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Research Article

The Correlation of Counting Speed with Visual Search and Visuomotor Organization: A Conjugate Study on Borderline and Normal People

Hassan Sabourimoghaddam[1], Shadi Akbari[*2], Jalil Babapour[3]

1- Assistant Professor, Department of Neuroscience, School of Education and Psychology, University of Tabriz, Tabriz, Iran
2- PhD Student, Department of Neuroscience, School of Education and Psychology, University of Tabriz, Tabriz, Iran
3- Professor, Department of Psychology, School of Education and Psychology, University of Tabriz, Tabriz, Iran

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Corresponding Author:
Shadi Akbari
Emial: sh_akbari@tabrizu.ac.ir
Tel: +989122991512
Fax: +9822114457

ABSTRACT

Introduction: Counting is of the most basic mathematical abilities. Many researches have demonstrated that different perceptual abilities can affect counting skills. We investigated the impact of visual search (VS) and visuoumotor organization (VMO) on counting speed.

Material and Methods: A total of 40 people in two groups of borderline and normal intellectual ability (20 subjects in each group) participated in the study. Three areas were evaluated: (1) VS, (2) VMO, and (3) counting speed. We used three self-designed evaluation softwares to examine VS and counting speed. VMO was assessed by Loewenstein Occupational Therapy Cognitive Assessment.

Results: We calculated the Pearson rank correlation in both groups, to investigate the relation between counting speed and two other variables. According to the results, the speed of counting was related to VMO ($P < 0.050$). However, VS was correlated to counting speed just in normal people ($P < 0.050$). In contrast, the effect of VMO on counting speed was influenced by the spatial distribution of the objects in each set.

Conclusion: Counting in different sets of objects is influenced by VMO and VS depending on their characteristics such as spatial distribution and the number of contents.

Keywords: Visual search; Counting speed; Visuomotor organization; Spatial perception

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Introduction

Counting is of the most basic mathematical skills and is defined as the action of finding the number of elements in a finite set of objects. Eves (1976) (1) confirm that there is archeological evidence suggesting that humans have been counting for at the last 50,000 years.

But what are the cognitive components of counting? Researches show that there is a close relation between numerical and spatial representations, and this relation is deeply rooted in brain's organization for these capacities (2-4). In an investigation in Chicago University, Harms (2012) showed that spatial skills and conceptualization of number are related in children and those children who do better in spatial relation tasks have better understanding of numbers (5). Another evidence for such a relation is presented by Galton (1881) (6) who studied people with synesthesia. These persons declared that they experienced numbers with a spatial arrangement. This phenomenon is known as "number form." Behavioral studies confirm the relationship between number understanding and spatial skills. Dehaene et al. (7) found that subjects respond faster when large numbers are presented in the right side of the visual field. This is true for small numbers which are presented in the left side of the visual field. This phenomenon is called Spatial-Numeric Association of Response Codes. Neuroimaging studies also assert this correlation. According to Dehaene (1992) (8), some areas of the parietal cortex are activated during both number and spatial processing. Sathian et al. (9) have revealed that many parts of the brain are activated during counting. Piazza et al. (10) have reported the activity of frontal and superior parietal cortices during counting and activity in these areas were concomitant with shift of spatial attention). The intraparietal sulcus is another area which is permanently activated while counting (10, 11) and finally, lateralized activity in left premotor and temporal areas is observed while counting; which is related to verbal component of counting and includes inner talk and verbal working memory. Piazza and Izard (12) emphasize that shifts of spatial attention and working memory are two main mechanisms of counting.

Oyama et al. (13) reported that alternative attentional shift is a prerequisite of counting and it would be impossible to count if we prevent ocular eye movements . In fact, saccade eye movements are necessary for counting (14, 15) and preparation of saccades can evoke a variety of attentional effects because attention is directed to the saccadic goal during this process (16). Visual search (VS) is one of the areas investigated in relation to attention and vision. Sheliga et al. (17) introduced two types of VS: feature search and conjunction search. Feature search is a parallel process in which the target and the distractors are maximally different, differentiated by a single property such as color, shape orientation, or size. However, conjunction search occurs when the target and the distractor share similarities in more than one single visual property. For example when the target is a black horizontal line while the distractors are made up of white horizontal lines and a black and white vertical lines. Considering the above, VS (18) seems to be effective on counting speed. At the present research, we have tried to proceed to this effect. On the other hand, regarding the importance of spatial perception in counting which is emphasized in previous researches, we aimed to investigate the relation of visuomotor organization (VMO) skills to counting speed. VMO skills are a combination of perceptual, motor, and spatial components which are integrated together (19). By these abilities people can understand the organization of patterns and reconstruct them, therefore, they are important in drawing, model construction, and coping skills. On the other hand, according to some researches these abilities are affected in people with intellectual disabilities (20); therefore, it would be so helpful if we examine the effect of such perceptual defects on enumeration skills while we are comparing performance in normal subjects with those who have lower IQ score. We studied these relations in both small and large sets and in different spatial arrangements to investigate the impact of set size and its arrangement on the relation of VS and VMO to the speed of enumeration. We aimed to understand if VMO and VS are correlated to enumeration skills and if there is such correlation, is it influenced by different factors such as arrangement of items, the set size, and individual's cognitive ability?

Materials and methods

About 40 individuals in two groups with different intellectual abilities (20 borderline and 20 normal) were enrolled in the study. We evaluated borderline subjects (with IQ score ranging from 70 to 90) because the comparison of cognitive function in normal and mental handicapped people has indicated that VMO area is of the most affected areas in these people (20). We preferred borderline subjects to educable ones due to their better understanding of numbers and cardinality although they were not as good as normal people.

Borderline participants were selected among clients in a vocational rehabilitation center. We referred to their rehabilitation and psychological documents to ensure their IQ score is in the range of borderline intelligence. All participants were able to count and read numbers. The participants with attention deficit disorders, speech disturbances, movement disorders, and uncorrected visual defects were excluded from the study.

VS ability was assessed using a target-detection task, designed by psytask designing tool. The task consisted of 11 slides including small blue circles in an orange background. The target was defined as a blue rectangle between the circles (Figure 1). The participants were asked to click the mouse when they could see the rectangle in each slide. The target was not situated at the center of the slides and participants required to search it visually. The presentation for each single slide was 700 ms and we showed each slide 3 times in a random manner. After each slide, a latency of 3 seconds was considered for response.

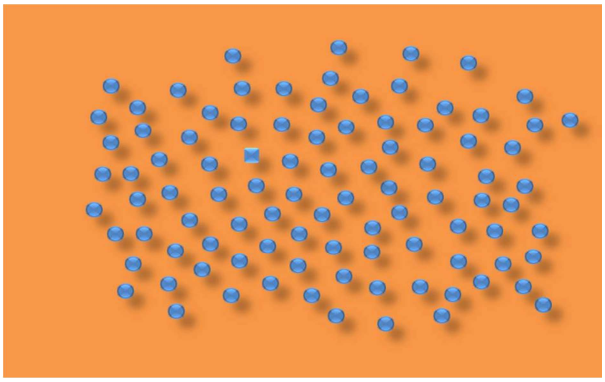


Figure 1. A sample of slides used for visual search assessment

VMO was evaluated via the VMO section of Loewenstein Occupational Therapy Cognitive Assessment (LOTCA). This test has been shown to have a high validity of 0.82-0.92 (21). LOTCA is a cognitive assessment which evaluates six different perceptual and cognitive areas and one of them is VMO. This area is assessed through seven components including copying geometrics, two-dimensional model construction, pegboard construction, colored and plain block design construction, drawing a clock, and puzzle construction. Its score ranges from 7 to 28 with 7 indicating fully impaired VMO area.

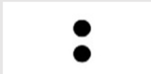
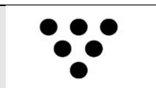
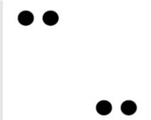
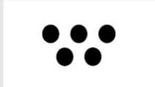
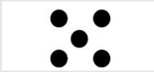
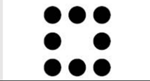
Small and large sets		
diffused and centered sets		
symbolic and non-symbolic arrangements		

Figure 2. Samples of slides in each categorization

We used a self-designed computer task to assess counting speed. The task consisted of 25 slides; each slide contained 1-10 dots in a different arrangement (Figure 2). We asked participants to count dots as fast as possible and the reaction time was recorded if their answer was correct.

We designed another computer task to calculate the participants' reaction time to distinguish and express the numbers: we showed numbers 1-10 in 10 slides and asked subjects to name the number in each slide. Then, the reaction time was recorded. This task helped us to exclude borderline individuals with very low speed of processing. If the reaction time was more than 3 seconds, the participant was eliminated from the study.

All of the computer tasks were designed via psytask software version 1.0 manufactured by Mitsar company. We used a 14" monitor for slide presentation which was placed with the distance of 60 cm from participants.

Descriptive statistics was computed for demographic variables. Correlation and regression were the statistical analyses used to determine the correlation between counting speed, VMO, and VS. T-test was conducted to distinguish subitizing from counting process. We used one-sample Kolmogrov-–Smirinov test to understand which variables are distributed normally and could be investigated by parametric correlation analysis. All statistical analyses were conducted using SPSS (version 21; SPSS Inc., Chicago, IL., USA). A $P < 0.050$ was considered statistically significant.

For more exact investigation, we divided our counting slides into three categories of small and large sets, symbolic and non-symbolic arrangements and diffused and centered dot sets.

Results

Around 40 subjects (18 men and 22 women) participated in the study. In normal group, subjects aged between 20 and 42 years old (mean 29.0 ± 4.6) and in the borderline group the age range from 23 to 35 years (mean 27.7 ± 3.3). The educational background was varied between 8-20 years (mean 16.3 ± 3.6) in the normal group and 2-14 years (mean 8.0 ± 2.6) in the borderline group. Table 1 shows the demographic features of the study sample.

Table 1. Demographic features of variables in both borderline and normal group

N Borderline = 20 Normal = 20	**Min**	**Max**	**Mean ± SD**
VS			
Normal	18	32	27.5 ± 3.8
Borderline	3	31	16.2 ± 9.3
VMO			
Normal	28	28	28 ± 0
Borderline	11	28	20.0 ± 4.3
Counting speed (5)			
Normal	668.7	1275.4	938.1 ± 150.4
Borderline	707.9	4680.9	2466.0 ± 11.8
Under 4 (5)			
Normal	333.5	602.2	485.9 ± 72.9
Borderline	336.2	2670	914.7 ± 519.3
Upper 4 (5)			
Normal	929.4	1881.9	1293.6 ± 240.6
Borderline	999.9	6260.8	3685.0 ± 1656.7
Diffused			
Normal	716.6	1231.4	940.0 ± 141.5
Borderline	738.9	5167.1	2868.2 ± 1344.3
Centered			
Normal	593	1578.6	935.1 ± 226.1
Borderline	661	3951.4	1862.8 ± 823.1
Regular			
Normal	983.5	2069.9	14.5.7 ± 263.1
Borderline	1048.4	5724.4	3536.0 ± 1489.1
Irregular			
Normal	938.3	2864.7	1590.6 ± 408.4
Borderline	1157.9	5756.1	3459.4 ± 1328.4

SD: Standard deviation; VMO: Visuomotor organization, VS: Visual search

Table 2. Pearson rank correlation between VMO, VS and counting speed for different conditions

Group		**Counting speed**	**Under 4**	**Upper 4**	**Diffused**	**Centered**	**Regular**	**Irregular**
Borderline	VS	-0.383	-0.406	-0.358	-0.361	-0.407	-0.331	-0.231
	VMO	-0.469*	-0.289	-0.489*	-0.491*	-0.376	-0.440*	-0.286
Normal	VS	-0.443*	-0.185	-0.440*	-0.569*	-0.189	-0.402	-0.144

*$P < 0.050$. VMO: Visuomotor organization, VS: Visual search

Table 3. Paired t-test between small and large groups in borderline subjects

N = 20	Mean ± Standard deviation	Mean of standard error	t	Significant
Under 3-Upper 3	-2574.95 ± 1283.64	287.03	-8.97	< 0.001
Under 4-Upper 4	-2770.30 ± 1315.52	294.15	-9.41	< 0.001
Under 5-Upper 5	-2960.39 ± 1437.33	321.39	-9.21	< 0.001
Under 6-Upper 6	-3712.31 ± 1781.86	398.43	-9.317	< 0.001

The time duration of counting process was acquired by a simple mathematical calculation. This is the formula:

$$C - B = A$$

Which, A is the average time of counting process; B is the average response time to the number slides and C is the average response time to the dot slides. Hereafter, our meaning of counting speed is the A value acquired from this formula.

Is counting speed correlated with VS and VMO?

Pearson's rank correlation was used to examine the relationships between variables. VMO was only investigated in the borderline group due to intact performance of normal subjects. VS was addressed in both groups. Results are shown in table 2.

According to these results, in borderline group, VMO was correlated to counting speed ($P < 0.050$) while no correlation was found between VS and counting speed. Inversely in normal group, a significant correlation between VS and counting speed was found ($P < 0.050$). Regression analysis showed that in the normal group VS can predict 18% of changes in counting speed ($R^2 = 0.18$), this value in borderline group was 14%. On the other hand, VMO can predict 22% of changes of counting speed in borderline group ($R^2 = 0.22$).

Is the correlation among counting speed, VMO and VS affected by set size?

We categorized the dot sets into two categories of small and large sets. The evidence of such categorization was the subitizing principle. Subitizing is the process of rapid and accurate enumeration of small sets (< 5 items) without counting (22). Research findings show a significant difference between counting speed in small (1-4 dots) and large (5-10) sets (23-26) and in most of these studies, number 4 is determined as the border between subitizing and counting process (27).

However, since we had two different groups of subjects in our study, the average of counting speed in different ranges was measured separately to determine this border according to the amount of these differences. This measurement was done in four stages while the border was considered 3, 4, 5 and 6 in each stage and paired t-test was used to measure the difference of response times in each group separately. The results are shown in tables 3 and 4. According to these results, the differences are significant in all stages but in both groups of subjects, the amount of the difference is larger for number 4. Hence, we hypothesized that number 4 is the border between subitizing and counting process. Then, we investigated the correlation between the above-mentioned perceptual skills and counting in small and large sets (Table 2). Results showed that in borderline subjects, VMO was correlated to counting large sets while in the normal group counting large amounts was correlated to VS ($P < 0.050$).

Regression analysis showed that in the normal group, VS can predict only 3% of changes in counting small sets ($R^2 = 0.03$) while this amount is 19% in large sets ($R^2 = 0.19$). In contrast in borderline subjects, no relation was found between set size and VS in counting tasks. On the other hand, since VMO is able to considerably predict counting speed in large sets ($R^2 = 0.23$) but not in small ones ($R^2 = 0.08$), we infer that the VMO is correlated to set size during counting.

Is the correlation among counting speed, VMO and VS affected by spatial arrangement of dots?

We divided our dot sets into two categories of symbolic and non-symbolic arrangements. Symbolic arrangements were defined as those ones with well-known patterns such as domino patterns which are more familiar to people. Then, the correlation of VMO and VS with counting speed was calculated for each of these categories (Table 2). VMO score was only correlated to symbolic arrangements ($P < 0.050$). No significant correlation was found between VS and type of arrangements. For more exact investigation, a regression analysis was done and the relation between VMO and counting different arrangements was calculated for small and large sets. In small symbolic sets, VMO explained 32% of changes in counting speed ($R^2 = 0.32$) while this relation was 64% for large symbolic sets ($R^2 = 0.64$).

Table 4. Paired t-test between small and large groups in normal subjects

N = 20	Mean ± Standard deviation	Mean of standard error	t	Significant
Under 3-Upper 3	-733.87 ± 207.72	46.44	-15.80	< 0.001
Under 4-Upper 4	-808.14 ± 222.02	49.64	-16.27	< 0.001
Under 5-Upper 5	-913.73 ± 292.42	65.38	-13.97	< 0.001
Under 6-Upper 6	-1004.41 ± 381.28	85.25	-11.78	< 0.001

We also investigated the correlation between sparseness of dots and above perceptual skills. We categorized our slide into diffused and centered ones considering the diffusion of dots over the background. In this categorization, it was not considered if the arrangement is symbolic or not (Figure 2). Results are shown in table 2.

Discussion

Our results indicate that the speed of counting is related to subjects' performance in VMO area and VS.

As mentioned above, many studies suggest that spatial skills are prerequisites necessary for counting ability (Harms, 2014; Dehaene, 1993; and Dehaene, 2002). On the other hand, spatial perception is of the most important components of VMO skills. Therefore, we can infer that our result about the correlation between VMO and counting speed is a verification of previous study results. According to our results, VMO disorders can decrease the speed of counting in those sets which are larger or have symbolic pattern or are more scattered.

Mervis (28) state that VMO area includes visuospatial constructive cognition which is the ability to see an object or picture as a set of parts and then to construct a replica of the original from these parts. Ansari et al. (29) have confirmed the important role of visuospatial ability in the development of cardinality understanding.

On the other hand, our results showed, VS is affecting on counting speed just in normal group (those with normal VMO performance). This relation was observed in the case of large sets with scattered arrangement. It means that an impaired ability of VS will cause decreased counting speed in such sets. The fact that small sets enumeration is not affected by VS is that counting in small sets is done in the manner of subitizing which is so faster than counting (Kaufman, 1994; Mandler, 1982; Chi, 1975). We also found this different reaction time during counting and subitizing process. Explaining this finding, some researchers have claimed that counting and subitizing are two different cognitive processes with different mechanisms (23, 30). Pincham, and Dénes (2012) infer that subitizing includes an automatic pre-attentive mechanism, but regarding the reaction time in subitizing it is not acceptable. Trick and Plyshyn (1993 and 1994) proposed that subitizing is based on a limited capacity pre-attentive visual process that is capable of individuating a maximum of four items in parallel, while counting requires serial shifts of spatial attention. Both Simon (1996) and Atkinson (1976) investigated the enumeration performance in after images under conditions of disabled eye movements and observed error-free enumeration up to 4 dots and error-prone enumeration above 4 dots. Simon concluded that accurate enumerating of large numerosities requires the eyes and thus the attentional focus, to be shifted through the display. Sathian (1999) has also pointed to eye-movements in the counting action. Our results in the normal group, also confirm the relation of VS to counting (in large sets). However, the point is that our t-test analysis in borderline subjects showed less difference between counting speed in small and large sets in comparison to the normal group. In other words, in normal subjects, we observed a sudden decrease in counting speed after number 4 which reflects shifting from subitizing to counting process (24, 26, 27), but in borderlines this effect was not as prominent as it was in the normal group. Therefore, we infer that borderline people do not subitize small sets and use the same counting process in both conditions.

According to Pearson Rank correlation results, VMO is correlated to counting in large sets with the symbolic arrangement and those sets which have scattered items. Therefore in contrast to subitizing, counting has a spatial component. This finding is consistent with other studies which have demonstrated the correlation of counting and spatial skills and have revealed that unlike subitizing, speed of counting is affected by arrangement of objects because it simplifies groupitizing (24, 25, 31) in another study Dehaene and Cohen (32) investigated individuals with counting problem and showed that counting small sets (< 3) in these subjects is error free while they were not able to count larger sets. They clarified that counting is a serial spatial processing while subitizing is a parallel process used for small amounts.

Conclusion

Although more confirmation is needed, this study distinctively shows the correlation of VS and VMO with counting. The noteworthy point is that this correlation is affected by different factors such as number of items, their sparseness, and their arrangements in each set. On the other hand, subjects' cognitive ability has a determining role, as we could see that VMO disorders can eliminate the role of VS in the enumeration.

Conflict of Interests

Authors have no conflict of interests.

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