The Expanding Telephone Number: Immediate Memory for Multiple-digit Numbers

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Abstract

To evaluate the most effective way to present (telephone) numbers, factors of practical and theoretical relevance were studied. This includes list length (i.e. number of digits); visual vs. auditory presentation; duration of the presentation; and digit-grouping format (chunking). In the present study, auditory (i.e. sequential) presentation was compared directly with simultaneous visual presentation (all digits together). Not surprisingly, list length is the most critical factor for immediate recall (the more digits, the less recalled), and a longer presentation time favours both modalities. An effect of the digit-grouping format was found only for auditory presentations, where ungrouped numbers did worse. Plots of serial-position effects for different digit-grouping formats show that the digits in ungrouped, visually presented numbers are, in fact, subjectively grouped in twos.

1. Introduction

Many daily activities in modern society require users to remember strings of digits (e.g. telephone numbers), at least for some minimum amount of time to enter them. There is usually no clear structure in most numbers to aid people memorising them, and there is no latitude for errors since every digit must be correctly entered every time.

The present study deals with the immediate memory for novel multiple-digit numbers, using an immediate-recall task that resembles telephony. To evaluate the most efficient ways of presenting numbers, factors of combined practical and theoretical relevance were studied, including number length, visual (simultaneous) vs. auditory (sequential) presentation mode, presentation time and digit grouping (chunking) format.

The visual and auditory presentation mode have been compared in a number of studies, with the aim to study modality effects, e.g. the strong *recency* effect observed in the auditory mode. The standard procedure for investigating the modality effect has been to compare auditorilly presented lists with visually *sequentially* presented lists. Such sequential presentations may be disadvantageous for the visual modality. A number of studies have reported that when visual items are presented *simultaneously* rather than sequentially, the recall scores are better (see Frick, 1985). In the present study, we have compared auditory

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The present paper gives an abridged version of data presented in full in Nordby *et al*. (2001) and Raanaas *et al.* (2001).

presentation directly with a simultaneous visual presentation. We have focused on the serial-position curves to determine where on the curve any advantages may be found by using a visual simultaneous presentation.

The effect of presentation time on immediate memory has important practical implications. For auditory presentation, some studies show that faster rates result in poorer recall (see Gerver, 1969), while other studies report enhanced recall with faster presentation rates (see Dornbush, 1969). For visual presentation, it is generally observed that recall rises with increasing presentation time (see Woodward, 1970).

In his classical paper, Miller (1956) suggested that re-coding information-items into a smaller number of cognitive units or 'chunks' increases the number of items that may be recalled. Substantial grouping effects have been observed for temporal and non-temporal grouping of auditorily presented material (see Frankish, 1989). One way of grouping auditory numbers that is common in everyday use, but that has not been studied systematically, is to re-code multiple-digit numbers 'linguistically' into number words, e.g. 'twenty-three' instead of 'two' and 'three'. This so-called 'linguistic' re-coding of verbally presented material is examined in the present study.

Some studies have shown spatial grouping of visually presented digit strings to be advantageous (Magnussen *et al*., 1997). Data, however, are sparse and inconsistent as to the best grouping format. In the present study a non-grouped condition, called '1+1' (e.g. 1 2 3 4 5 6…), was compared with a two-by-two grouping condition, called '2+2' (e.g. 12 34 56 78…), and a three-by-three condition, called '3+3' (e.g. 123 456…).

2. Method

We used a basic four-variable (4×2×2×3) design, with list length (4, 6, 8 or 10 digits) and presentation mode (visual or auditory) as within subject variables, and presentation time (0.5 sec./digit or 1.0 sec./digit) and digit group size (1+1, 2+2 or 3+3) as between subject variables. The task was to key in each number immediately after presentation

A total of 144 subjects (72 female and 72 male) recruited from the student population at the University of Oslo participated. A telephone with a standard 12-key keypad was provided for the subjects to enter numbers generated by a PC into the PC. In the visual mode, the numbers were displayed on the PC screen (16mm tall Helvetica, black on a light grey background, providing very high legibility). In the 1+1 condition, a space was typed between each digit (e.g. 1 2 3 4 5 6), while in the 2+2 and 3+3 conditions a space was typed between each digit group (e.g. 12 34 56 or 123 456). In the 3+3 condition, when the number of digits was not divisible by three, the extra digits were placed on the left side (e.g. 12 345 678 or 1 234 567 890).

In the auditory mode, pre-recorded number-words (read by a female voice) were presented from a pair of loudspeakers. In the 1+1 condition, digits were spoken as single-digit words (e.g. 'one' 'two' 'three'), in the 2+2 condition, the digit-pairs were spoken as number words (e.g. 'twelve' 'thirty-four'). To create vocal 3-digit groups, a single-digit word and a two-digit number word were combined (e.g. '123' being pronounced 'one-twenty-three' rather than 'one-hundred-twenty-three').

For the two presentation rates used, a fixed rate was used per digit or digit group, i.e. only the *interval* between digits or digit groups varied. The nominal presentation time was the average presentation time per digit, rather than the absolute time used per single digit. The total presentation duration for each number length read verbally was the same as the presentation time for the same number length displayed on the screen.

Random numbers were generated by the PC for stimulus material, but numbers with leading zeros were rejected (to simulate telephone numbers). Each subject had one run for each of the eight within-subject factors (4, 6, 8 and 10 digits, visual and auditory mode). Each run consisted of 20 self-paced trials. All data were analysed according to split-plot ANOVAs. For a description of significance values see Nordby *et al.* (2001).

3. Results

The over-all effects of list length, presentation mode, presentation time and grouping format on the immediate recall of whole numbers are shown in *Figure 1*. Beyond four digits, where the recall performance is almost perfect (mean 97 % correct), the curves demonstrate an almost linear fall-off with increasing number of digits: 6-digit numbers: mean 88 % correct, 8-digit numbers: mean 47 % correct, and 10-digit numbers: mean 14 % correct. For a number to be correct, digits must be in correct order.

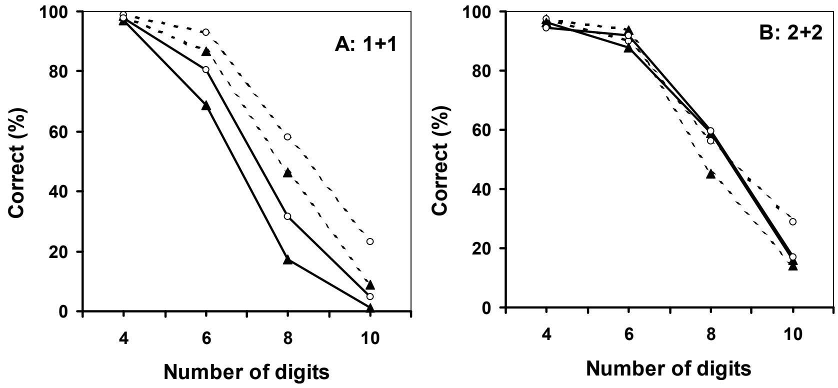

Figure 1. *Percent correctly entered whole numbers as a function of list length, presentation mode, presentation time and grouping format. Grouping format is presented in different panels; 1+1 (panel A), 2+2 (panel B), and 3+3 (panel C), while presentation mode and time are curve parameters, as indicated in inset (panel C).*

A visual inspection of the plots reveals that the curves for visual and auditory presentation are quite similar. An interaction effect between presentation mode and grouping format can be seen, compounded by the difference between non-grouped numbers presented visually and auditorily. No difference between the modes is seen when the non-grouped numbers are excluded.

Separate analyses of visual and auditory presentations show no effect of grouping format on recall in the visual mode, but a significant effect on recall in the auditory mode. However, no interaction between presentation mode and number of digits can be seen.

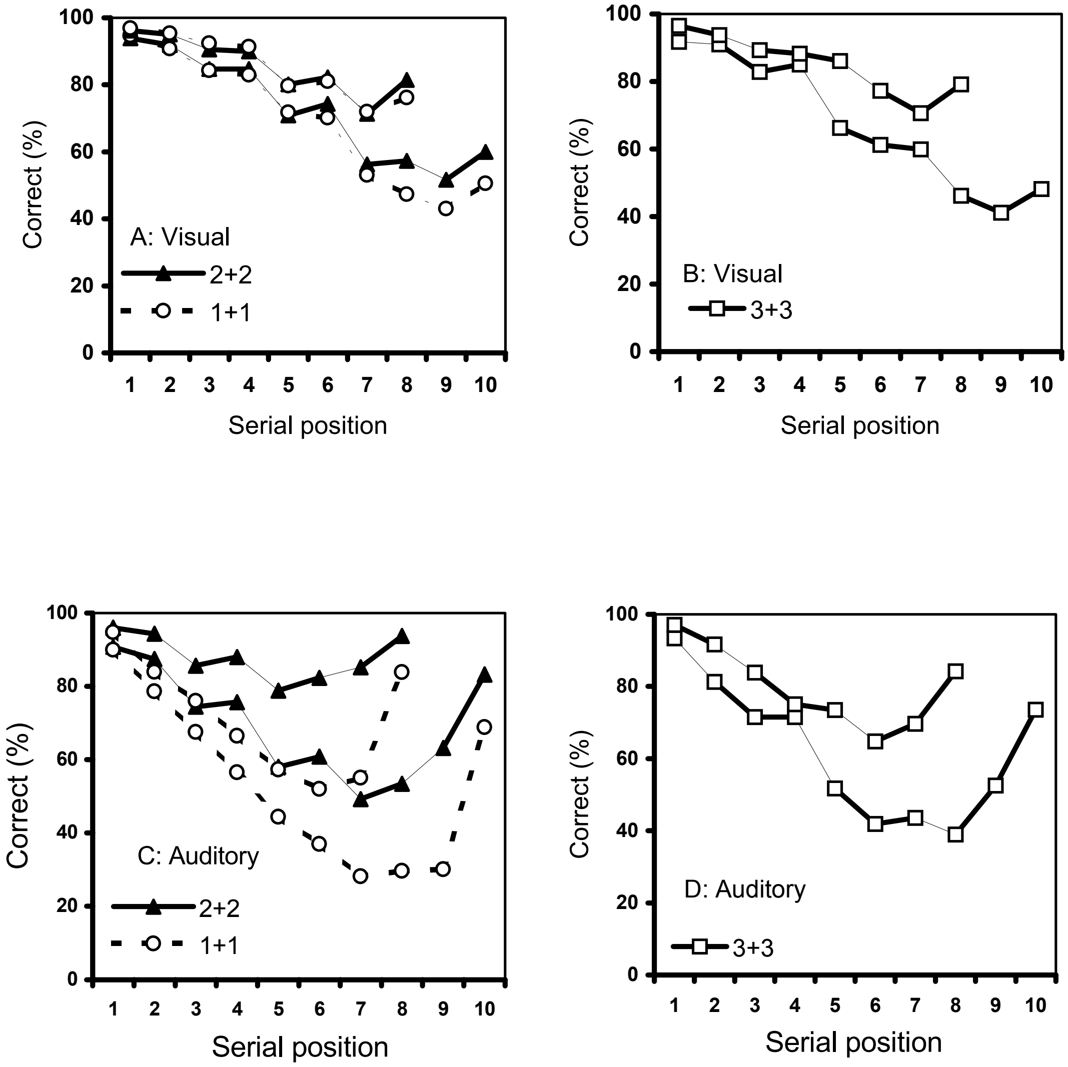

Figure 2. *Percent correctly entered digits as a function of serial position, list length (8- and 10-digit numbers), grouping format and presentation mode (data collapsed over presentation time). Combinations of presentation mode and grouping format are presented in four panels; visual 1+1 and 2+2 (panel A), visual 3+3 (panel B), auditory 1+1 and 2+2 (panel C), and auditory 3+3 (panel D).*

The serial-position curves are shown in *Figure 2*. The longer presentation time improves recall by an average of 7.6 points compared with the shorter presentation time. Presentation time does not interact with presentation mode or with grouping format.

The well-known *modality effect* is clearly seen, displaying only a modest *recency* effect for the visual condition, as compared to the more substantial recency effect seen in the auditory condition. Comparing panels A–B with C–D, however, indicates a second type of ‘modality’ effect, in the form of superior memory performance for the middle digits in the visual mode. This is statistically supported by interactions between presentation mode and digit position for the first six digits in the 8-digit strings, and for the first eight digits in the 10-digit strings.

In the visual mode the serial-position curves for the 1+1 and 2+2 grouping conditions coincide. *Local* serial-position effects, i.e. similar recall scores for individual digits in the pairs but drops in recall scores between digit pairs, are found. The curve for the 3+3 condition follows a somewhat different course for both 8-digit and 10-digit numbers. Regarding the auditory condition, the tendency for grouping-dependent local serial-position effects are clear for the 2+2 presented numbers, while it is just as clear that the non-grouped numbers have not been grouped subjectively, giving a regular fall-off of the curves, instead of a stair-like function.

4. Discussion

Our immediate memory operates within fairly narrow limits of processing capacity, and beyond six digits, performance of even the most mundane domestic application is dependent upon multiple repetitions to get novel number correctly entered. Selecting optimal values for digit presentation, as regards sensory channel, presentation rate or digit grouping, provided only modest improvement of the memory performance.

A significant effect of the presentation mode is found only for the ungrouped numbers (i.e. 1+1). Thus, the visual condition is not inferior to the auditory condition, as found in previous studies using a visual sequential format. The serial position curves revealed a higher recall level in the middle part of the list for the visual simultaneous condition compared to the auditory condition. The two conditions are equivalent but with different advantages and disadvantages.

The absence of a beneficial effect of grouping in the visual condition is somewhat surprising in view of several previous findings (e.g. Magnussen *et al*., 1997), but is possibly due to methodological factors. Magnussen *et al*. (1997), presented the non-grouped numbers without spaces between individual digits, which reduces legibility (perceptual crowding) compared to digit strings presented with spaces between digits as used in the present experiment, allowing subjects to group digits subjectively, as seen here.

Human Factors engineers should be aware of the limitations of immediate memory for multiple-digit numbers presented only once and promote compensatory approaches to alleviate it. Such approaches might include making any structure in the numbers more explicit or to advocate well-designed assistive technologies, e.g. number storage and ‘call me’ buttons on web-sites, as part of a complete solution. This may also include methods for making it easier to write down or temporarily store a number, encouraging people to do so; and to design processes that allow users to compose and then check a number (visually or by hearing) before ‘entering’ it into the system.

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