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## Subitizing in tactile perception

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**Count number = 997 words.**

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Enumerating small sets of up to 3 to 4 items is fast, accurate and effortless and is known as subitizing (Kaufman, Lord, Reese & Volkman, 1949) but gets slower, less accurate and more effortful with more than 4 items (counting). For over a hundred years (Jevons, 1871; Warren, 1897) researchers have focused on visual enumeration and many theories propose that subitizing and counting are two distinct processes in visual perception (Mandler & Shebo, 1982; Trick, & Pylyshyn, 1994; Dehaene & Cohen, 1994). Here we demonstrate for the first time that subitizing also occurs in tactile perception.

In a standard visual subitizing task, subjects are asked to name the number of items presented on a computer screen as accurately and as fast as possible. Typical findings are that accuracy is near perfect for small set sizes up to 3 items, but starts to fall off at 4 items. Naming times exhibit a marked discontinuity producing a shallow slope for 1 to 3 items (40 to 100 ms/item in adults) and a much steeper slope from 4 items upwards (250 to 350 ms/item). In children these naming times are considerably greater (200 ms/item for small set sizes and 1000 ms/item at larger set sizes). It is important to note that subitizing is characterized by a discontinuity in the naming time slopes and not by the absolute values of the slopes themselves (Trick, & Pylyshyn, 1994). Thus children produce the subitizing / counting discontinuity in much the same way as adults do (Svenson & Sjöberg, 1978).

To investigate subitizing in tactile perception, we designed software and built novel apparatus to simultaneously stimulate the fingertips of both hands. Each hand rested naturally on a separate box with the fingertips spaced well apart from each other. Participants were asked to name the number of stimulated fingertips as quickly and as accurately as possible.

## **Method**

### **Participants**

The participants were 16 adult students and staff (6 males, 10 females) at the University René Descartes, Paris, France, aged between 19 and 28 years.

## **Apparatus and Stimuli**

Two boxes (381mm long, 22mm wide, 64mm high) were constructed to stimulate the fingertips of each hand. Five holes - one for each digit - were drilled into each box to allow small metal rods (6mm long, 1.6mm diameter) to protrude from the box and stimulate the fingertips. Fingers did not rest directly on the boxes but rested on small rubber rings (4mm high, 17mm outer diameter, 7mm inner diameter) to help keep the fingertips in place during the testing session. The metal rods used to stimulate the fingertips were activated by electro-magnets and shot up from the boxes with a speed of 6.33 m/s, to a height of 2mm above the top of the rubber rings applying a force to the fingertips of 5 N. The stimulation trials were controlled via a Pentium III running dedicated software written in Delphi. The participants responded into a microphone (Sennheiser e855) attached to a voice-activated relay, which stopped the computer's clock.

## **Procedure**

After a training period of 40 trials, each participant received 50 trials with each of 10 numerosities, for a total of 500 trials. Participants rested for a few minutes after every 100 trials. Fingertips were stimulated until subjects responded by speaking into a microphone attached to a voice-key recording naming times to the nearest milliseconds and retracting the rods. There was a 4000 ms interval between the vocal response and the next stimulus presentation. Stimulus sizes were presented randomly across all 10 fingers. The experimenter was present in the room to type the participant's numerical response into the computer.

## **Results**

In the 7 to 10 finger range, participants reported responding by enumerating the fingers not stimulated. We therefore restricted our analysis to set sizes of 1 to 6 fingers.

We found that both accuracy and correct naming times varied with numerosity (see Figure 1). There was a clear discontinuity in accuracy performance. For 1 to 3 fingers, accuracy was near perfect (99%, 98%, and 93% respectively) but was severely impaired in the range of 4 to 6 fingers (74%, 66%, and 48%).

A one-way analysis of variance performed on the naming times showed a significant effect of numerosity [ $F(5,75)=162.05$ ,  $p\text{-rep}>.99$ ,  $n^2=0.91$ ]. The average correct naming time for 1 to 3 fingers was quicker than the average naming time for 4 to 6 fingers (270 ms/item vs. 627 ms/item). Importantly, there was also a clear discontinuity in the naming times slope for 1 to 6 fingers.

## Discussion

Our findings support the view that subitizing occurs in tactile perception. The reaction times we report for enumerating small array sizes (1 to 3 fingers) is higher than that reported in the visual subitizing literature, but this is likely to reflect the fact that adults have little or no experience of enumerating items with their fingertips.

How do our findings relate to theoretical accounts of subitizing reported in the literature? Our results clearly pose a problem for accounts that are primarily visual. For example, in the pattern based explanation of Mandler and Shebo (1982), subitizing occurs because participants visually 'recognize' the canonical patterns produced by small array sizes.

However, a recent and influential account of subitizing that may be able to accommodate our findings is the FINST hypothesis (Pylyshyn, 1989; Trick & Pylyshyn, 1994). These authors argue that the FINST hypothesis makes use of a pre-attentive mechanism that individuates small numbers of objects. Although they apply this idea to visual subitizing, our results are clearly consistent with the idea that there is a mechanism for individuating small numbers of objects in tactile perception.

In sum, our findings suggest that subitizing is not restricted to visual perception but also extends to tactile perception. Subitizing may occur as the result of a general perceptual mechanism for individuating small numbers of objects. We might even want to take the view that subitizing reflects a fundamental limitation of the cognitive system: perhaps humans are restricted to holding 3 to 4 items in mind at any one time.

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**Figure 1.** Correct naming times as a function of the number of fingers stimulated (black dots). We fitted linear functions relating naming RTs to numerosity within and beyond the subitizing range. For numerosities of 1 to 3, the regression equation was  $RTs = 490 + 270N$ ,  $r = 0.99$ . For numerosities of 4 to 6, the regression equation was  $RTs = -668 + 627N$ ,  $r = 0.99$ . This replicates the standard bi-linear function reported in the visual subitizing literature. For comparison (white dots), we plotted the classical results obtained in visual perception by Mandler and Shebo (1982, p. 14, Experiment 3A, Figure 7).

