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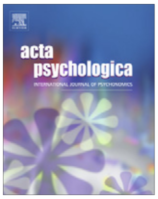

Enumeration: Shape information and expertise

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ABSTRACT

This study examined the interaction between grouping information and expertise in a simple enumeration task. In two experiments, participants made rapid judgements about the number of items present in a visual display. Within each display, items were grouped into a canonical representation (e.g., triangle, square, and pentagon) or were arranged linearly. In both experiments, grouping information facilitated enumeration performance, replicating previous findings in the literature. In Experiment 2, the facilitative effect of grouping information was found to be greater for Air Traffic Controllers (ATCs) than for matched novices, though they were no better than novices on linear arrays. This may be because linear, like canonical arrays, hold unique numerosity information, but only when they contain the minimum number of points necessary to define a line (i.e., 2). So ATCs' performance on linear arrays containing more than two items does not benefit from a facilitative effect of grouping information. That their experience of being ATCs, in terms of years served, was shown to account for the expertise effect suggests that such visuospatial expertise is acquired through frequent exposure to spatial arrays.

1. Introduction

When asked to make a rapid decision about how many items are presented in a visual display, people typically show a distinctive pattern of response times and accuracy (e.g., Trick & Pylyshyn, 1993, 1994). For displays containing small numbers of items (up to 3 or 4), accuracy tends to be close to ceiling and response times are fast and relatively constant. For displays containing greater numbers of items, accuracy generally decreases and response times increase as a function of each additional item in the display. Kaufman, Lord, Reese, and Volkmann (1949) coined the term *subitizing* to describe the rapid and accurate enumeration of small numbers of items and to distinguish it from the processes of *counting* or *estimating* involved in quantifying larger (>4) numbers of items.

Mandler and Shebo (1982) proposed that subitizing was the result of geometric cues in the arrangement of items in the display leading to fast pattern recognition and access to associated information on numerosity (i.e., a triangular pattern is associated with the number three; a square with the number four, etc.). They presented participants with displays in which items were arranged either in a familiar pattern, such as is seen on the face of a die, or randomly. Participants demonstrated a pattern recognition advantage in that they responded faster and more accurately to the familiar patterns than to random arrangements. Similar responses were reported by Wender and Rothkegel (2000) who, in addition, demonstrated that when presented with more complex displays, participants would, where possible, partition these into small canonical patterns prior to enumeration. In fact, that enumeration is easier when the elements group in a manner conducive to form recognition has been extensively explored (see, for example, van Oeffelen & Vos, 1982; Vos, van Oeffelen, Tibosch, & Allik, 1988).

The fact that subitizing appears restricted to displays containing up to about four items has been attributed to the difficulties that arise when generating canonical patterns for displays of greater numbers of items. As the number of items within a display increases, the number of possible configurations into which they can be arranged becomes too large to facilitate the development of simple representative patterns. For example, Logan and Zbrodoff (2003) demonstrated that perceived similarity between different configurations of the same number of elements decreased as the number of elements in the displays increased. Similarity between displays containing three items was very high but then fell dramatically as the number of elements per display increased beyond this point.

Difficulties in generating a canonical pattern notwithstanding, there is evidence suggesting that the pattern recognition advantage can be extended, albeit to a small extent, by practice. For example, Mandler and Shebo (1982) demonstrated that, with around 50 trials using fixed patterns, response times to displays

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with more than 4 items fell. This practice effect has also been reported by Wolters, Van Kempen, and Wijlhuizen (1987). On each of the five consecutive days they tested subjects on their ability to enumerate displays consisting of between 4 and 18 items. For one group, items in the displays were presented in different random configurations on each day, and for the other, in consistent patterns. Practice with the consistent-pattern stimuli led to both large decreases in response times and improvements in accuracy, while only small improvements were found for the random configurations. In discussing their results, Wolters et al. suggest that an implication of their findings is that, given sufficient experience with the possible configurations of items in a display, subitizing should be possible for any number of items.

Using a multiple-target tracking task, Allen, McGeorge, Pearson, and Milne (2004) examined the ability of radar operators to keep track of the locations of sets of randomly moving identical visual targets. Radar operators were chosen as their work environment means that they are constantly exposed to complex dynamic visual pattern information in which they need to keep track of the locations of many items. These experts in dynamic spatial cognition were found to be significantly better than a matched group of novices at target tracking, typically being able to track additional items even under conditions of increased workload.

Trick and Pylyshyn (1993) have proposed that a common mechanism underpins performance on both multiple-target tracking and enumeration tasks. Green and Bavelier (2006) have shown that experienced action video game players show significantly better performance on both multiple-target tracking and enumeration tasks. Hence, it is possible that the multiple-target tracking advantage shown by the radar operators (expert group) in the Allen et al. (2004) study would also be manifested if they were tested on an enumeration task. Further, if the advantage shown by radar operators in multiple-target tracking is "in some way" related to the pattern recognition processes, then any advantage in an enumeration task might be greater where the stimuli consist of regular/canonical patterns, particularly because of our bias towards regular forms (Feldman, 2000). Moreover, previous research has shown that special configurations (e.g., collinearity, parallelism, convexity versus concavity) often play a role in perceptual grouping and shape perception, even when it is made task-irrelevant (e.g., Feldman, 1996, 1997; Kukkonen, Foster, Wood, Wagemans, & Van Gool, 1996; Wagemans, Lamote, & Van Gool, 1997; Wagemans, Van Gool, Lamote, & Foster, 2000).

The suggestion that pattern information may play a role in multiple-target tracking has received some support from work by Yantis (1992). Yantis demonstrated that performance on a multiple-target tracking task was improved for participants who were provided with grouping information during the target acquisition phase, relative to those not provided with this information. Yantis also noted that the advantage of being provided with grouping information was relatively short-lived, something that he attributed to those participants not explicitly provided with grouping information discovering their own grouping strategy.

The following study sets out to test whether air traffic controllers (ATCs), whose role relies on significant expertise in spatial cognition, show an extension to the subitizing range relative to matched participants without this experience, and whether this is in someway related to more experience, and so a greater ability to make use of different geometric patterns for items in a visual display. The aim of Experiment 1 is to replicate the previous finding of a performance advantage when stimuli are presented as canonical patterns (e.g., Mandler & Shebo, 1982; Puts & de Weert, 1997; Wender & Rothkegel, 2000; Wolters et al., 1987), using the current stimuli and procedure. Experiment 2 then addresses the influence of expertise and the interaction of expertise and pattern information.

2. Experiment 1

2.1. Method

2.1.1. Participants

Twenty-seven psychology students (6 males) at the University of Aberdeen, aged between 18 and 44 ($M = 25.3$, $SD = 7.93$), took part in the experiment for course credits. All had normal or corrected-to-normal vision.

2.1.2. Materials

All stimuli were prepared in advance on a computer-aided drawing package before being converted to bitmaps for presentation. Each stimulus contained a number of identical items ("+"s in bold Times New Roman, subtending a visual angle of approx 1.25^{o} at a viewing distance of approximately 57 cm), ranging from 1 to 6, whose extent was always the circumference of a notional 50 mm diameter circle centred in the middle of the screen. When stimuli contained from 3 to 6 items, these were arranged in canonical or linear patterns. In line with the notion of a virtual polygon suggested by Yantis (1992) as facilitating performance in multiple-target tracking, particularly where concavities within the polygon were avoided, the canonical patterns were all regular geometric shapes (i.e., triangle, square, pentagon, and hexagon) with equal sides. Linear patterns were lines of "+"s, always arranged equidistantly along the full length of the notional 50 mm circle's diameter. Linear patterns were used, instead of random arrays, because the former seemed less able to convey quantitative information by dint of their arrangement, as the latter always provide opportunities for partial grouping and chunking. The various stimulus configurations are shown in Fig. 1. (Note, that whilst the co-linearity of parts of the pluses (+'s) might facilitate the percept of a square this was not expected to be significant; nor does the situation arise from any other arrangement.)

Each trial began as a static frame consisting of a centralised black fixation letter 'o' subtending a visual angle of 0.42°, on a white background subtending a visual angle of 21.5°. After a delay of 500 ms, a bitmap was presented, almost immediately replaced by a screen display with the instruction that participants should respond as to how many items the bitmap image had contained.

Trials were displayed using E-prime software (Psychology Software Tools Inc., Pittsburgh, PA) running on a 350 MHz Pentium II PC with a 17-in. monitor set to a resolution of 800 × 600 (SVGA) at a viewing distance of approximately 57 cm.

2.1.3. Design

All participants undertook an enumeration task in which the stumlus presentation time (17/34/51 ms – multiples of the computer's refresh rate), number of items (1–6) and arrangement (canonical/linear) were systematically manipulated. To minimise pattern learning during the study, several versions of every arrangement were created, the orientation of each differing by its degree of rotation. Order of presentation was completely randomised by the presenting software. In total, there were 864 trials that took approximately 45–60 min to complete.

2.1.4. Procedure

In order to minimise extraneous visual distractors, participants were tested individually in a darkened room. Each participant was instructed that they were to be presented with a series of images such that each contained a number of identical items. For each image, once presented, they were simply to indicate, using the numeric keys above the QWERTY keys, how many items it had contained. They were also cautioned that they might sometimes feel they had not been shown an image because the presentation