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Alerting cues enhance the subitizing process

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ABSTRACT

Enumeration of elements differs as a function of their range. Subitizing (quantities 1–4) is considered to be an accurate and quick process with reaction times minimally affected by the number of presented elements within its range. In contrast, small estimation (range of 5–9 elements exposed briefly) is a less precise linear process. Subitizing was consider to be a pre-attentive process for many years. However, recent studies found that when attentional resources were occupied elsewhere, the subitizing process was impaired. In the current study, we examined whether subitizing can be facilitated by improving engagement of attention. Specifically, brief alerting cues that increase attentional engagement were presented in half of the trials during enumeration tasks. In Experiment 1, participants were required to enumerate dots presented in random arrays within the subitizing or small estimation range. Alerting facilitated enumeration of quantities in the subitizing range, but not in the small estimation range. We suggested that the benefit of alerting on the subitizing process was achieved via enhancement of global processing, a process that was previously associated with both alerting and subitizing. In Experiment 2, we provided direct evidence for this hypothesis by demonstrating that when global processing was used for items in the small estimation range (i.e., presenting quantities in a canonical array), a subitizing-like pattern was revealed in quantities beyond the subitizing range.

1. Introduction

Is enumeration modulated by attention? Recent reports suggested that the answer is positive. In the current study, we examined if and how one specific aspect of attention—alertness, the mechanism responsible for achieving and maintaining an optimal level of arousal during task performance—modulates enumeration processes.

1.1. Enumeration processes and the mechanisms underlying them

Enumeration is one of the building blocks of math ability. The ability to enumerate 1–4 elements has been referred to as subitizing (Kaufman, Lord, Reese, & Volkmann, 1949)—a fast and accurate process. In contrast, if more than 4 elements are presented, enumeration is serial, much slower, and is termed *counting*. A third process is *estimation*, which was described by Dehaene (1992) as the ability to determine the approximate numerosity of elements that cannot be efficiently subitized or counted. Estimation is required when elements are presented for short exposures and therefore cannot be counted. If the number of elements presented is in the counting range, but for a short exposure duration, the elements are considered to be in the small estimation range.

Throughout the past decades, a lot of research has been devoted to investigating the underlying mechanisms of enumeration processes. While there is an agreement that the enumeration process in the small estimation range requires attentional resources and is conducted serially, less is clear regarding the involvement of attentional processes in enumeration within the subitizing range. Several studies suggested that subitizing does not require attention at all (Atkinson, Campbell, & Francis, 1976; Trick & Pylyshyn, 1994). These studies argued that subitizing is a pre-attentive process because there are no differences in response latency between quantities in the subitizing range (i.e., as opposed to the small estimation range), and because subitizing can be performed in parallel with other processes. However, other more recent studies suggested otherwise.

Egeth, Leonard, and Palomares (2008), and Olivers and Watson (2008) conducted experiments using the attentional blink task combined with an enumeration task. Their results indicated that when attentional resources were captured by a letter identification task, the subitizing process was impaired in a parallel enumeration task (for similar results see also Railo, Koivisto, Revonsuo, & Hannula, 2008; Vetter, Butterworth, & Bahrami, 2008). The authors concluded that subitizing requires attentional resources.

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Overall, previous evidence suggested that subitizing is impaired when attentional engagement in the enumeration task is reduced. An interesting complementary question, which has not been examined previously, is whether enhancement of attention during an enumeration task can improve the subitizing process.

Alerting is an attentional system that regulates the intensity of attention to a given stimulus and responding to it (Petersen & Posner, 2012; Posner & Petersen, 1990). Alerting can be manipulated by introducing brief warning cues (e.g., an auditory beep sound) that exert a state of high arousal (Posner, 1978). The warning cues do not deliver any information regarding the identity of the subsequent target or its spatial location. Nonetheless, reaction time (RT) is faster in trials with a warning cue compared with a no-cue condition. In the present study, we examined the impact of such warning cues on the subitizing process.

Cumulative evidence indicates that alerting might have a specific role in the subitizing process by modulating processing of spatial configurations. Mandler and Shebo (1982) argued that arrays of 1 to 4 items create familiar shapes, such as a line (2 items), a triangle (3 items), or a square (4 items). Namely, items in the subitizing range are recognized by their spatial configuration. That is, arrangement of several small elements can create a whole familial figure (i.e., hierarchical figure). Navon (1977) suggested that such figures could help dissociate between global perceptual processing (i.e., attention to the whole figure) and local perceptual processing (i.e., attention to the details that comprise the whole).

It should be noted that a familiar pattern can be created for quantities above the subitizing range (above 4). Indeed, canonical arrangements of dots can create familiar shapes (like on a dice) for quantities in the small estimation range. Studies revealed that when applying a canonical arrangement, adults and children presented a subitizing-like pattern of results, even for the quantities in the small estimation range (Ashkenazi, Mark-Zigdon, & Henik, 2013; Kaufmann & Nuerk, 2008). Such results hint that attention to a global figure might play a crucial role in the subitizing process.

Interestingly, alerting was found to enhance global processing. Weinbach and Henik (2011) used a variation of Navon's task in which participants were presented with a large arrow (i.e., global level) made of small arrows (i.e., local level). Participants were required to indicate the direction of the small or large arrow in different blocks. The small and large arrows could point in the same direction (i.e., congruent condition) or in opposite directions (i.e., incongruent condition). The mean difference in RTs between the incongruent and congruent conditions was used as a measure of interference by the irrelevant dimension. Auditory alerting cues were presented in half of the trials prior to the arrow target. It was found that alerting increased the global interference (i.e., the interference from the big arrow was larger in the alerting compared to the no-alerting condition) when participants had to respond according to the local level (small arrows), but did not affect local interference when participants had to respond according to the global level. The authors suggested that alerting acts to enhance global processing. Other studies used this task to show that alerting can improve global processing in populations that are known for having deficient global processing abilities such as those with attention deficit hyperactive disorder (Kalanthroff, Naparstek, & Henik, 2013) and congenital prosopagnosia (born with difficulty in recognizing faces; Tanzer, Weinbach, Mardo, Henik, & Avidan, accepted for publication). In addition, Van Vleet and colleagues showed that a short training procedure aimed to increase alertness level induced a bias towards global processing of attention and reduced local processing (Van Vleet, Hoang-duc, DeGutis, & Robertson, 2011). To conclude, there is much support that alerting facilitates global processing. If the subitizing process relies on the spatial configuration of small elements into a familiar pattern (Mandler & Shebo, 1982), alerting should also facilitate processing of elements in the subitizing range, but not elements in the small estimation range (which do not create a familiar global pattern).

1.2. The current study

As was described in the introduction, alerting acts to increase attentional engagement in a given task, and was found to enhance attentional bias towards global elements. Since arrays of element in the subitizing range create a familiar global configuration, we hypothesized that the subitizing process would benefit from alerting cues. This hypothesis was examined in two experiments.

In both experiments, participants were presented with an array of dots and were instructed to report the quantity of the dots. The number of dots presented was either in the subitizing range (quantities 1–4) or in the small estimation range (quantities 5–9). In half of the trials, an alerting warning cue was presented prior to the array. In Experiment 1, the arrangement of the dots was random, and the influence of the alerting cues was examined in both the subitizing and small estimation ranges. We hypothesized that only the subitizing range would benefit from the alerting cue. In Experiment 2, two different arrangements of arrays were compared: canonical vs. random. Importantly, a canonical arrangement is symmetrical and relies on pattern recognition. Namely, small local elements create a larger global element that enables participants to grasp all the presented dots at once rather than count the dots one by one (for discussion of canonical arrangements see Ashkenazi et al., 2013; Piazza, Mechelli, Butterworth, & Price, 2002). In Experiment 2, we examined the influence of alerting cues on performance for each quantity separately. Because under a canonical arrangement participants can engage in global processing even in the small estimation range, we hypothesized that quantities above the subitizing range would also benefit from an alerting cue, supporting the role of alerting in facilitating global processing when involved in enumeration.

2. Experiment 1: The interaction between enumeration and alertness

2.1. Method

2.1.1. Participants

Twenty-four undergraduate students from Ben-Gurion University of the Negev (aged 21–30 years old) took part in this experiment in return for monetary payment (about $7) and were naïve as to the purpose of the study. They reported normal or corrected-to-normal vision, with no diagnosed attention disorder or learning disabilities. All participants gave their informed consent prior to their participation in the study.

2.1.2. Apparatus

The experiment was run on an IBM-PC with a 17-inch color screen monitor. E-Prime version 2.0 software was used for programming, presentation of stimuli, and timing operations. A headphone set was used to deliver an alerting cue. A microphone was used to register vocal input. RT was recorded electronically by a response box controlled by E-Prime software and was measured from onset of the stimulus to onset of the vocal response. The content of the subject's vocal response in each trial was input into the computer by the experimenter's key-press.

2.1.3. Stimuli

The number of dots varied from 1 to 9 per array. The dot arrays (white on a black background) were created with MATLAB™ code created by Gebuis and Reynvoet (2011). MATLAB code was also used to program the computer to record the absolute values of five different continuous properties, as were used and reported in Leibovich and Henik (2014). These properties included 1) average diameter (the dots in the array differed in size, therefore, the average diameter of the dots in an array was computed); 2) total surface area (i.e., the sum of the surface area for the dots in each array); 3) area extended (i.e., the smallest contour that included all of the dots, as if an elastic band was wrapped around the dots); 4) density (i.e., area extended divided