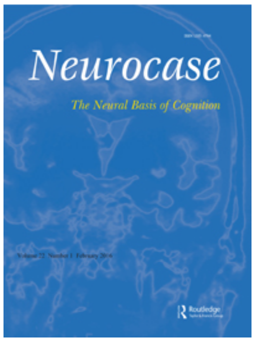

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Early occipital injury affects numerosity counting but not simple arithmetic

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This study investigated the effects of early occipital injury on the development of counting and simple arithmetic abilities in an occipital epileptic patient. This patient had obvious softening lesions in the bilateral occipital regions due to viral encephalitis at the age of 1.5 years. Results showed that she could perform subitizing and simple arithmetic very well, but could not perform numerosity counting tasks. These results suggest that the occipital cortex plays an important role in the development of numerosity counting skills, but not in the development of subitizing and simple arithmetic.

Keywords: occipital cortex; counting; numerical processing; language processing; early brain injury

Children begin to learn numerosity counting at a very early age (Gelman, 1986), such as 2–3 years (Wynn, 1990), or even 18 months (Slaughter, Itakura, Kutsuki, & Siegal, 2011). Counting skill is critical for children's mathematical development. According to Baroody (1987), "Counting puts abstract number and simple arithmetic within the reach of the child" (p. 33). If children cannot count well, they cannot do arithmetic well (Delazer & Butterworth, 1997; Geary, Hoard, & Hamson, 1999; Gordon, 2004; Muldoon, Towse, Simms, Perra, & Menzies, 2013). For example, Gordon (2004) found that numerical cognition was clearly affected by a lack of a counting system in language. Geary et al. (1999) also established that early difficulties in counting portended later difficulties with arithmetic operations, such as simple addition. Muldoon et al. (2013) revealed that arithmetic and number-estimation skills are closely related to counting ability.

However, counting is not the only way for children to acquire simple arithmetic skills. First, children can rely on procedure, e.g., 5 + 6 might be solved by 5 + 5 + 1 because 5 + 5 is easier to solve. The repeated applications of procedures result in the direct retrieval of arithmetic facts from long-term memory later on (Ashcraft, 1992; Siegler & Shrager, 1984). Second, schoolchildren could use a rote memory strategy to acquire arithmetic skills. For example, they can utilize rote verbal memory to acquire multiplication facts (Dehaene & Cohen, 1997; Roussel, Fayol, & Barrouillet, 2002; Steel & Funnell, 2001; Zhou et al., 2006, 2007).

Previous neuropsychological and neuroimaging research has shown that the occipital cortex would be involved in counting (Dehaene & Cohen, 1994; Demeyere, Lestou, & Humphreys, 2010; Hinton, Harrington, Binder, Durgerian, & Rao, 2004; Piazza, Mechelli, Butterworth, & Price, 2002; Piazza, Mechelli, Price, & Butterworth, 2006; Piazza, Pinel, Le Bihan, & Dehaene, 2007; Sathian et al., 1999). For example, Piazza et al. (2002) found that counting (six to nine items) was correlated with increased activity in the occipito-parietal network. Sathian et al. (1999) showed that subitizing (one to four targets) activated foci in the occipital cortex. Two neuropsychological studies reported a close relation between occipital lesions (also extending to parietal regions) (i.e., Dehaene & Cohen, 1994; Demeyere et al., 2010) and counting disability. Dehaene and Cohen (1994) reported that five patients with parietal-occipital lesions exhibited severe difficulties in serial counting (four to six dots). Demeyere et al. (2010) reported a patient with lesions in parietal-occipital and bilateral lentiform nuclei, the heads of the caudate nuclei; for this patient, the percentage of correct counting was 44.2% (five to nine dots).

Besides, the parietal cortex might also be important for counting. Using an adaptation paradigm, Piazza et al. (2007) found that the horizontal segment of the intraparietal sulcus (IPS) was activated by numerosity (dot pattern). Relative to subitizing, counting (five to eight targets) activated large regions of the superior parietal cortex bilaterally (Sathian et al., 1999). However, a focal lesion in the parietal cortex may (Lemer, Dehaene, Spelke, & Cohen, 2003) or may not (Ashkenazi, Henik, Ifergane, & Shelef, 2008) impair counting. Lemer et al. (2003) reported one patient, who had a focal lesion of the left parietal lobe, and showed deficiency in counting performance (four to eight dots). Ashkenazi et al. (2008) found that an acalculia patient with an infarct restricted to the left IPS showed high accuracy (100%) in counting (5–14 items).

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Although neuropsychological, as well as imaging, studies have shown the importance of the occipital cortex in counting skills, no neuropsychological studies have been conducted to investigate whether early lesions in the occipital cortex impair number-related skills beyond counting (e.g., simple arithmetic). On the one hand, because counting is critical for simple arithmetic, lesions that impair counting are expected to affect simple arithmetic, as well. On the other hand, it is plausible that other brain regions may be more important to simple arithmetic than the occipital region (Andres, Pelgrims, Michaux, Olivier, & Pesenti, 2011; Dehaene, Piazza, Pinel, & Cohen, 2003; Rivera, 2005; Zago et al., 2001).

A battery of neuropsychological tests measuring mathematical, general cognitive, and language abilities were administered to a patient with early injury in the occipital cortex.

1. Case report

The patient ZQQ, the younger one of monozygotic twins, was 23 years old when she was tested. She was right-handed and had two years of primary school education. She suffered from viral encephalitis when she was a year and a half old. She had temporary blindness for about four months after she was out of the coma, which lasted for about one week. Six months after the encephalitis, she had her first epileptic seizure. By the time of the study, she had been taking anti-epileptic medicines for more than 10 years.

A structural brain scan using magnetic resonance imaging (MRI) in 2011 showed obvious softening lesions in the bilateral occipital lobe (see Figure 1). In terms of her eyesight, the Vision of Oculus Dexter was 0.4, and the Vision of Oculus Sinister was 1.0. In China, doctors generally use the Snellen chart to measure visual acuity as scored by the LogMAR scale, in which visual acuity of 0.4 and 1.0 is described as normal (Cline, Hofstetter, & Griffin, 1997; Pan et al., 2009).

1.1. *Control group*

To match the patient's education level, control subjects were 10 (five females) right-handed native Chinese-speaking first graders in primary school. They had normal visual acuity according to the visual examination administered when they were admitted into primary school. Subjects were free of any history of neurological or psychiatric disorders. The controls' mean age was 6.7 years, ranging from 6 to 7 years. All control subjects and their parents, as well as the patient, signed written informed consent/assent forms. The procedures of the study were approved by the Institutional Review Board of the National Key

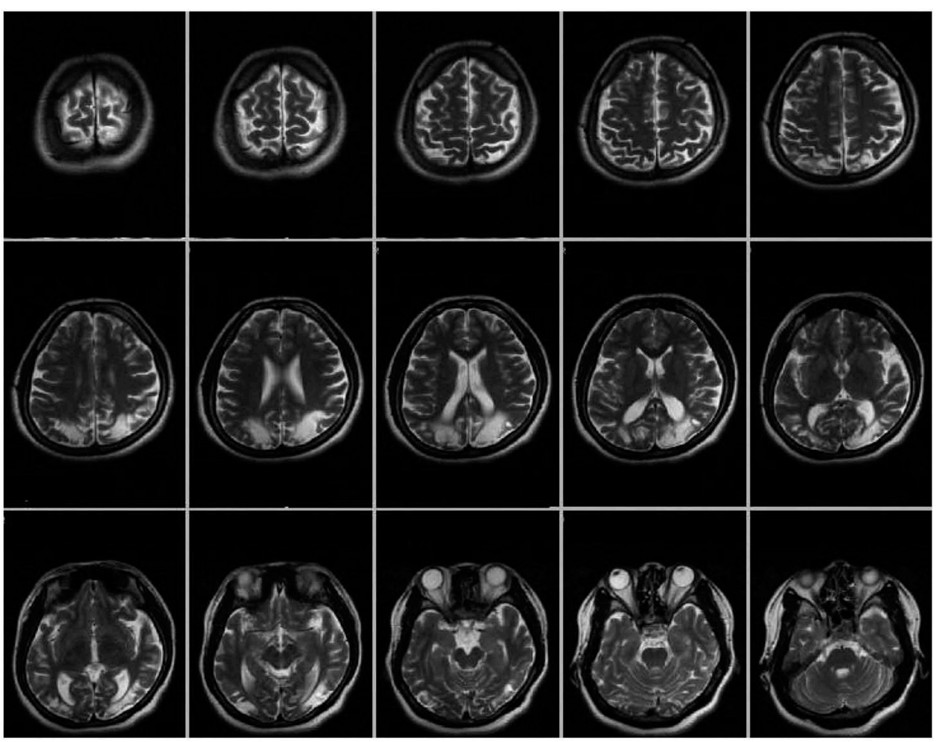

Figure 1. T2-weighted horizontal structural MRI result of patient ZQQ.
Notes: The result showed that her brain had a softened lesion in the bilateral occipital cortex. The left side of the images represents the right hemisphere.

Laboratory of Cognitive Neuroscience and Learning of Beijing Normal University.

2. Experimental investigations

2.1. *General procedures*

Testing was conducted within one week, when ZQQ was under clinical examinations in the Department of Epilepsy at Yu Quan Hospital, affiliated with Tsinghua University. All of the tasks were programmed using Web-based applications available at www.dweipsy.com/lattice. For the verbal and spatial working memory tasks, we used the highest scores obtained by ZQQ. All other tests were neuropsychological tests and were scored as correct ratios (the number of correct trials divided by the total number of trials, which were randomly selected). The controls were given the following tasks: counting, dot enumeration, simple subtraction, and applied arithmetic problem-solving. They were individually tested in a quiet classroom by a female experimenter.

2.2. *General cognitive tasks*

2.2.1. *Visual tracing*

The task was adapted from Groffman's (1966) visual tracing test. Several curved lines within a square interweaved with one another, starting from the left side of the square and ending at the right side. Participants were asked to track a particular line from the beginning to the end by using their eyes only (i.e., they were not allowed to use fingers, cursor, or object to trace the line) and then mark the correct end point. This task became more difficult as the total number of lines increased. There were 36 trials in all, and the time limit was 4 min. ZQQ completed 12 trials in that time.

2.2.2. *Arrow direction judgment*

This test was adopted from Fan et al.'s attention network test (Fan, McCandliss, Sommer, Raz, & Posner, 2002). It has been extensively used to assess attention (Greene et al., 2008; Rueda et al., 2004; Weaver, Bédard, McAuliffe, & Parkkari, 2009). Subjects judged the direction of an arrow in the middle of the screen, which was flanked by two other arrows of the same direction on either side (congruent condition), arrows of opposite direction (incongruent condition), or by two lines without arrows on either side (neutral condition). Subjects responded by pressing the left or the right key. Before each trial, a blank was presented for 2000 ms. The stimulus remained on the screen until the subjects pressed a key. There were 48 trials presented with no time limit.

2.2.3. *Verbal working memory (Digit Span Task)*

This test was similar to the Digit Span subtest of the Wechsler Intelligence Scale (Conklin, Curtis, Katsanis, & Iacono, 2000; Spafford, 1989). It required the experimenter to verbally present digits at a rate of one per second. The forward digit span test required the patient to repeat the digits verbatim. The backward digit span test required the patient to repeat the digits in reverse order. The test started with a list of two digits and increased by one digit until the subject consecutively failed three trials of the same length.

2.2.4. *Spatial working memory*

This task was similar to the Corsi block task (Milner, 1971). Dots were sequentially presented in a 3 × 3 lattice on the computer screen. Each dot was presented for 500 ms. After the last dot disappeared, the subject pointed to the positions where the dots had appeared in the same sequence as their appearance. Corresponding to verbal working memory, the test started with two dots and increased by one dot until the subject consecutively failed three trials of the same number of dots.

2.2.5. *Taylor Complex Figure Test*

This test was designed by Taylor (1969), based on the Rey Complex Figure Test designed by Rey (1941). It is used to evaluate the perceptual structure and visual memory of patients with brain lesions. In this task, the subject was asked to copy the Taylor complex figure without time pressure (Figure 2). The test was scored following the guidelines by the developer (Hamby, Wilkins, & Barry, 1993; Hubley & Tremblay, 2002; Taylor, 1969).

2.2.6. *Identical pictures test*

This test was used to assess the ability to pick the correct object quickly (Ekstrom, French, Harman, & Dermen,

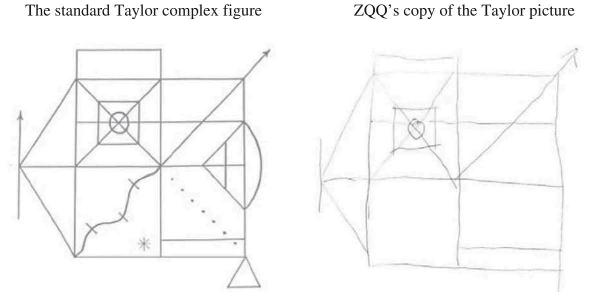

Figure 2. ZQQ's drawing on the Taylor Complex Figure Test.
Notes: The left figure shows the standard Taylor complex figure, and the right one is ZQQ's copy. She could copy the main structure of the figure.

1976). On the left was the target object, and to its right were three test objects. One or none of the test objects matched the target object. The subject was asked to decide whether one of the test objects matched the target object. This test was administered without any time limit. There were 10 trials.

2.3. *Language tasks*

2.3.1. *Picture–word matching*

In this test, four pictures were shown on the screen. The subject was asked to choose the picture that matched the word spoken by the computer (e.g., Perani et al., 1999; Ralph et al., 2001; Sahgal, Galloway, McKeith, Edwardson, & Lloyd, 1992; Sidman, 1971; Sidman & Cresson, 1973). All pictures in this test were selected from the corpus of line drawings by Snodgrass and Vanderwart (1980). There were 50 sets in the original test, and 10 sets were randomly selected for this study.

2.3.2. *Picture naming*

The picture–naming task (Glaser, 1992; Riddoch & Humphreys, 1987; Thompson-Schill, Aguirre, d'Esposito, & Farah, 1999) included 50 pictures of objects in each of four familiar categories, i.e., action, animals, plants, and man-made objects. During the task, a picture was shown in the center of the screen, and the subject was asked to name the object in the picture with no time pressure. In this study, 10 pictures from each category were randomly selected.

2.3.3. *Word semantic processing*

This task was similar to the one used by Siegel and Ryan (1988) and So and Siegel (1997). The materials (i.e., 32 sentences) in the task were adapted from the primary school examination used in China in recent years. In the task, a sentence was presented in the center of the computer screen with a missing word. Participants needed to select one of two candidate words presented beneath the sentence without any time pressure. Eleven trials were randomly selected for ZQQ.

2.3.4. *Sentence verification*

This task had 20 statements measuring common knowledge, such as "北京是中国的首都" ("Beijing is the capital of China"). They were verbally presented to the subject, who was asked to decide whether each statement was true or false (e.g., Cappelletti, Butterworth, & Kopelman, 2006). Twenty statements were used, and they were randomly presented. There was no time limit for this test.

2.4. *Mathematical tasks*

2.4.1. *Visual counting*

Subjects were asked to count aloud the number of dots that appeared in clusters. The number of dots ranged from 1 to 12, each presented twice (randomly and canonically) (Dehaene & Cohen, 1994), yielding 24 trials in all. There was no time limit for this task.

2.4.2. *Aural counting*

Subjects were asked to count how many "*Da*s" they heard from the experimenter. The experimenter said "*Da*" at the rate of one digit per second and asked the patient to count while the stimuli were presented. During the test, if the subject said that they did not hear the "*Da*" clearly, then the experimenter should repeat the trial until the subject was certain about how many "*Da*s" that there were. The number of "*Da*s" ranged from 1 to 12, with each number used twice, to yield 24 trials. There was no time limit for this task.

2.4.3. *Dot enumeration*

The experimenter asked the subjects to compare the number of dots on half of the screen with the numeral on the other half of the screen, and to press the "Q" key if the two numbers matched and the "P" key if they did not match (Butterworth & Laurillard, 2010; Iuculano, Tang, Hall, & Butterworth, 2008). The stimuli remained on the screen until either the participants responded or 20 s elapsed. There were 18 trials.

2.4.4. *Abstract counting*

Arabic numerals were presented in the center of the screen, and subjects were asked to count backward (to 1) and count forward (until 10 numbers). They were asked to count canonically (i.e., by one). Ten numbers (from 3 to 89) were used, respectively. A trial was scored as incorrect when subjects made any mistake.

2.4.5. *Reading symbolic numbers*

Subjects were presented with one- to two-digit Arabic numbers and number words, and asked to read each stimulus aloud. There were 10 trials (0–9) each for one-digit Arabic numbers and number words. For two-digit numbers, 50 trials were designed, and 10 were randomly selected for use.

2.4.6. *Writing Arabic numerals*

Subjects were instructed to write down two- to four-digit numbers as dictated. There were 10 two-digit numbers, five three-digit numbers, and five four-digit numbers.

2.4.7. *Numerical comparison*

This test included two types of numerical comparisons. For the first type, subjects were presented with either two dot arrays or a pair of numbers and asked to indicate which dot array or number was larger. Dot arrays were between 11 and 99 dots, and the numbers all had two digits. Each type included 10 trials, randomly selected from a pool of 24 sets. The other type is a proximity-judgment task (e.g., Zhang, Chen, & Zhou, 2012). Subjects were presented with triplets of stimuli (one on the top and two at the bottom). The task was to decide which of the two numbers or dot arrays at the bottom were numerically closer to the number or dot array above. There were 10 trials for each type of stimuli, randomly selected from a pool of 80 sets. There was no time limit for both types of number comparison tasks.

2.4.8. *Calculation*

The patient was asked to perform simple single-digit subtraction and addition. There were 10 trials, randomly selected from all single-digit subtraction and addition questions. The addition trials included 4 + 9, 2 + 3, 5 + 5, 3 + 4, 2 + 7, 1 + 8, 6 + 7, 2 + 1, 3 + 8, and 7 + 7; the subtraction trials included 7 – 2, 5 – 3, 6 – 4, 9 – 5, 3 – 2, 8 – 2, 4 – 3, 6 – 4, 9 – 2, and 7 – 4.

The control subjects were given the simple subtraction task only (10 trials). For each trial, an arithmetic problem was shown in the center of the screen, and the participant was tasked to orally report the result. There was no time limit.

2.4.9. *Applied arithmetic word problems (orally presented)*

Subjects were asked to divide candies following the experimenter's direction. For example, the experimenter gave a pre-determined number (e.g., nine, which was not told to the subject) of candies to the subject and asked him or her to distribute them equally among three people. This task had eight trials.

3. Results

3.1. *General cognitive tasks*

ZQQ's performance on the visual attention task showed that she had little impairment in the arrow direction judgment task (correct ratio [CR] = 75%). However, she could not perform the visual tracing task (CR = 0) (see Table 1). This was likely due to her severe visual field problem, so that she could only see objects partially and, thus, was unable to trace the curved lines. This result also suggested that her visuospatial ability might be impaired.

In terms of working memory, ZQQ's forward digit span was five, much lower than the mean of nine for Chinese adults (Chincotta & Underwood, 1997). Furthermore, she could not perform any trials on the backward digit span task (Table 1). Her spatial working memory was also very limited (a score of 2) (Table 1).

In terms of visual perception, ZQQ exhibited mild impairment in the Taylor Complex Figure Task (CR = 61%, Figure 2), but was perfect on the identical pictures test (CR = 100%, Table 1).

Table 1. ZQQ's performance on the general cognitive tasks.

Tests	Correct/total trials	CR (%)
Visual attention		
Visual tracing	0/12	0
Arrow direction judgment	36/48	75
Visual perception		
Taylor complex figure	22/36	61
Identical pictures test	10/10	100
Working memory		
Digit span forward	–	5
Digit span backward	–	0
Spatial working memory	–	2

Note: CR = correct ratio.

3.2. *Language tasks*

ZQQ showed little or no impairment in language tasks: CR = 100% on the picture–word matching task; 80–100% on the picture–naming tasks; 82% on the word semantic processing task; and 90% on the sentence verification task (Table 2).

3.3. *Mathematical tasks*

On the visual counting test, ZQQ scored 100% in the subitizing range (i.e., counting dots from one to four), regardless of whether the dots were arranged randomly or canonically. Similarly, she got 80% of the trials correct

Table 2. ZQQ's performance on the language tasks.

Tests	Correct/total trials	CR (%)
Picture–word matching	5/5	100
Picture naming		
Action	9/10	90
Animal	8/10	80
Plant	9/10	90
Man-made objects	10/10	100
Word semantic processing	9/11	82
Sentence verification	18/20	90

Table 3. Impaired numerosity counting ability.

	Visual	Answer	Aural	Answer
Counting (5–12)	7	6	7	4
	11	–	11	5
	10	10	8	5
	6	6	5	4
	6	5	6	4
	10	10	9	5
	7	8	8	6
	12	12	7	4
	11	10	11	5
	5	5	12	5
	12	16	6	4
	5	4	5	3
	9	8	9	4
	8	9	10	4
	9	9	12	5
	8	8	10	4
No. correct	7/16**		0/16***	
Percentage	44		0	

Notes: The visual and aural columns showed the correct number of the dot array. The "answer" column contained the number told by ZQQ of the same dot array. " – " means that ZQQ told the experimenter that she did not know how many dots were in the array. $^{**}p < .01$; $^{***}p < .001$.

in the subitizing range of the aural counting test. When the dot number was more than four, however, ZQQ had substantial difficulty (CR = 44% for the visual counting task; CR = 0% for the aural counting task, Table 3). The differences between the correct numbers of dots and the answers in the visual condition were small, from one to four, but the differences in the auditory condition were larger, from one to seven. Moreover, the larger the number of dots, the greater the difference (Table 3). Similarly, in the dot enumeration task, ZQQ showed severe impairment (CR = 44%, Figure 4).

In contrast, ZQQ had no difficulty with abstract counting (CR = 100%), number reading and writing (CR = 80–100%), numerical comparison (100%), calculation (CR = 100%), and applied arithmetic word problems (CR = 100%) (Table 4, Figure 3). It is worth noting that, when performing the word problems, ZQQ always first counted how many candies there were and then distributed the candies. If the sum was more than four, she distributed the candies one-by-one to every person until there were no candies left. Using this strategy, she successfully distributed four candies to two people, and four people; distributed six candies to two people, and three people; distributed eight candies to two people, and four people; distributed nine candies to three people; and distributed 12 candies to four people. The order of these trials was random.

3.4. *Control group's performance*

As expected, the control group performed well on all tests administered to them (Figure 4).

Table 4. ZQQ's performance on the mathematical tasks.

Tests	Correct/total trials	CR (%)
Numerosity counting		
Visual	7/16	44
Aural	0/16	0
Dot enumeration	8/18	44
Abstract counting		
Forward	10/10	100
Backward	10/10	100
Reading symbol numbers		
One-digit Arabic numeral	10/10	100
Two-digit Arabic numeral	10/10	100
One-digit verbal number	10/10	100
Two-digit verbal number	10/10	100
Writing Arabic numerals		
Two-digit Arabic numeral	10/10	100
Three-digit Arabic numeral	5/5	100
Four-digit Arabic numeral	4/5	80
Numerical comparison		
Two Arabic numerals	10/10	100
Two dot arrays	10/10	100
Three Arabic numerals	10/10	100
Three dot arrays	10/10	100
Calculation		
Addition	10/10	100
Subtraction	10/10	100
Applied arithmetic word problems	8/8	100

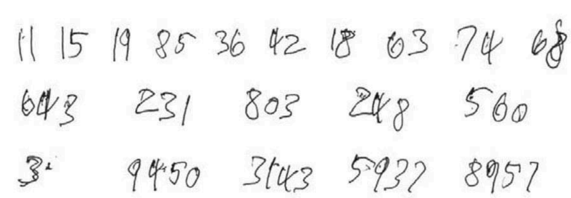

Figure 3. Perfect writing of Arabic numerals by ZQQ.

4. Discussion

The goal of the current study was to investigate whether lesions in the occipital cortex impaired arithmetic as well as counting. Patient ZQQ showed normal (relative to her education level) language abilities and basic numerical processing, and simple arithmetic ability, but had severe difficulty in visual and auditory counting. She could solve simple addition and subtraction problems containing numbers from 1 to 9. Although she did not show a regular or formal division concept due to her limited formal school education (i.e., just two years), she could evenly distribute the candies among three people with a one-to-one matching approach. These results suggest that early occipital injury led to disability in counting, but did not impair the development of simple arithmetic.

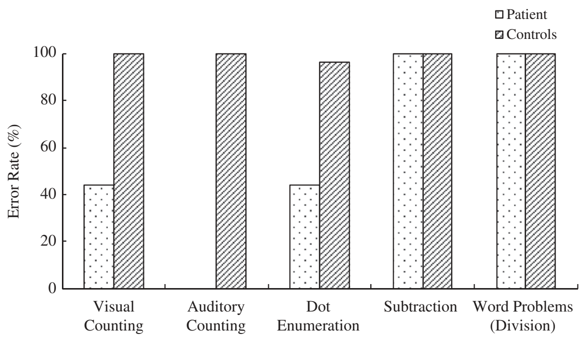

Figure 4. Comparison between ZQQ and the controls in numerosity and simple arithmetic abilities.

Single-digit arithmetic was used in the current study. Previous researchers also used the similar arithmetic task to evaluate calculation ability for children in the first grade, or even higher grades (Adams & Hitch, 1997; Jordan, Kaplan, Locuniak, & Ramineni, 2007; Levine, Jordan, & Huttenlocher, 1992; McLean & Hitch, 1999). The patient seemed to have normal simple arithmetic skill.

Most studies of counting were under unimodal stimulus presentation, such as visual modality (Atkinson, Campbell, & Francis, 1976; Jevons, 1871; Trick & Pylyshyn, 1994; Weiss, 1965), auditory modality (Cheatham & White, 1954; Kashino & Hirahara, 1996; Ten Hoopen & Vos, 1979), and even tactile modality (Gallace, Tan, & Spence, 2006; Posey & James, 1976) (Gallace et al., 2006; Posey & James, 1976). To the best of our knowledge, there have been only three studies comparing visual and auditory modalities (Kobayashi, Hiraki, & Hasegawa, 2005; Lechelt, 1975; Piazza et al., 2006). Lechelt (1975) directly compared counting among different modalities and found a significant modality difference in counting (two to nine signals), and subjects performed better in aural counting than visual and tactile counting. Kobayashi et al. (2005) indicated that infants were capable of performing intermodal matching of small numerosities, i.e., they could relate numerosities of sets presented with visual and auditory modalities. Piazza et al. (2006) compared the brain activation of counting across visual and auditory modalities and found that brain activation was independent of stimulus modality. These results suggest that counting in visual and auditory modalities may be highly associated. While it may not be so surprising that "visual counting" is not good in a person with occipital lesions, the finding that "aural counting" is so poor is consistent with the close relation of visual and aural processing.

This poor counting ability might be associated with a general working memory deficit, because both auditory and visual working memories were impaired in this patient. Geary and colleagues (2004) have demonstrated a strong relationship between working memory and counting. However, aural counting in the current investigation was not based on auditory working memory because the patient could count the pitch stimuli instantly when they were presented one-by-one. For the aural counting task, the experimenter said "*Da*" at the rate of one per second and asked the patient to count while the experimenter presented the stimulus. At the end of the presentation, the patient reported how many "*Da*s" she had heard. The aural counting could be treated as numeric-specific processing and did not rely on aural working memory. The patient could solve the applied arithmetic word problems with a one-to-one matching approach, which might require more working memory than did the visually based counting task.

To the best of our knowledge, this is the first observation on the effects of early occipital injury on the development of mathematical abilities. One previous study found that patients who suffered from injuries around the occipital regions during adulthood showed normal arithmetic skill, but impaired counting ability (Dehaene & Cohen, 1994). The role of counting in the development of mathematical abilities has long been debated. Some researchers have demonstrated that counting skills play an important role in the development of arithmetic abilities (e.g., Delazer & Butterworth, 1997; Geary et al., 1999; Gordon, 2004; Muldoon et al., 2013). The current study provided evidence on the dissociation of the development of counting and simple arithmetic. Brain lesions in the occipital cortex can lead to counting difficulty, but not difficulty with simple arithmetic skills. The latter may have relied on the preserved inferior parietal cortex around the IPS, which has repeatedly been shown to be involved in mathematical processing (e.g., Arsalidou & Taylor, 2011; Andres et al., 2011; Brannon, 2006; Dehaene et al., 2003; Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999; Piazza et al., 2007).

Disclosure statement

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References

Adams, J. W., & Hitch, G. J. (1997). Working memory and children's mental addition. *Journal of Experimental Child Psychology*, *67*, 21–38. doi:10.1006/jecp.1997.2397

Andres, M., Pelgrims, B., Michaux, N., Olivier, E., & Pesenti, M. (2011). Role of distinct parietal areas in arithmetic: An fMRI-guided TMS study. *NeuroImage*, *54*, 3048–3056. doi:10.1016/j.neuroimage.2010.11.009

Arsalidou, M., & Taylor, M. J. (2011). Is 2+2=4? Meta-analyses of brain areas needed for numbers and calculations. *NeuroImage*, *54*, 2382–2393. doi:10.1016/j.neuroimage.2010.10.009

Ashcraft, M. H. (1992). Cognitive arithmetic: A review of data and theory. *Cognition*, *44*, 75–106. doi:10.1016/0010-0277(92)90051-I

Ashkenazi, S., Henik, A., Ifergane, G., & Shelef, I. (2008). Basic numerical processing in left intraparietal sulcus (IPS) acalculia. *Cortex*, *44*, 439–448. doi:10.1016/j.cortex.2007.08.008

Atkinson, J., Campbell, F. W., & Francis, M. R. (1976). The magic number 4±0: A new look at visual numerosity judgements. *Perception*, *5*, 327–334. doi:10.1068/p050327

Baroody, A. J. (1987). *Children's mathematical thinking: A developmental framework for preschool, primary, and special education teachers*. New York, NY: Teachers College Press.

Brannon, E. M. (2006). The representation of numerical magnitude. *Current Opinion in Neurobiology*, *16*, 222–229. doi:10.1016/j.conb.2006.03.002

Butterworth, B., & Laurillard, D. (2010). Low numeracy and dyscalculia: Identification and intervention. *ZDM Mathematics Education*, *42*, 527–539. doi:10.1007/s11858-010-0267-4

Cappelletti, M., Butterworth, B., & Kopelman, M. (2006). The understanding of quantifiers in semantic dementia: A single-case study. *Neurocase*, *12*, 136–145. doi:10.1080/13554790600598782

Cheatham, P. G., & White, C. T. (1954). Temporal numerosity: III. Auditory perception of number. *Journal of Experimental Psychology*, *47*, 425–428. doi:10.1037/h0054287

Chincotta, D., & Underwood, G. (1997). Digit span and articulatory suppression: A cross-linguistic comparison. *European Journal of Cognitive Psychology*, *9*, 89–96. doi:10.1080/713752545

Cline, D., Hofstetter, H. W., & Griffin, J. R. (1997). *Dictionary of visual science*. Boston, MA: Butterworth-Heinemann.

Conklin, H. M., Curtis, C. E., Katsanis, J., & Iacono, W. G. (2000). Verbal working memory impairment in schizophrenia patients and their first-degree relatives: Evidence from the digit span task. *American Journal of Psychiatry*, *157*, 275–277. doi:10.1176/appi.ajp.157.2.275

Dehaene, S., & Cohen, L. (1994). Dissociable mechanisms of subitizing and counting: Neuropsychological evidence from simultanagnosic patients. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 958.

Dehaene, S., & Cohen, L. (1997). Cerebral pathways for calculation: Double dissociation between rote verbal and quantitative knowledge of arithmetic. *Cortex*, *33*, 219–250. doi:10.1016/S0010-9452(08)70002-9

Dehaene, S., Piazza, M., Pinel, P., & Cohen, L. (2003). Three parietal circuits for number processing. *Cognitive Neuropsychology*, *20*, 487–506. doi:10.1080/02643290244000239

Dehaene, S., Spelke, E., Pinel, P., Stanescu, R., & Tsivkin, S. (1999). Sources of mathematical thinking: Behavioral and brain-imaging evidence. *Science*, *284*, 970–974. doi:10.1126/science.284.5416.970

Delazer, M., & Butterworth, B. (1997). A dissociation of number meanings. *Cognitive Neuropsychology*, *14*, 613–636. doi:10.1080/026432997381501

Demeyere, N., Lestou, V., & Humphreys, G. W. (2010). Neuropsychological evidence for a dissociation in counting and subitizing. *Neurocase*, *16*, 219–237. doi:10.1080/13554790903405719

Ekstrom, R. B., French, J. W., Harman, H. H., & Dermen, D. (1976). *Manual for kit of factor-referenced cognitive tests*. Princeton, NJ: Educational Testing Service.

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience*, *14*, 340–347. doi:10.1162/089892902317361886

Gallace, A., Tan, H. Z., & Spence, C. (2006). Numerosity judgments for tactile stimuli distributed over the body surface. *PERCEPTION-LONDON*, *35*, 247–266. doi:10.1068/p5380

Geary, D. C., Hoard, M. K., Byrd-Craven, J., & Catherine DeSoto, M. (2004). Strategy choices in simple and complex addition: Contributions of working memory and counting knowledge for children with mathematical disability. *Journal of Experimental Child Psychology*, *88*, 121–151. doi:10.1016/j.jecp.2004.03.002

Geary, D. C., Hoard, M. K., & Hamson, C. O. (1999). Numerical and arithmetical cognition: Patterns of functions and deficits in children at risk for a mathematical disability. *Journal of Experimental Child Psychology*, *74*, 213–239. doi:10.1006/jecp.1999.2515

Gelman, R. (1986). *The child's understanding of number*. Cambridge, MA: Harvard University Press.

Glaser, W. R. (1992). Picture naming. *Cognition*, *42*, 61–105.

Gordon, P. (2004). Numerical cognition without words: Evidence from Amazonia. *Science*, *306*, 496–499. doi:10.1126/science.1094492

Greene, D. J., Barnea, A., Herzberg, K., Rassis, A., Neta, M., Raz, A., & Zaidel, E. (2008). Measuring attention in the hemispheres: The lateralized attention network test (LANT). *Brain and Cognition*, *66*, 21–31. doi:10.1016/j.bandc.2007.05.003

Groffman, S. (1966). Visual tracing. *Journal of American Optometric Association*, *37*, 139–141.

Hamby, S. L., Wilkins, J. W., & Barry, N. S. (1993). Organizational quality on the Rey-Osterrieth and Taylor Complex Figure Tests: A new scoring system. *Psychological Assessment*, *5*, 27–33. doi:10.1037/1040-3590.5.1.27

Hinton, S. C., Harrington, D. L., Binder, J. R., Durgerian, S., & Rao, S. M. (2004). Neural systems supporting timing and chronometric counting: An FMRI study. *Cognitive Brain Research*, *21*, 183–192. doi:10.1016/j.cogbrainres.2004.04.009

Hubley, A. M., & Tremblay, D. (2002). Comparability of total score performance on the Rey-Osterrieth Complex Figure and a Modified Taylor Complex Figure. *Journal of Clinical and Experimental Neuropsychology*, *24*, 370–382. doi:10.1076/jcen.24.3.370.984

Iuculano, T., Tang, J., Hall, C. W. B., & Butterworth, B. (2008). Core information processing deficits in developmental dyscalculia and low numeracy. *Developmental Science*, *11*, 669–680. doi:10.1111/j.1467-7687.2008.00716.x

Jevons, W. S. (1871). The power of numerical discrimination. *Nature*, *3*, 281–282.

Jordan, N. C., Kaplan, D., Locuniak, M. N., & Ramineni, C. (2007). Predicting first-grade math achievement from developmental number sense trajectories. *Learning Disabilities Research & Practice*, *22*, 36–46. doi:10.1111/j.1540-5826.2007.00229.x

Kashino, M., & Hirahara, T. (1996). One, two, many—Judging the number of concurrent talkers. *The Journal of the Acoustical Society of America*, *99*, 2596–2603.

Kobayashi, T., Hiraki, K., & Hasegawa, T. (2005). Auditory–visual intermodal matching of small numerosities in 6-

month-old infants. *Developmental Science*, *8*, 409–419. doi:10.1111/j.1467-7687.2005.00429.x

Lechelt, E. C. (1975). Temporal numerosity discrimination: Intermodal comparisons revisited. *British Journal of Psychology*, *66*, 101–108. doi:10.1111/j.2044-8295.1975.tb01444.x

Lemer, C., Dehaene, S., Spelke, E., & Cohen, L. (2003). Approximate quantities and exact number words: Dissociable systems. *Neuropsychologia*, *41*, 1942–1958. doi:10.1016/S0028-3932(03)00123-4

Levine, S. C., Jordan, N. C., & Huttenlocher, J. (1992). Development of calculation abilities in young children. *Journal of Experimental Child Psychology*, *53*, 72–103. doi:10.1016/S0022-0965(05)80005-0

McLean, J. F., & Hitch, G. J. (1999). Working memory impairments in children with specific arithmetic learning difficulties. *Journal of Experimental Child Psychology*, *74*, 240–260. doi:10.1006/jecp.1999.2516

Milner, B. (1971). Interhemispheric differences in the localization of psychological processes in man. *British Medical Bulletin*, *27*, 272–277.

Muldoon, K., Towse, J., Simms, V., Perra, O., & Menzies, V. (2013). A longitudinal analysis of estimation, counting skills, and mathematical ability across the first school year. *Developmental Psychology*, *49*, 250–257. doi:10.1037/a0028240

Pan, Y., Tarczy-Hornoch, K., Cotter, S. A., Wen, G., Borchert, M. S., Azen, S. P., & Varma, R. (2009). Visual acuity norms in pre-school children: The multi-ethnic pediatric eye disease study. *Optometry and Vision Science*, *86*, 607–612. doi:10.1097/OPX.0b013e3181a76e55

Perani, D., Schnur, T., Tettamanti, M., Gorno-Tempini, M., Cappa, S. F., & Fazio, F. (1999). Word and picture matching: A PET study of semantic category effects. *Neuropsychologia*, *37*, 293–306. doi:10.1016/S0028-3932(98)00073-6

Piazza, M., Mechelli, A., Butterworth, B., & Price, C. J. (2002). Are subitizing and counting implemented as separate or functionally overlapping processes? *NeuroImage*, *15*, 435–446. doi:10.1006/nimg.2001.0980

Piazza, M., Mechelli, A., Price, C. J., & Butterworth, B. (2006). Exact and approximate judgements of visual and auditory numerosity: An fMRI study. *Brain Research*, *1106*, 177–188. doi:10.1016/j.brainres.2006.05.104

Piazza, M., Pinel, P., Le Bihan, D., & Dehaene, S. (2007). A magnitude code common to numerosities and number symbols in human intraparietal cortex. *Neuron*, *53*, 293–305. doi:10.1016/j.neuron.2006.11.022

Posey, T. B., & James, M. R. (1976). Numerosity discrimination of tactile stimuli. *Perceptual and Motor Skills*, *42*, 671–674. doi:10.2466/pms.1976.42.2.671

Ralph, M. L., Powell, J., Howard, D., Whitworth, A., Garrard, P., & Hodges, J. (2001). Semantic memory is impaired in both dementia with Lewy bodies and dementia of Alzheimer's type: A comparative neuropsychological study and literature review. *Journal of Neurology, Neurosurgery & Psychiatry*, *70*, 149–156. doi:10.1136/jnnp.70.2.149

Rey, A. (1941). L'examen psychologique dans les cas d'encéphalopathie traumatique. (Les problems.). *Archives de psychologie*, *28*, 215–285.

Riddoch, M. J., & Humphreys, G. W. (1987). Picture naming. In G. W. Humphreys & M. J. Riddoch (Eds.), *Visual object processing: A cognitive neuropsychological approach*. Hove: Erlbaum.

Rivera, S. M. (2005). Developmental changes in mental arithmetic: Evidence for increased functional specialization in the left inferior parietal cortex. *Cerebral Cortex*, *15*, 1779–1790. doi:10.1093/cercor/bhi055

Roussel, J.-L., Fayol, M., & Barrouillet, P. (2002). Procedural vs. direct retrieval strategies in arithmetic: A comparison between additive and multiplicative problem solving. *European Journal of Cognitive Psychology*, *14*, 61–104. doi:10.1080/09541440042000115

Rueda, M. R., Fan, J., McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., & Posner, M. I. (2004). Development of attentional networks in childhood. *Neuropsychologia*, *42*, 1029–1040. doi:10.1016/j.neuropsychologia.2003.12.012

Sahgal, A., Galloway, P. H., McKeith, I. G., Edwardson, J. A., & Lloyd, S. (1992). A comparative study of attentional deficits in senile dementias of Alzheimer and Lewy body types. *Dementia and Geriatric Cognitive Disorders*, *3*, 350–354. doi:10.1159/000107037

Sathian, K., Simon, T. J., Peterson, S., Patel, G. A., Hoffman, J. M., & Grafton, S. T. (1999). Neural evidence linking visual object enumeration and attention. *Journal of Cognitive Neuroscience*, *11*, 36–51.

Sidman, M. (1971). Reading and auditory-visual equivalences. *Journal of Speech and Hearing Research*, *14*, 5–13. doi:10.1044/jshr.1401.05

Sidman, M., & Cresson, J. O. (1973). Reading and crossmodal transfer of stimulus equivalences in severe retardation. *American Journal of Mental Deficiency*, *77*, 515.

Siegel, L. S., & Ryan, E. B. (1988). Development of grammatical-sensitivity, phonological, and short-term memory skills in normally achieving and learning disabled children. *Developmental Psychology*, *24*, 28–37. doi:10.1037/0012-1649.24.1.28

Siegler, R. S., & Shrager, J. (1984). Strategy choices in addition and subtraction: How do children know what to do? In C. Sophian (Ed.), *Origins of cognitive skills* (pp. 229–293). Hillsdale, NJ: Erlbaum.

Slaughter, V., Itakura, S., Kutsuki, A., & Siegal, M. (2011). Learning to count begins in infancy: Evidence from 18 month olds' visual preferences. *Proceedings of the Royal Society B: Biological Sciences*, *278*, 2979–2984. doi:10.1098/rspb.2010.2602

Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory*, *6*, 174.

So, D., & Siegel, L. S. (1997). Learning to read Chinese: Semantic, syntactic, phonological and working memory skills in normally achieving and poor Chinese readers. *Reading and Writing*, *9*, 1–21. doi:10.1023/A:1007963513853

Spafford, C. S. (1989). Wechsler digit span subtest: Diagnostic usefulness with dyslexic children. *Perceptual and Motor Skills*, *69*, 115–125. doi:10.2466/pms.1989.69.1.115

Steel, S., & Funnell, E. (2001). Learning multiplication facts: A study of children taught by discovery methods in England. *Journal of Experimental Child Psychology*, *79*, 37–55. doi:10.1006/jecp.2000.2579

Taylor, L. (1969). Localisation of cerebral lesions by psychological testing. *Clinical Neurosurgery*, *16*, 269.

Ten Hoopen, G., & Vos, J. (1979). Effect on numerosity judgment of grouping of tones by auditory channels.

Perception and Psychophysics, *26*, 374–380. doi:10.3758/BF03204162

Thompson-Schill, S., Aguirre, G., d'Esposito, M., & Farah, M. (1999). A neural basis for category and modality specificity of semantic knowledge. *Neuropsychologia*, *37*, 671–676. doi:10.1016/S0028-3932(98)00126-2

Trick, L. M., & Pylyshyn, Z. W. (1994). Why are small and large numbers enumerated differently? A limited-capacity preattentive stage in vision. *Psychological Review*, *101*, 80–102. doi:10.1037/0033-295X.101.1.80

Weaver, B., Bédard, M., McAuliffe, J., & Parkkari, M. (2009). Using the Attention Network Test to predict driving test scores. *Accident Analysis & Prevention*, *41*, 76–83. doi:10.1016/j.aap.2008.09.006

Weiss, W. (1965). Influence of an irrelevant stimulus attribute on numerosity judgments. *Perceptual and Motor Skills*, *21*, 404–404. doi:10.2466/pms.1965.21.2.404

Wynn, K. (1990). Children's understanding of counting. *Cognition*, *36*, 155–193. doi:10.1016/0010-0277(90)90003-3

Zago, L., Pesenti, M., Mellet, E., Crivello, F., Mazoyer, B., & Tzourio-Mazoyer, N. (2001). Neural correlates of simple and complex mental calculation. *NeuroImage*, *13*, 314–327. doi:10.1006/nimg.2000.0697

Zhang, H., Chen, C. S., & Zhou, X. L. (2012). Neural correlates of numbers and mathematical terms. *Neuroimage*, *60*, 230–240. doi:10.1016/j.neuroimage.2011.12.006

Zhou, X., Chen, C., Dong, Q., Zhang, H., Zhou, R., Zhao, H., … Guo, Y. (2006). Event-related potentials of single-digit addition, subtraction, and multiplication. *Neuropsychologia*, *44*, 2500–2507. doi:10.1016/j.neuropsychologia.2006.04.003

Zhou, X., Chen, C., Zang, Y., Dong, Q., Chen, C., Qiao, S., & Gong, Q. (2007). Dissociated brain organization for single-digit addition and multiplication. *Neuroimage*, *35*, 871–880. doi:10.1016/j.neuroimage.2006.12.017