtest comprises 38 items, which increase in complexity as the subtest progresses. The first item is "Señala el pie" ("Point to the foot") and the last is "Señala la línea horizontal" ("Point to the horizontal line"). The subtest is finished either when children answer all the items or when they answer five consecutive items incorrectly. Children are given one point for each correct response.

Block design. This subtest is a timed subtest composed of 20 items in which children are asked to reproduce designs that are either physically present or shown on a printed card. The subtest is finished either when they complete the 20 items or when they have three consecutive scores of zero.

Object assembly. This subtest comprises 14 items in which children have to put together pieces of a puzzle to form a familiar object (e.g., ball, hot dog, or car). Children have 90 s to complete each item. The complexity of the puzzles increases as the subtest progresses.

Count list elicitation task. To determine the highest number word they could recite, children were presented with a single row of 10 colored plastic turtles and asked to count them. The last number word they said correctly was considered the highest number they could recite. For example, if a child said "one, two, three, six," it was determined that the child could count to three.

Preferential looking task. To evaluate children's comprehension of the one-to-one correspondence principle, we employed an adapted version of the preferential looking task employed by Slaughter et al. (2011). Children were assigned in a counterbalanced manner to either the number condition or the control condition (hereafter, the beep condition). Both conditions consisted of 16 flash-created videos of 9.7 s presented in four blocks. Videos were either principle-consistent or principle-inconsistent. In the number condition, principle-consistent videos started with an image of six identical cartoon-like yellow fish arranged in two rows of three; simultaneously, the phrase "¡Ve los peces!" ("Look at the fish!") was heard. Then, a cartoon-like hand appeared from one of the four corners of the image and pointed to each fish while reciting the count list, in Spanish, up to six. In the principle-inconsistent videos, the hand only pointed toward two of the six fish (the two left-most or the two right-most); however, the six number words were still heard (see Figure 1). The beep condition was similar to the number condition, but number words were replaced by computerized beeps. As in Slaughter et al. (2011), there were two different hands and two different female speakers for both conditions.

The assignment of the two different hands and the two female speakers in the two types of trials was counterbalanced across children. The appearance of the hand from the right or left side, or from the top or bottom corner, was counterbalanced across blocks. As in the original work by Slaughter et al. (2011), a given block presented two consecutive principle-consistent or principle-inconsistent videos; the start of the block with a principle-

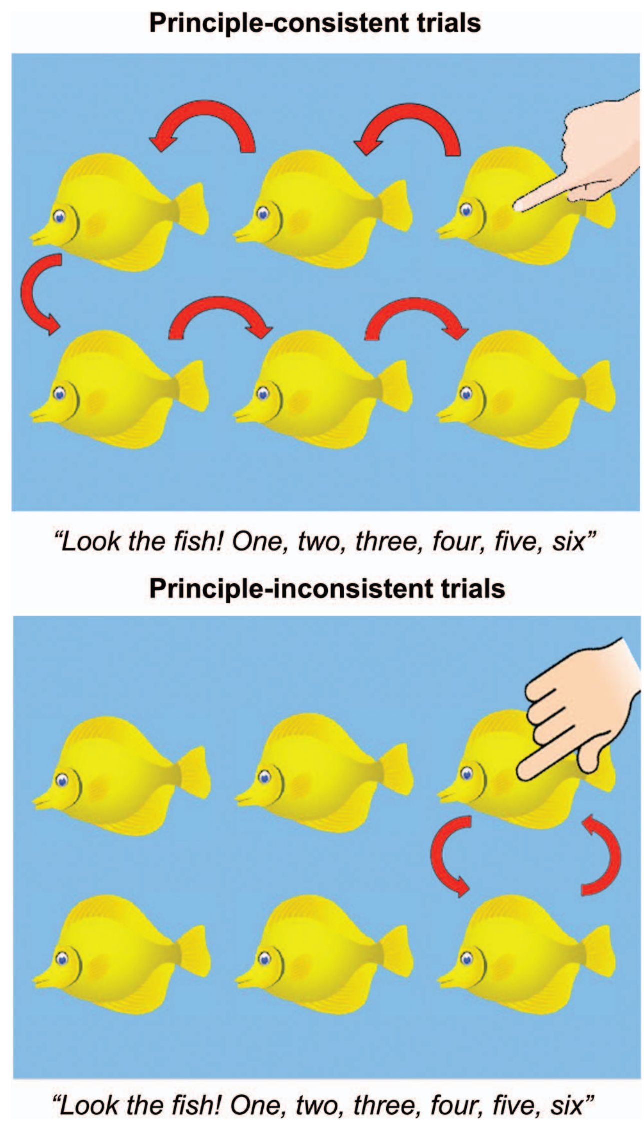

Figure 1. An example of trial presentation in the number condition. Red (dark gray) arrows were not used in the actual videos. See the online article for the color version of this figure.

consistent or principle-inconsistent video was counterbalanced across blocks.

Children were seated 65 cm from a 23-inch LED monitor. A portable eye-tracker (Tobii ×2-30, Tobii Technology, Danderyd, Sweden) placed in the lower area of the monitor frame registered the binocular gaze position with a sampling rate of 30 Hz. Before task presentation, children's eye-gaze was calibrated with a five-point infant calibration.

General procedure. Before the experiment, parents gave informed consent for their children to participate in the study. Participants were evaluated in a quiet room at their schools or in our laboratory. The session began with the mental age assessment, followed by the count list elicitation task and the Give-a-Number task (see Experiment 2). There was then a 10-min break before the preferential looking task.

Statistical analyses. To analyze children's performance in the preferential looking task, we first averaged looking times in the two consistent trials and the two inconsistent trials of each block. Then, for each block, we subtracted the average looking times for the principle-inconsistent videos from those for the principle-consistent videos. Finally, we averaged the differences for all blocks (total attention difference). A positive difference, significantly greater than chance level (0 ms), would indicate a preference for the principle-consistent videos.

We tested homogeneity of variances with Levene's test, and then, with Total Attention Difference as the dependent variable, we performed a 3 × 2 analysis of variance (ANOVA) with Group (noncounting group with DS, counting group with DS, or noncounting typically developing group) and Condition (number vs. beep) as between-subjects factors. Finally, to determine children's preference for the principle-consistent videos, we performed one-sample t tests against chance. Partial eta-squared and Cohen's d are reported as effect size measures for main effects and one-sample t tests, respectively.

Results and Discussion

Levene's test for equality of variances was not significant (p = .569). The ANOVA with Group and Condition as between-subjects factors yielded a main effect of Condition ($F(1, 42) = 12.40$, $p < .001$, $\eta_p^2 = .23$): children in the number condition had positive looking times, in contrast to those in the beep condition. There was no other significant effect, Group; $F(2, 42) = 0.51$, $p = .604$, $\eta_p^2 = .02$ or significant interaction, Group x Condition; $F(2, 42) = 0.27$, $p = .76$, $\eta_p^2 = .01$. To evaluate whether children preferred the principle-consistent to the principle-inconsistent videos, we performed post hoc one-sample t tests against chance level (zero). These analyses indicated that children in the number condition preferred the principle-consistent videos ($M = 363.21$ ms, $SD = 807.42$; $t(23) = 2.20$, $p = .038$, Cohen's $d = 0.45$); however, children in the beep condition preferred the principle-inconsistent videos ($M = -474.69$ ms, $SD = 796.63$; $t(23) = -2.92$, $p = .008$, Cohen's $d = 0.59$) (see Figure 2).

These results replicate and expand the findings of Slaughter et al. (2011), showing that children with DS, independent of their ability to recite the count list, and typically developing children who do not recite number words, prefer to watch videos that are consistent with the one-to-one correspondence principle. Furthermore, children in the control (beep) condition did not show this preference, suggesting that the preference for the consistent videos in the number condition is not driven by the perceptual salience of these videos (e.g., that the hand moved a greater distance). In fact, children in the beep condition showed an unexpected pattern: They had a significant preference for the inconsistent videos.

Because the videos differed only in the audio presented, it is difficult to interpret this preference. One possible explanation is that because the beep sound did not change, children may have interpreted principle-inconsistent videos in which there were vertical movements and only one beep sound as more consistent than

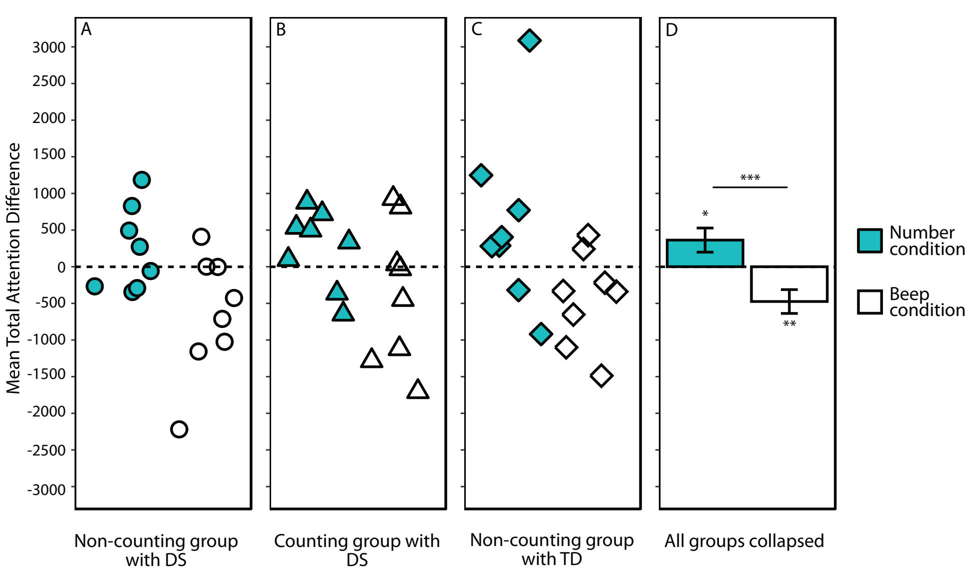

Figure 2. Panels A to C show data points for children from the three groups. Panel D shows the mean (± 1 SE) Total Attention Difference with the data of the three groups collapsed. Dotted lines represent chance level (0 ms). *$p < .05$. **$p < .01$. ***$p < .001$. See the online article for the color version of this figure.

principle-consistent videos in which there were vertical and horizontal movements and only one beep sound. However, this interpretation is unlikely. Slaughter et al. (2011) used a condition using Japanese number words instead of a beep sound and found no difference between the Japanese word condition and the beep condition. Their findings still do not explain children's preference in our study for the inconsistent videos in the beep condition.

An alternative explanation may be related to the expectations that children had in each condition. Number words during a counting routine are associated with specific movements, such as those from left to right. Even adults instructed to count out loud have specific eye-movement patterns (Hartmann, Mast, & Fischer, 2016). If children have knowledge about the relationship between these movement patterns and number words, number words will create an expectation of what should happen during the videos. Beep sounds, however, are not associated with a movement pattern. Children thus do not have any prior knowledge based on acoustic input and may have to rely only on the perceptual information available in the videos. In both conditions, number and beep, horizontal movements were presented only in the principle-consistent videos, but vertical movements were shown in both consistent and inconsistent videos. Another possible explanation for children's preference in the beep condition for the inconsistent videos is that they spent more time looking to figure out the movement pattern of the hand because the beep sound was not sufficient to make sense of the event displayed.

Experiment 2

Method

Participants. This experiment included 25 children with DS (11 girls), 21 from Experiment 1 and four others. Their mean chronological age was 8.28 years (SD = 2.36) and their mean mental age 3.5 years (SD = 0.66). To include as many children with DS as possible, but also rule out the possibility that children's performance in the give-a-number task was limited to the lack of production of number words, we included only children who were able to recite the count list up to at least two.

Instruments and procedure.

Receptive vocabulary subtest. The reliability reported for this subtest is appropriate (α = *.87;* Wechsler, 2011), and within our sample it was also appropriate (α = .88). The maximum possible score on this subtest is 38.

Block design subtest. The reliability reported for this subtest is appropriate (α = *.89;* Wechsler, 2011), and within our sample it was α = .82. The maximum possible score on this subtest is 40.

Object assembly subtest. The reliability reported for this subtest is appropriate (α = *.87;* Wechsler, 2011), and within our sample it was α = .80. The maximum possible score on this subtest is 37.

Number word knowledge. Children's number word knowledge was evaluated by means of the give-a-number task (Wynn, 1990, 1992), following the procedure described in Abreu-Mendoza, Soto-Alba, and Arias-Trejo (2013). A child was seated in a chair facing the experimenter and told that the experimenter wanted to play a game with turtles. The experimenter placed the plastic container with 10 turtles in front of the child and said: "Mira estas tortugas, son bonitas, ¿te gustan? ¿Quieres jugar con ellas?" ("Look at these turtles, they are nice, do you like them? Do you want to play with them?"). Once the child said "Sí" ("Yes"), the experimenter asked: "¿Podrías darme una tortuga? ¿Podrías poner una tortuga en la mesa?" ("Could you give me one turtle? Could you put one turtle on the table?"). In the absence of a response, the same two questions were repeated a maximum of two times. If the child gave one turtle, the experimenter provided positive feedback and proceeded to ask for two: "¿Podrías darme dos tortugas? ¿Podrías poner dos tortugas en la mesa?" ("Could you give me two turtles? Could you put two turtles on the table?"). If the child gave the correct number of turtles, the experimenter asked for the next number, up to six turtles. If not, the experimenter said "Pero yo quiero dos tortugas. ¿Puedes arreglarlo para que haya dos?" ("But I want two turtles. Can you fix it so there are two?") and waited for a change in response. If the child did not correct the response, the experimenter went back to the preceding number. If there was one success and one failure, the experimenter asked a third time for the target number, and if the child succeeded, asked for the next number. The task stopped either when the child failed to give the same number twice or gave six turtles correctly twice.

To determine whether children knew the meaning of given number words, we followed the criteria used in other studies (Le Corre & Carey, 2007; Negen & Sarnecka, 2012; Wynn, 1990). Children were categorized as knowers of the highest number they were able to give correctly two out of three times, but only if they did not give the number more than half as often when asked for a different number. Furthermore, children who failed to give the number one were considered pre-number-knowers, whereas those who succeeded twice in giving six turtles correctly were considered to know the cardinality principle.

Statistical analysis. As a first step, we performed analyses similar to those reported by Negen and Sarnecka (2012) in their Experiments 1 and 2: Pearson correlations between children's knower level and their raw scores in the Receptive Vocabulary, Block Design, and Object Assembly subtests. We then performed partial correlations between the knower level and the raw scores of the three subtests, controlling for chronological age. Finally, to find the percentage of variance accounted for by receptive vocabulary after controlling for chronological age, and to exclude the possibility that chronological age could contribute to children's number word knowledge after controlling for receptive vocabulary, we performed two hierarchical lineal regressions. In the first model, we introduced chronological age as first predictor and then receptive vocabulary. In the second model, we first introduced receptive vocabulary and then chronological age.

Results and Discussion

Children's mean raw scores on the three subtests of the WPPSI-III were as follows: Receptive Vocabulary, M = 15.12 (SD = 6.91, range = 4–28); Block Design, M = 16.92 (SD = 5.51, range = 3–26); and Object Assembly, M = 13.24 (SD = 6.97, range = 4–29). Table 2 shows children's categorization based on their performance in the give-a-number task; importantly, there were no differences in children's count list length across the different Knower levels, $\chi^2(6)$ = 6.32, p = .39.

Table 3 shows the results of the Pearson correlations between children's knower level, chronological age, and the raw scores on

Table 2
Count List Length as Function of Knower-Level

Knower level	*n*	Count list length	
		Median	Range
Pre-knowers	9	7	2–10
One-knowers	6	10	5–10
Two-knowers	1	10	10
Three-knowers	3	5	3–10
Four-knowers	2	9.5	9–10
Five-knowers	1	10	10
CP-knowers	3	10	10

Table 4
Hierarchical Regression Models With Number Word Knowledge as Dependent Variable

Step	Predictor	R^2	ΔR^2
Model 1			
1	Chronological age	.182	.182*
2	Receptive vocabulary	.338	.155*
Model 2			
1	Receptive vocabulary	.270	.270**
2	Chronological age	.338	.068

* $p < .05$. ** $p < .01$.

the three subtests. In line with Negen and Sarnecka (2012), there was a significant correlation between children's knower level and their raw scores on the Receptive Vocabulary subtest, $r = .52$, $p = .008$. There were also significant correlations between children's knower level and the other three variables: Chronological age, $r = .43$, $p = .033$, block design, $r = .43$, $p = .0330$, and object assembly, $r = .40$, $p = .045$. Because chronological age could mediate the aforementioned correlations, we performed partial correlations controlling for this variable. Table 3 shows that, after controlling for chronological age, Receptive Vocabulary was the only subtest that significantly correlated with children's number word knowledge, $r = .44$, $p = .033$. Finally, Model 1 shows that, after controlling for chronological age, receptive vocabulary still explains a significant variance of children's number word knowledge (15% of variance); more importantly, Chronological age does not explain any significant variance when controlling for receptive vocabulary (see Table 4).

The same relationship found in typically developing children was also found in children with DS (Negen & Sarnecka, 2012). Those children with DS who understand more words are also those who know the meaning of more number words, even after controlling for chronological age. This relationship was true only for these two variables. Correlation between the scores of other two subtests and number word knowledge was no longer significant after controlling for chronological age.

General Discussion

Several explanations have been given for the difficulty that children with DS have in learning to count. Some authors have suggested a deficit in the core systems for number (Paterson et al., 2006; Sella et al., 2013), some an impaired ability to use the how-to-count principles (Gelman & Cohen, 1988), and others have highlighted the role of linguistic abilities (Nye et al., 1995). The current study aimed to shed light on this difficulty with two experiments that explored whether it is related to a lack of understanding of the one-to-one correspondence principle or the role of receptive vocabulary in learning the meaning of number words. In Experiment 1, we showed that children with DS, regardless of their ability to produce the count list, and typically developing children who do not produce number words, prefer to watch videos that show a counting routine that is consistent with the one-to-one correspondence principle over videos that are not. In Experiment 2, we found a strong link between the receptive vocabulary of children with DS and their knowledge of number words. In the following paragraphs, we discuss these outcomes.

Table 3
Simple Correlation and Partial Correlation, Controlling for (Chronological) Age

Variable	1	2	3	4	5
1. Age	—	.43*	.35	.54**	.22
2. Number word knowledge	—	—	.52**	.43*	.40*
3. Receptive vocabulary	—	.44*	—	.42*	.52**
4. Block design	—	.27	.30	—	.50*
5. Object assembly	—	.35	.48*	.46*	—

Note. Simple correlations appear above the diagonal, partial correlations below the diagonal.
* $p < .05$. ** $p < .001$.

The Understanding of the One-to-One Correspondence Principle in DS

It has been argued that children with DS do not use the how-to-count principles to acquire counting; instead, they might use rote learning for this purpose (Gelman & Cohen, 1988). Prior studies have shown that in error detection tasks, children with DS failed to report whether counting sequences follow the principles (Porter, 1999). The current study, however, suggests that the understanding of the one-to-one correspondence principle is preserved in children with DS. Using an adaptation of the task proposed by Slaughter et al. (2011), we showed that both these children and typically developing children, regardless of their ability to recite the count list, preferred to watch videos in which a hand pointed to and tagged once each of the six fish presented over videos in which a hand pointed to three times and tagged two fish out of the six fish presented. This result might be related to the low cognitive demands of the preferential looking task: instead of providing a verbal or motor response, children in this task only had to watch a video.

An unexpected finding was children's preference for the inconsistent videos in the beep condition, for which there are two possible explanations. Children may have interpreted these videos as more perceptually consistent (one beep-one gesture). However, Slaughter et al. (2011) showed that there were no differences between a control condition with a beep sound and one with unfamiliar linguistic input (Japanese number words to American children). Alternatively, they may have spent more time looking at these videos to understand the hand movement because the beep sound was not sufficient to make sense of the event.

More generally, our results suggest the possibility that children with DS, like their typically developing peers, learn to count guided by the how-to-count principles. Children with DS may understand these principles but fail to employ them in their counting routines because of deficits in non-numerical abilities (e.g., working memory, Lanfranchi, Jerman, & Vianello, 2009). To support this view, future evidence would be required to show that children with DS understand the stable order and cardinality principles in low cognitive demand tasks. It is also important to mention that this possibility, unlike the continuity hypothesis (Gelman & Gallistel, 1978, 2004), still requires children with DS to learn the how-to-count principles in the appropriate developmental time, that is, accordingly to their mental age, recalling that at certain stages of development, even typically developing children fail to show an understanding of these principles in error detection tasks (Le Corre et al., 2006).

The Role of Receptive Vocabulary on the Number Word Knowledge of Children With DS

In line with two previous studies, one with typically developing children (Negen & Sarnecka, 2012) and the other with children with DS (Porter, 1999), the receptive vocabulary of children with DS in this study was found to be related to their number word knowledge. After controlling for chronological age, receptive vocabulary scores explained 15% of the variance in number word knowledge. As causal direction is unclear in correlational studies, one question still unanswered is how receptive vocabulary and number word knowledge are related in children with DS. The simplest explanation involves not an interaction between number words and words in general, but the general ability to learn new words: that the relationship between receptive vocabulary and number word knowledge reflects only that some children with DS are better at learning words, in general, than others.

An alternative explanation is that children with DS who know the meaning of more words might spend more time finding the meaning of number words than those who know fewer words. This explanation is indirectly supported by studies with typically developing children showing that children are better at learning the meaning of number words when they are presented after familiar nouns (e.g., "Look! Bears, can you show me *four*?") than when they are presented before those nouns (e.g., "Look! Can you show me *four* bears?") (Ramscar, Dye, Popick, & O'Donnell-McCarthy, 2011). That is, when children hear a new number word after a familiar noun, they can rule out the already known noun as a meaning of the number word. Children with DS with larger vocabularies might discard the meaning of an already known noun as a possible meaning of a number word.

One last possibility is the role of a third factor mediating the relationship between receptive vocabulary and number word knowledge. Nye et al. (1995) found a significant correlation between the receptive grammar scores of children with DS and their numerical abilities, but failed to find a correlation between receptive vocabulary scores and those abilities. As we evaluated only receptive vocabulary and not grammatical knowledge, it is possible that the latter may mediate the relationship. However, this explanation is unlikely because grammatical abilities are more affected in children with DS than lexical abilities (Vicari, Caselli, & Tonucci, 2000).

These conclusions of the current study should be considered in light of its limitations, one of which is the sample size of the groups in Experiment 1. Although there were 16 children in each group, a sample size typically reported in experimental studies (Abreu-Mendoza & Arias-Trejo, 2015; Camos, 2009; Sella et al., 2013), there were only eight children in each condition. Further studies with larger samples would be useful, and now that two studies have reported similar findings, those studies could use a within-subjects design to overcome the limitation imposed by a small sample. Another limitation, in Experiment 2, is the lack of other linguistic predictor variables. Future studies could expand upon our results by including such variables to determine whether another aspect of language mediates the relationship found in Experiment 2.

Finally, though it was beyond the scope of this study to investigate the interaction of the core cognition systems with linguistic abilities, future studies could explore the effects of this interaction and the independent effect of number core cognition and language to explain the numerical difficulties of children with DS.

Two overall conclusions can be drawn from this study. First, children with DS, independent of their ability to recite the count list, show an understanding of the one-to-one correspondence principle. Second, as in typically developing children, there is a strong link between the receptive vocabulary abilities of children with DS and their knowledge of number words. These results could have practical implications. Aside from specific interventions to improve numerical abilities (Lanfranchi, Aventaggiato, Jerman, & Vianello, 2015), children with DS could benefit from interventions that improve their receptive vocabulary, as it could help them to learn the meaning of new number words.

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