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Does colour influence subitization?

Marco J.H. Puts *, Charles M.M. de Weert

Nijmegen Institute for Cognition and Information, University of Nijmegen, P.O. Box 9104, 6500 HE Nijmegen, The Netherlands

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Abstract

A reaction time experiment was performed with patterns that have a close resemblance to the patterns used in the Bourdon–Vos test. These patterns were of three, four and five dots arranged in different familiar shapes. Subjects had to determine as fast as possible whether four dots had been presented. In the Bourdon–Vos test the dots are achromatic, while in this experiment, colour was used as a distractor. The reaction time was the same for the one-colour dot patterns as for the two-colour dot patterns. It is hypothesised that the lack of difference was due to overlearnedness of forms in the classic Bourdon–Vos test. A similar test was performed with only one type of forms. Reaction times were different for one- and two-colour dot patterns in the latter experiment. © 1997 Elsevier Science B.V.

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1. Introduction

As the word suggests, subitizing is historically defined as the ability of immediately perceiving the quantity of sparse numbers of dots (up to about six dots). It is intuitively expected that this process is of a very primitive nature. In our view, subitization can be defined as the enumeration of a sparse number of dots (without the emphasis on the 'immediate' character). We will justify our definition below.

* Corresponding author. Tel.: +31 24 3616288; fax: +31 24 3616066; e-mail: puts@nici.kun.nl.

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In a study of Trick and Pylyshyn (1994), the effect of colour on subitization was measured using distractors of a different colour. They showed that distractors of a different colour or form do not influence the speed of subitization; this can be readily explained by the Feature Integration Theory (Treisman and Gelade, 1980; Treisman, 1988, 1993; Mozer, 1991). Colour is a primitive feature, and in this theory the differently coloured dots are projected on different colour maps. The colour map of the target colours is read out and the subject can ignore the distractor colour completely. In Trick and Pylyshyn's study, colour was used to segregate the targets from the distractors. In the experiment to be presented here, however, colour is used to introduce 'false' segmentation by randomly colouring the dots to be subitized. In this case, the dots will also be projected onto two different colour maps and the two feature maps have to be integrated to read out the total number of dots. The last step takes extra time, i.e., a slower reaction is expected.

Subitizing is used in selective attention tests, e.g., in the Bourdon–Vos test, a pen-and-paper test (Vos, 1992). This test detects attention and concentration problems in children. The test form consists of 33 lines with 24-dot patterns on each line. A dot pattern has a diameter of 5 mm. and the space between dot patterns is also 5 mm. Eight of the patterns are four-dot patterns (the targets), eight are three-dot patterns and eight are five-dot patterns (the non-targets). The patterns consist of three, four or five dots. The three dot patterns are triangularly shaped, the four-dot patterns are square or diamond shapes and the five-dot patterns are 'dice-five' or pentagonal shapes (see also Fig. 1). Each dot has a positional uncertainty of approximately 1 mm. In this test, the subject has to mark the target patterns per line as fast as possible with a felt-tip pen. The time needed to mark the patterns is registered per line. In our experiment, we used similar dot patterns but presented on a monitor.

2. Experiment 1

In this experiment, the hypothesis tested is that differently coloured dots in Bourdon–Vos patterns lead to longer subitizing times. In this experiment, a particular

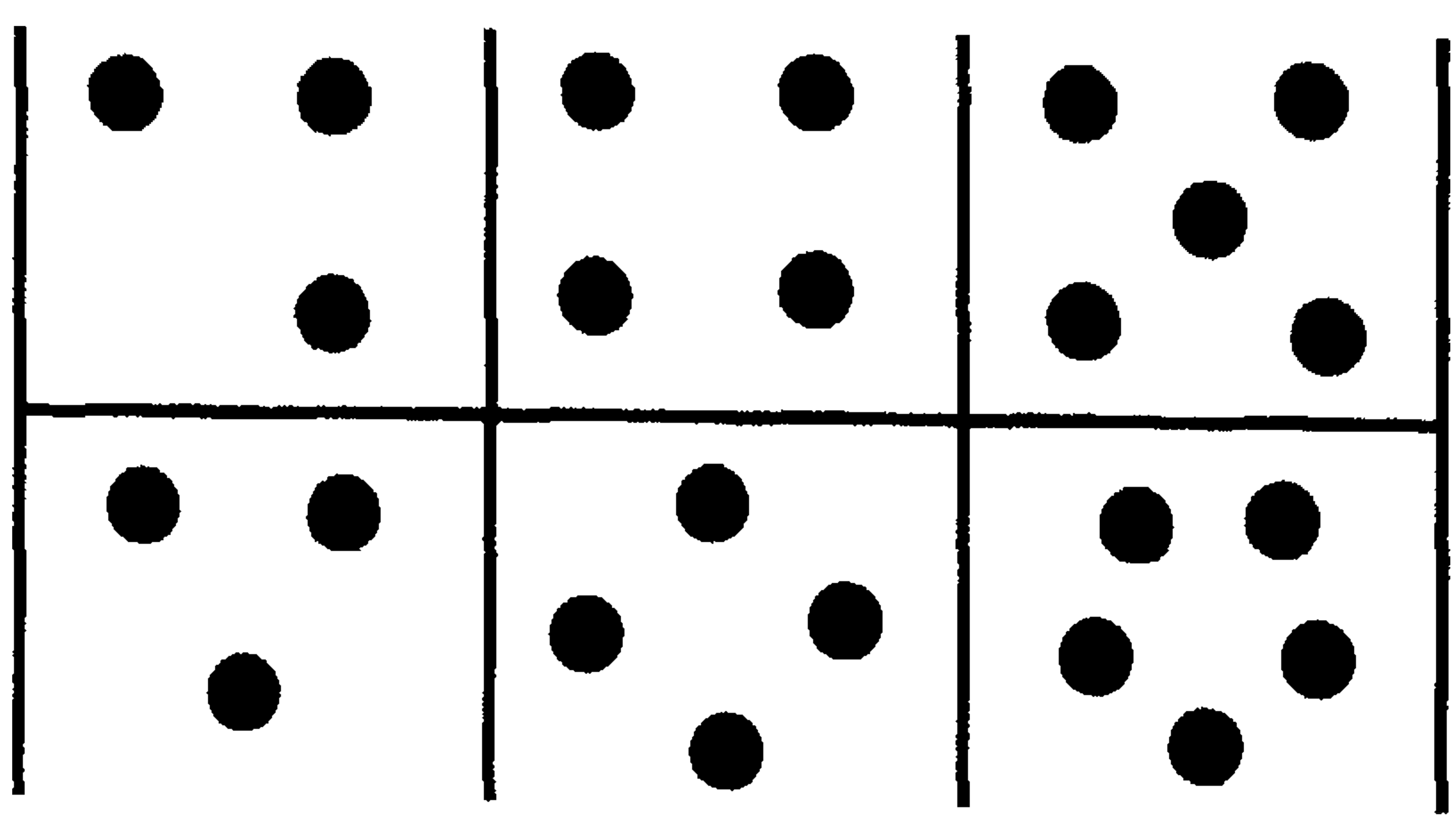

Fig. 1. Patterns as used in Experiment 1. In each column all possible patterns are listed for a certain number of dots.

number of dots must be detected, whereas in Trick and Pylyshyn (1994) any number of dots had to be determined.

2.1. Method

2.1.1. Subjects

Fifteen subjects participated in the experiment. All were tested for colour blindness and had normal or corrected-to-normal vision.

2.1.2. Stimulus

The stimuli were presented on a Philips 15A monitor connected to a personal computer. The stimulus consisted of three-, four- and five-dot patterns in configurations as shown in Fig. 1. The configurations have a close resemblance to the patterns used in the Bourdon–Vos test. The dots were presented on a white background (23 cd/m^2). There were two conditions: a one-colour condition (all dots were red), and a two-colour condition (each dot was randomly coloured red or green). The luminance of the red dots was 8 cd/m^2 and that of the green dots was 9 cd/m^2. The size of the dots was 9 arcmin and the total configuration subtended approximately 2° of arc. Each dot had a positional uncertainty of 10 arcmin. This uncertainty was introduced to minimise the possible cues introduced by local dot densities. The patterns were presented for 200 ms and the interstimulus time was 1 s.

2.1.3. Procedure

Regardless of the colour of the dots, subjects had to press the left mouse button when a four-dot pattern (the target) was presented. When a non-target (three- or five-dot pattern) was presented, the subjects had to press the right mouse button. Subjects had to react as fast as possible and were instructed to make as few errors as possible. In the case of a mistake or when the reaction time was faster than 150 ms or slower than 600 ms, the same trial was repeated later in the experiment. Subjects had to give a correct response to 120 targets and 120 non-targets (60 three-dot patterns and 60 five-dot patterns).

2.2. Results and discussion

The results of this experiment are summarised in Table 1. The mean reaction time of the two-colour condition minus the mean reaction time of the one-colour condition has a mean value of −0.74 ms. A *t*-test for within-subjects-measurements was performed on the mean reaction times. Contrary to the expectation from the Feature Integration Theory there is no significant effect between the one- and two-colour condition ($t_{obs} = -0.2121$, $p = 0.83$, $df = 14$). There was no speed-accuracy trade-off. Subjects did not make more mistakes in the two-colour condition than in the one-colour condition (an average of 85.55% correct in the one-colour condition versus 86.20% correct in the two-colour condition), so the reaction times can be compared.

There are two possible explanations for the lack of difference. One explanation is that the subitization process is insensitive to colour differences. This idea is

Table 1
Results of Experiment 1. The mean of the differences between the reaction times is −0.74 ms and the standard deviation of the differences is 13.44 ms. The differences between the percentages correct do not deviate significantly from zero (the mean of the differences is 0.01 and the standard deviation is 0.05)

Ss	One colour condition Reaction times		Two colour condition Reaction times		Difference between means	Score one colour (% correct)	Score two colours	Difference between scores
	Mean (ms)	SD	Mean (ms)	SD				
1	483	96	481	89	−1	96.00	90.23	−5.77
2	489	83	524	66	35	96.77	99.17	2.40
3	554	97	548	97	−6	78.43	91.60	13.17
4	528	102	522	89	−6	91.60	90.23	−1.38
5	556	91	554	98	−2	80.54	76.92	−3.61
6	487	85	478	86	−8	96.00	93.02	−2.98
7	481	92	484	92	2	82.76	80.54	−2.22
8	504	102	509	111	5	88.89	85.11	−3.78
9	386	51	404	67	17	84.51	88.89	4.38
10	560	93	562	95	1	86.33	92.31	5.98
11	532	82	524	75	−7	96.77	97.56	0.79
12	603	125	604	109	1	59.70	64.17	4.47
13	534	85	516	78	−18	93.02	97.56	4.54
14	542	117	526	101	−16	84.51	82.19	−2.32
15	533	120	523	118	−9	67.42	63.49	−3.92

compatible with the notion that subitizing is a primitive (feature-detection) mechanism. Another explanation is concerned with the used configurations of dots. The used forms are overlearned and in the Feature Integration Theory overlearned elements behave like primitives. These primitives are assigned to their own feature maps independent of other features (in this case, colour). Thus, reaction time is not influenced by colour. May be subjects do not subitize but recognise overlearned dot patterns. These two explanations are compared in Experiment 2.

3. Experiment 2

In this experiment the global form of the patterns was kept as constant as possible. The choice was made to place all the patterns in a triangular configuration. In this experiment the same hypothesis was tested as in Experiment 1, namely that differently coloured dots in sparse dot patterns lead to longer reaction times.

3.1. Method

3.1.1. Subjects

Fifteen subjects participated in this experiment. None of the subjects participated in Experiment 1 to prevent learning during Experiment 1 influencing the results of this experiment. All were tested for colour blindness and had normal or corrected-to-normal vision.

3.1.2. Stimulus

The same apparatus was used as in Experiment 1. The stimulus consisted of three, four or five dots in a triangular pattern configuration (see Fig. 2). We chose these configurations, because all possible configurations have the same global form-properties. The patterns were rotated over a random angle. The dots had the same size, colour and luminance as in Experiment 1. The same two conditions (i.e. a one-colour condition and a two-colour condition) as in Experiment 1 were tested.

3.2. Results and discussion

The results of Experiment 2 are summarised in Table 2. The mean reaction time of the two-colour condition minus the mean reaction time of the one-colour condition has a mean value of 14.32 ms. As in Experiment 1, a t-test for within-subjects-measurements was performed. The difference between reaction times was significant ($t_{obs} = 4.9993$, $p \ll 0.001$, $df = 14$). Subjects did not make more mistakes in the two-colour condition than in the one-colour condition (an average of 84.39% correct in the one-colour condition versus 84.05% correct in the two-colour condition), so there is no speed-accuracy trade-off.

The results lead to two conclusions. First, colour has an impact on subitization. The difference in reaction times suggests that the subitizing mechanism is disturbed by introducing colour if this colour is an irrelevant feature. Second, the form of the dot patterns has an influence on the quantification of the dots; so confirming the explanation of the 'overlearned' feature maps.

4. General discussion

From the combined results of our two experiments we conclude that Experiment 1 did not measure the influence of colour on subitization but the (lack of) influence of colour on perceiving overlearned global forms, while Experiment 2 did measure the influence of colour on subitization. The results of Experiment 1 corroborate the

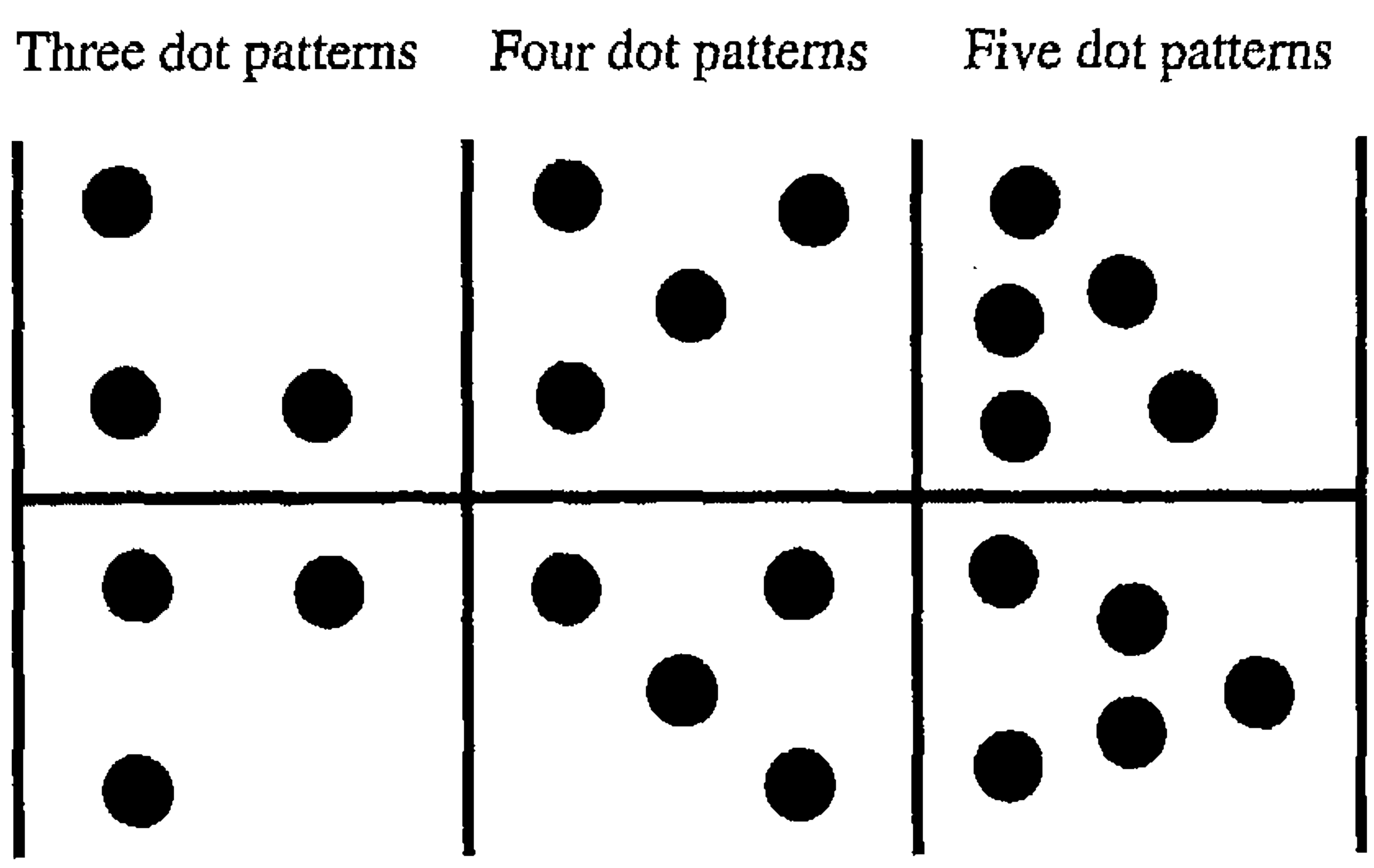

Fig. 2. Patterns as used in Experiment 2. In each column two examples of all possible patterns are listed. The global form of all patterns is triangular. The patterns were presented in an arbitrary orientation.

Table 2
Results of Experiment 2. The mean of the differences between the reaction times is 14.32 ms and the standard deviation of the differences is 11.09 ms. The differences between the percentages correct do not deviate significantly from zero (the mean of the differences is 0.00 and the standard deviation is 0.03)

Ss	One colour condition Reaction times		Two colour condition Reaction times		Difference between means	Score one colour (% correct)	Score two colours	Difference between means
	Mean (ms)	SD	Mean (ms)	SD				
1	549	89	554	85	4	82.19	76.92	−5.27
2	512	82	529	93	17	84.17	88.89	4.72
3	546	93	572	97	26	80.00	79.47	−0.53
4	580	74	604	58	24	98.36	96.00	−2.36
5	496	89	503	101	6	74.53	74.03	−0.50
6	441	90	458	106	17	88.24	92.31	4.07
7	525	81	529	83	3	89.55	86.96	−2.60
8	531	83	567	77	35	83.92	79.47	−4.45
9	476	94	489	85	12	95.24	93.75	−1.49
10	532	86	563	95	31	86.33	89.55	3.22
11	543	95	550	93	7	75.95	78.43	2.48
12	461	65	478	74	16	81.08	83.92	2.84
13	358	92	356	94	−1	95.24	92.31	−2.93
14	562	114	569	116	7	61.54	64.17	2.63
15	541	98	548	102	6	89.55	84.51	−5.05

theory that overlearned elements behave like primitive features, as proposed by Treisman and Gelade (1980).

The evidence for the role of global form detection in subitization is not unequivocal. Neisser (1966) suggested that during subitization the global form is used. This was also proposed by Mandler and Shebo (1982) who concluded from a series of experiments that the enumeration mechanism consisted of three processes. One of the processes determines the number of dots in one-, two- and three-dot patterns on the basis of canonical information in the patterns. For more than three dots, another mechanism based on mental counting is used. For more than six or seven dots, the subjects guess. This was seen as the third mechanism. Free (1995) suggested that two separate mechanisms are involved in subitization, a shape-based and a non-shape-based mechanism. The shape-based mechanism is comparable with the 'canonical' mechanism of Mandler and Shebo and with what we call global form perception. The non-shape subitization mechanism is what we would more appropriately call subitizing.

Recapitulating these studies, it is thought that subitization is for a major part the result of shape recognition. In contrast, Dehaene and Cohen (1994) argued that small sets of elements are not quantified by pattern recognition. They tested five simultanagnosic patients (i.e. patients who are not capable of integrating the presented visual information). These patients could not perceive the global form of the dot patterns, but could subitize. Similarly in a study of Davidoff and Warrington (1993) a patient was described who was unable to discriminate different forms, but who could point to or name different objects in a three-dimensional scene, given a forced choice of one, two or three objects in the scene. The reverse dissociation was found in Kartsounis and Warrington (1991); they described a patient who was able to discriminate different forms but was unable to count them. The findings of these four studies suggest that subitization differs from global form perception. This global form perception is what was measured in the first experiment.

The results of Experiment 2 suggest that subitizing is not a primitive mechanism. If it were primitive, irrelevant colour would not have any influence on it. Pylyshyn (1989) also concluded, that subitization is a non-parallel process.

We end with a remark on the Bourdon–Vos test. The above findings somewhat question the subitization status of the Bourdon–Vos test. Whether the Bourdon–Vos test is a subitization test or not is, to some extent, a matter of definition. However, if one defines subitization as enumerating a small number of dots, regardless of the underlying mechanism that is used, the Bourdon–Vos test can be seen as a subitization test.

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