Subitization and attentional engagement by transient stimuli

LOUISE ALSTON1,*, and GLYN W. HUMPHREYS2

1 Centre for Cognition and Neuroimaging, Department of Human Sciences, Brunel University, Uxbridge, UK
2 Behavioural Brain Sciences Centre, School of Psychology, Birmingham University, Edgbaston, Birmingham, UK

Received 30 July 2002; revised 11 January 2003; accepted 12 January 2003

Abstract—A series of experiments investigated the visual selection of moving and static items during enumeration. Small numbers of visual targets can be enumerated with little increase in reaction time and error with set size, a process referred to as ‘subitization’. The number of items that can be ‘subitized’ is typically between one and four and known as the subitization range. This study looked for evidence of subitizing of subsets of items presented on a computer display. Fast and accurate enumeration was found for random configurations of moving targets even when presented among static distractors. This was not the case for static targets presented among moving or transient distractors. RTs to these targets were longer and showed a steady increase in RT with target number, even in the subitization range.

However, when static targets and moving distracters were presented foveally, fast enumeration/subitization of the static targets was again possible. This was not due to reduced inter-item spacing, since linear effects of the number of targets still emerged when stimuli were presented peripherally but the size-spacing ratio was matched to the foveal presentations. There was indication that instead performance reflected perceived differences in movement speed for stimuli presented in parafoveal and more peripheral retinal regions. In support of this, subitization of static items improved as the movement speed of the distracters increased. The data suggest that the processes supporting subitization are highly sensitive to dynamic stimuli and depend on the ease of segmentation between static and moving arrays.

Keywords: Subitization; enumeration; visual attention; movement filter; dorsal stream.

INTRODUCTION

There is evidence of two distinct processes operating during the enumeration of small and large numbers of visual items, with abrupt changes in reaction times (RTs)

*To whom correspondence should be addressed.
and errors for counting below and above about four items (Klahr, 1973; Trick and Pylyshyn, 1993, 1994). The cost of increasing the number of items is small until about four or five items is reached. This phenomenon has been termed ‘subitization’ (Kaufman et al., 1949) and gives gradients of RT against target number of less than 100 ms/item. Beyond this number, RTs and errors increase in proportion to numerosity and can give gradients typically of 250–350 ms/item. There is also neuropsychological evidence for separate processes of subitizing and counting with impairments specific to counting and not subitizing in simultanagnosic patients (Dehaene and Cohen, 1994). Several theories have been developed to explain the mechanisms underlying subitizing and its limitations, but most would seem to favour either a pattern-recognition explanation or one in which the visual selection process is limited.

Subitization as pattern recognition

The main proponents of the pattern recognition approach have been Mandler and Shebo (1982). They propose that the flat RT and error functions during subitization are due to the items forming recognisable patterns. In support of this, it would be unusual to individually count the dots when reading a die, for instance. Since a line can be made from two points, a triangle from three, a square from four, it is possible that by recognising these characteristics we identify the number of items present when their configuration fits the structure of a known shape. However, it is unlikely that fast enumeration typically occurs in this way, since items can be presented in a shape that is inconsistent with the number present and despite this clear subitization functions are still evident. An example of this is the distinctive flat RTs produced when the enumerated items are arranged in a line (Frick, 1987). Further evidence against subitization by shape recognition is the finding of a difference in brain activity during fMRI for the same display presentations between naming the shape formed by an arrangement of items and identifying their numerosity (Fink et al., 2001).

A separate account of subitization, related to the idea of recognising patterns, has been proposed by Atkinson and her colleagues (Atkinson et al., 1976a, b). They suggest that subitization depends on low spatial frequency cells that are sensitive to a particular phase. These cells signal a response when the bright and dark parts of the image pattern match the excitatory and inhibitory arrangement of their receptive fields. The lack of subitizing for large numbers of items can be described as resulting from a lack of units sensitive to the particular phase information of the image. Again, however, this account seems unlikely, since subitization does not depend on items being organised in a regular configuration — clear subitization functions can be achieved for random arrays of items presented among distracters (Trick and Pylyshyn, 1993).

An interesting development from the work by Atkinson et al. is the finding that subitization does not occur for items placed close together. In an experiment in which the dots were presented at five different spatial frequencies: 2, 5, 8, 11 and 22 c/deg (with spatial frequency referring to the visual angle of the dot and