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Designing a licence plate for memorability

JAN MAARTEN SCHRAAGEN* and KEES VAN DONGEN

TNO Human Factors, P.O. Box 23, 3769 ZG Soesterberg, The Netherlands

Good memorability of licence plates is important in those cases where licence plates are viewed for a brief period of time and the information is essential for police investigations. The purpose of the current study was to design a new Dutch licence plate that could be remembered well. A memory experiment was conducted, in which 16 different character arrangements were presented for both 450 and 550 ms to 48 participants with ages varying between 20 and 57 years. Participants had to rehearse the stimuli for 6 s, after which they had to be written down. Based on literature on short-term memory for serial order, character arrangements differed on three dimensions: 1) number of alternations between letters and digits; 2) letter to digit ratio; and 3) equality of group size. Results showed that number of alternations between characters of different categories affected memory performance the most. Letter to digit ratio and equality of group size affected memory performance to a lesser, but still significant, extent. A significant interaction between the latter two factors indicates that equal groups only lead to fewer memory errors when more than three letters are used. With three or fewer letters, group size is not a significant factor any more. Based on these results, a new licence plate for Dutch vehicles was recommended, which was subsequently adopted.

Keywords: Short-term memory; Applied memory; Memory for licence plates;

1. Introduction

The primary function of licence plates, according to a survey among law enforcement officers and motor vehicle administrators, is to display the information necessary for fast and accurate identification of automobiles (Karmeier *et al*. 1960). In case of hit-and-run accidents or criminals fleeing by vehicle, eyewitness reports form an important part of police investigations. Eyewitnesses may be able to provide information on the licence plate, next to the colour, year and make of the vehicle. The more characters are remembered and reported to the police, the smaller the search space for the police. This puts a premium on the optimal design of licence plates, both in terms of legibility and memorability.

*Corresponding author. Email: schraagen@tm.tno.nl

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This article is not concerned with the issue of legibility, but solely with memorability. The customer, the Centre for Transport Technology and Information in The Netherlands, wanted to know, within the constraints of the current physical layout of Dutch licence plates, what alternative character arrangements would be optimal from a memorability point of view. This question arose from the expectation that the combinatorial possibilities of the current type of licence plates run out in 2004. Therefore, a new arrangement of digits and letters had to be developed, preferably one that would be remembered easily. Character height and width, distance between characters, colour of characters and background, etc. would all remain the same as they are now, and were therefore not subject to human factors research. The total number of characters would also remain as six, due to IT-data structure constraints. However, within these constraints, TNO Human Factors were at liberty to experiment with varying combinations of digits and letters, and with different groupings.

Human factors research on memory for licence plates should take advantage of the large literature on short-term memory for serial order. Based on this literature, the following general principles were formulated for the design of novel licence plates.

1.1. Avoid many alternations between letters and digits

Broadbent and Gregory (1964), Sanders and Schroots (1968a, b) and Hull (1976) all found that as the number of alternations between letters and digits increases, lists are remembered less well. Either straight digit or letter numbering systems can accomplish avoiding alternations. As long as it does not become necessary to use more than six characters, straight numerical systems will be better remembered than straight letter systems (following well-established differences between recall of letters and digits in memory span experiments, e.g. Brener 1940, Crannell and Parrish 1957). However, for practical purposes of obtaining a sufficient number of combinatorial possibilities for licence plates, straight numerical systems will often yield too few combinations to accommodate the foreseen demand for licence plates. In practice, therefore, some combination of letters and digits always needs to be used. Given that constraint, using a predictable grouping of letters and digits may minimize alternations. The number of alternations is defined as the number of changes between characters of different categories (e.g. letters and digits) within spatially separated groups. Hull (1976) found that regular patterns of alternation (e.g. TBD328 or WF93RD) were better remembered than irregular patterns of alternation (e.g. V1TG15 or P3B6DC). Regular patterns have fewer alternations than irregular patterns.

1.2. Use more digits than letters

Both Aldrich (1937) and Karmeier *et al.* (1960) found that with the introduction of more letters, the percentage of memory errors also increased. For instance, Karmeier *et al.* (1960) found that licence plates of the 123 456 type yielded 75% correct reproduction, whereas licence plates of the ABC 123 type yielded only 53% correct reproduction. However, the type AB 1234 did not significantly differ in the percentage correct reproduction from the all-numeric type 123 456 (70 vs. 75%, respectively). And AB 1234 was recalled significantly better than the seven-digit type 1234 567 (70 vs. 28%, respectively; 28% may seem an unusually small number for remembering seven digits. One has to remember, however, that Karmeier *et al.* (1960) used simultaneous visual presentation at 0.5 s rates; typical digit span studies employ auditory presentation with

1.0 s presentation rates). These results suggest that the number of digits should not exceed six, which is not surprising in light of classic findings on average digit span (e.g. Miller 1956). Even more so, the number of characters as a whole should not exceed six, given that memory span for letters is somewhat below digit span. More important, the results suggest that combinations of two letters and four digits are easier to remember than combinations of three letters and three digits. This principle only holds as long as the letters and digits are combined into same-category groups, thus minimizing alternations between letters and digits (see section 1.1 above). Four digits and two letters are less easy to remember than three letters and three digits when the four digits are split into groups of two, yielding the type 12AB34. Hull (1976), for instance, found that the 12AB34 type was less well remembered than the 123ABC type.

However, for practical purposes, two letters may yield too few combinatorial possibilities. Karmeier *et al.* (1960) calculated that two letters and four digits would give up to 6000 000 possibilities. This is true if one can use the entire alphabet of 26 letters. In The Netherlands, however, certain letters are reserved for certain special classes of vehicles (military, royal family, diplomatic corps), vowels are excluded, as well as visually similar letters (Q and O). This leaves 17 letters in total to choose from. The general principle to use more digits than letters, therefore, is at conflict with the desire to have a sufficient number of combinations. For instance, if one wants to be able to use a specific system of numbering for at least 5 years, and each year 1000 000 licence plates are issued, one needs at least 5000 000 combinations. With 17 letters, this can only be achieved with at least three letters and three digits, not with two letters and four digits, even though the latter system is desirable from a human factors point of view.

1.3. Use grouping by spatial separation

Short-term storage of material is usually facilitated when the entire material is sliced up into groups. For digits, chunk sizes of three to four are best (Murdock 1974). A telephone number of seven digits may therefore best be split up into groups of three and four (Severin and Rigby 1963, Klemmer and Stocker 1974). These studies employed experimenter-imposed groupings. Thorpe and Rowland (1965) investigated 'natural' groupings spontaneously employed by their participants in verbally recalling visually presented sequences of digits. For seven-digit sequences and 1 s/digit presentation time, the three to four grouping pattern was most often employed (with the more atypical unlimited time to memorize, the three–three–one grouping pattern was most often used).

For combinations of digits and letters, fewer studies have systematically investigated the effects of grouping. Two issues should be distinguished here. First, as digits and letters constitute different categories, they are grouped naturally as long as they remain together in subcategories. For instance, AB1234 constitutes the most extreme form of grouping; 12AB34 also provides some grouping, but the digits are now split into two subgroups; finally, 1A23B4 provides very little grouping. Framed this way, the issue becomes one of alternations between different categories, and research pertaining to this issue was discussed above. The second issue is grouping by spatial separation. For instance, is the format AB 1234 better remembered than AB1234? Kahneman and Henik (1977) found strong effects of spatial separation on immediate recall. Recall probabilities were similar within each group and varied sharply between spatially separated groups. An even more extreme form of spatial separation would be to place the letters above the digits. Biegel (1938) found better memory after tachistoscopic (0.5 s) presentation of licence plates where the letters were put above the digits, as compared with licence plates where letters and digits were placed on a single line (96 vs. 77%, respectively).

Although it is known that memory performance can be facilitated by spatially separating groups of characters, it is not known whether it matters how groups of characters are spatially separated. Does it, for instance, matter whether characters are arranged in groups of unequal sizes (e.g. ABC-D-EF, A-12-BCD, 12-ABC-3) or whether characters are arranged in groups of equal sizes (e.g. AB-CD-EF, AB-12-CD, ABC-123)?

1.4. *Research question*

In this experiment the effects that the factors 1) alternations, 2) letter to digit ratio and 3) equality of group size have on memory performance were tested and the relative contribution of these factors for memory performance were also tested.

2. Method

2.1. *Participants*

Forty-eight participants (24 males and 24 females) with an age ranging between 20 and 57 years, with an average of 41 years, were randomly selected from a database with a pool of drivers. The average driving experience of this group ranged between 1000 and 60 000 km per year, with an average experience of 17 260 km per year. For participation each participant received a reward of €40.

2.2. *Design*

A $5 \times 3 \times 2$ incomplete factorial design was used to test the effects of alternations, letter:digit ratio and equality of group size on memory performance (see table 1). The factor alternations had five levels ranging from no alternations between letters and digits within the spatially separated groups to four alternations. The factor letter:digit

Table 1. Experimental design

Letter-digit ratio	Equality of group size	Number of alternations				
		0	1	2	3	4
3:3	Yes	ABC-123*	AB-C1–23	AB1–23C	A1-B2-C3*	A1B-2C3
	No	12-ABC-3*	12–3AB-C	A1-BC2–3*	1A-B2C-3	–
4:2	Yes	AB-12-CD* AB-CD-12* 12-AB-CD*	A12-BCD*	A1-BC-3D*	A1B-2CD	A1B-C2D*
	No	A-12-BCD*	1–2A-BCD	A-1B-2CD	A-1B-C2D	–
5:1	Yes	AB-C1-DE	ABC-1DE*	ABC-D1E	–	–
	No	ABC-1-DE*	ABC-D-1E	A1B-C-DE	–	–
6:0	Yes	AB-CD-EF* ABC-DEF*	–	–	–	–
	No	ABC-D-EF*	–	–	–	–

* Character arrangements that were used in the experiment.
– indicates impossible combinations of the factors.
For further details of design, see p. 00.

ratio had four levels ranging from character arrangements with three letters and three digits to character arrangements with six letters and zero digits. The factor equality of group size had two levels, that is, character arrangements either consisted of groups of equal or unequal size. Because the levels of the factors alternations and letter:digit ratio were not completely independent, in that the possible number of alternations was limited when the letter:digit ratio reaches extremes, only the first three levels of the factor letter:digit ratio were used in the analysis. For economic reasons it was not possible to test all variants indicated in table 1; therefore, a full factorial experimental design was not possible.

The mean number of wrongly reported characters has been used as an indication of memory performance and was used as the dependent variable. The number of errors was calculated by comparing participant's responses with the actual presented character arrangements, including the placement of the dashes between the letters and digits. The first two responses to each sequence of ten licence plates were not used in the analysis since subjects had to adjust to the new character arrangement.

In addition to the objective assessment of memorability, a subjective measure was used. After the experiments, participants were asked to indicate which three of the new licence plate designs were most easy to remember and which three licence plate designs were most difficult to remember. Memorability for each licence plate design was determined by subtracting the number of indications for difficult memorability from the number of indications of easy memorability.

2.3. *Stimulus materials*

For each of the 16 types of character arrangements 20 variants were randomly generated for each participant using digits and letters with the exclusion of the letters: A, C, E, I, M, O, Q, U and W (these are not used in current Dutch licence plates). The character arrangements had the form of official Dutch licence plates. The presented licence plates had an onscreen size of 6.0 x 1.3 cm and were perceived from a distance of 85 cm on a computer screen with a size of 33.8 x 27.1 cm. With a horizontal and vertical visual angle of 4.04° x 0.86° in the experimental setting this corresponded to a viewing distance of a real licence plate from a distance of 7.4 m.

2.4. *Procedure*

The participants received written instructions, a demonstration of the task and a training session before the experiment.

Participants were instructed to remember the order of consonants and digits for the licence plates for 6 s, after which the remembered character arrangement had to be written down and subsequently entered into the computer. Participants were able to correct typing errors as they entered the numbers and letters into the computer. The rationale behind this procedure was to reproduce the real-life phenomenon in which witnesses frequently have to engage in some form of verbal rehearsal before they are able to write down or report the licence plate they have seen. Furthermore, by first asking participants to write down the character arrangement, it was hoped to minimize the memory decay that could occur when participants have to search for keys on their keyboard. The participants were instructed to press the 'enter' button when they completed their response to a licence plate for the next presentation. They were told that ten licence plates of a certain type would be presented before a new sequence of ten would start. After the first block of 16 types there was a break of 10 min, after the break the second block started.

After the instructions were read individually, the experimenter demonstrated to the groups of four participants how the task was performed. In the training session participants were given the opportunity to individually familiarize themselves with the memory task. In the training session 20 licence plates of the variants 12–34-AB and AB-12–34 were presented for 550 ms and 450 ms respectively (these types of licence plates were not used in the experiment). After the training the participants had the opportunity to ask questions and it was ensured that all participants were able to perform the task

In two experimental blocks, with stimulus presentation times of 450 and 550 ms, the 16 types of character arrangements were randomly presented to the participants in two series of ten. Pilot studies had indicated that these presentation times yielded a sufficient number of errors. However, individual participants differed in their error rate, depending on the exact presentation time. It was therefore decided to use both presentation times. Each participant participated in both blocks and the order of the blocks was balanced between participants. So as to avoid repetition effects it was ensured that no character occurred in the same serial position as the preceding presentation. The experiment, including training, demonstration and instructions took, in total, 3 h.

3. Results

The results of an ANOVA using a General Linear Motor type III procedure, in which the effect of individual differences was filtered from the error term, pointed out that the effects on memory performance of the number of alternations, the letter:digit ratio, the equality of group size and presentation time were statistically significant (see table 2). Further, a significant interaction between the effect of letter:digit ratio and equality of group size was found. Since interaction effects with presentation time were not statistically significant all further analyses were conducted on the pooled presentation times.

Table 2. ANOVA for the effects of alternations, letter:digit ratio, equality of group size, participant and presentation time†

Source	df	F
Alternations (A)	4	475.15*
Letter-digit ratio (L)	2	104.81*
Group size equality (E)	1	39.85*
Participant (P)	47	94.45*
Presentation time (T)	1	35.94*
A* T	4	2.74
L * T	2	.58
E * T	1	2.50
L * E	2	20.39*
Error	9919	

*Statistical significance at $p < 0.01$.

†Variants with a letter:digit ratio of 6:0 were left out of the ANOVA because for these variants the factors letter:digit ratio and alternations were confounded.

3.1. Effect of alternations

The number of errors in memory performance was higher for character arrangements with more alternations between letters and digits, F (4, 9919) = 475.15, $p < 0.001$. For variants with no alternations between letters and digits within the spatially separated groups, the mean number of errors was 1.14 characters; for variants with one alternation, the mean number of errors increased to 1.43 characters. For variants with two, three or four alternations the mean number of errors increased further to respectively 2.29, 1.96 and 2.44 characters. Unexpectedly, fewer errors were made for character arrangements with three compared to two alternations (M = 1.96 vs. M = 2.29). However, character arrangements with two (for instance, A1-BC2–3) and three alternations (A1-B2-C3) differed in that in the latter a letter in a group is always followed by a number. This replicates Hull's (1976) result that regular patterns of alternation are better remembered than irregular patterns of alternation.

For the variants in which the levels of the factors letter:digit ratio (4:2) and equality of group size (equal) were held constant, the number of errors systematically increased with increasing alternations. For the variants with zero (AB-12-CD), one (A12-BCD), two (A1-BC-3D) and four (A1B-C2D) alternations the mean number of errors increased respectively from 0.92, 1.19, 2.27 to 2.44. Pairwise comparisons showed that all variants differed significantly from each other (Tukey Honestly Significantly Different, $p < 0.05$).

3.2. Effect of letter:digit ratio

The number of errors in memory performance was higher for character arrangements with more letters and correspondingly fewer digits, F (2, 9919) = 104.81, $p < 0.001$. For variants with three or four letters, the mean number of errors was 1.51 and 1.48, respectively. The mean number of errors increased to 1.74 characters for variants with five letters, and 1.87 characters for variants with six letters. Unexpectedly, the number of errors for character arrangements with three letters did not significantly differ from the number of errors for character arrangements with four letters, F (1, 47) < 1. However, when the effect of letter:digit ratio was isolated from the other factors, that is, when the number of alternations (none) and equality of group size (unequal) were held constant, the number of errors systematically increased with an increasing number of letters. For the variants with a letter:digit ratio of 3:3 (12-ABC-3), 4:2 (A-12-BCD), 5:1 (ABC-12-D) and 6:1 (ABC-D-EF) the mean number of errors increased respectively from 0.82, 1.44, 1.80 to 2.20. Pairwise comparisons showed that all variants differed significantly from each other (Tukey HSD, $p < 0.05$).

3.3. Effect of equal group size

The number of errors in memory performance was on average higher for character arrangements with unequal group sizes compared to character arrangements with equal group sizes, F (2, 9919) = 39.53, $p < 0.001$. For variants in which the groups were of equal size, the mean number of errors was 1.50 characters compared to 1.59 characters for arrangements with unequal group sizes. However, the effect of equal group size is not independent of the factor letter:digit ratio as is indicated by the significant letter:digit ratio x equality of group size interaction effect, F (2, 9919) = 20.39, $p < 0.001$.

The difference in the number of errors between character arrangements with equal and unequal group size disappears when the number of letters in character arrangements decreases. When the number of alternations in variants was held constant (no alternations), the results showed that the number of errors for character arrangements with equal and unequal group size significantly differed for variants with a letter:digit ratio of 6:0 and 4:2, respectively F (1,47) = 11.10, $p < 0.01$ and F (1,47) = 15.21, $p < 0.01$. The respective means for variants with a 6:0 ratio were $M = 1.75$ (AB-CD-EF) and $M = 2.20$ (ABC-D-EF); for variants with a 4:2 ratio, the means were $M = 0.92$ (AB-12-CD) and M = 1.44 (A-12-BCD) (see figure 1). For variants with a 3:3 letter:digit ratio, however, the mean number of errors between variants with unequal and equal group sizes did not differ significantly, F (1,47) = 2.51, $p = 0.12$, with $M = 0.94$ (ABC-123) compared to $M = 0.82$ (12-ABC-3).

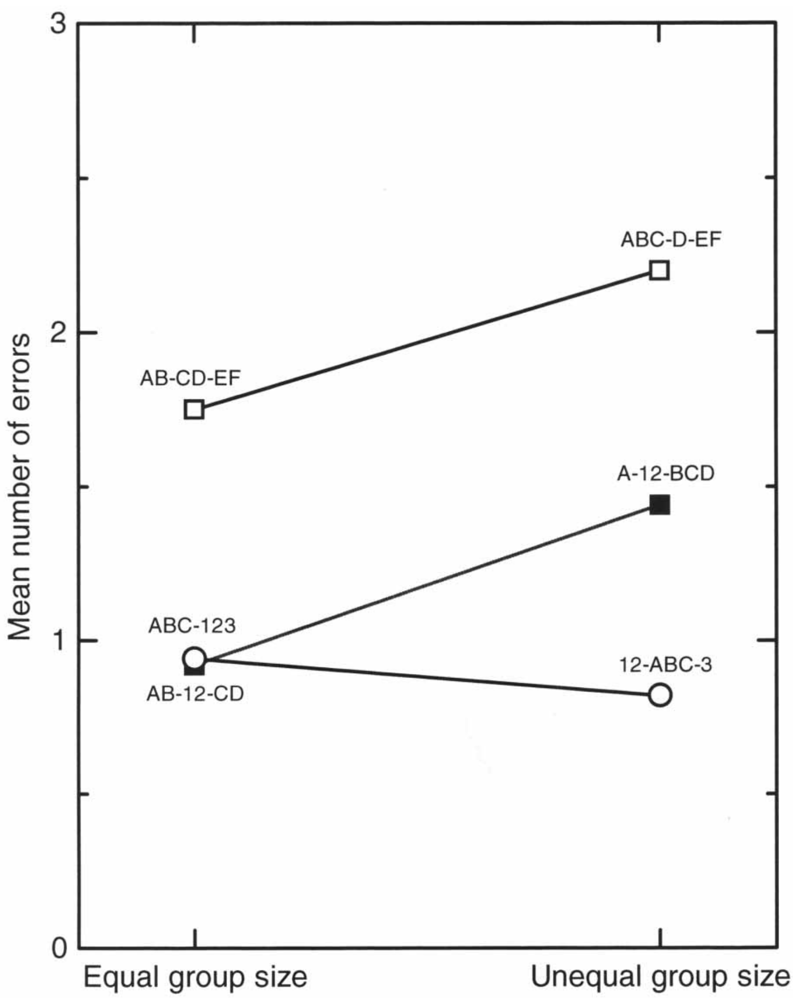

Figure 1. Main and interaction effects of the factors equality of group size and letter-digit ratio on memory performance.

Table 3. Comparison of objective and subjective indications of memorability

Character arrangement	Objective rank*	Subjective rank*	Average number of errors**	Number judgements easy minus difficult**
12-ABC-3	1	2	0.82	18
AB-12-CD	2	–	0.92	–
ABC-123	3	1	0.94	37
AB-CD-12	4	–	1.03	–
12-AB-CD	5	–	1.06	–
A12-BCD	6	6	1.19	4
A-12-BCD	7	4	1.44	7
ABC-DEF	8	5	1.67	6
ABC-1DE	9	8	1.68	−3
AB-CD-EF	10	3	1.75	11
ABC-1-DE	11	7	1.80	−1
A1-B2-C3	12	10	1.96	−9
ABC-D-EF	13	11	2.20	−13
A1-BC-2D	14	9	2.27	−3
A1-BC2-D	15	12	2.31	−24
A1B-C2D	16	13	2.44	−31

Existing designs of type AB-12-CD, AB-CD-12, and 12-AB-CD were not included in the subjective judgements.
*Spearman's *rho*: $r_s = 0.90$, $p < 0.001$.
**Pearson's *rho*: $r_p = 0.95$, $p < 0.001$.

3.4. Correlation objective and subjective measurements

Table 3 lists the character arrangements according to their objective ranking and, in the third column, according to their subjective judgement of memorability. Note that subjective judgements were not asked on existing arrangements, in order to avoid biased judgements due to familiarity with the existing types. The fifth column in table 3 shows the difference between the number of participants who indicated that a particular licence plate was 'easy to remember' and the number of participants who indicated that a particular licence plate was 'difficult to remember.' For instance, with the licence plate arrangement 12-ABC-3, 23 participants indicated they found this 'easy to remember', and five indicated they found this 'difficult to remember.' The difference score of 18 appears in column 5 of table 3.

The correlation between objective (number of errors) and subjective measures (number of judgements easy minus difficult) of memorability was high, $r_p = 0.95$, $p < 0.001$. The rank order correlation, Spearman's *rho*, based on objective and subjective ranking of the same measures, was $r_s = 0.90$, $p < 0.001$.

3.5. Relative importance of factors

The relative importance of the factors alternations, letter:digit ratio and equality of group size was assessed by calculating the standardized coefficients of the regression equation. The weak and non-significant intercorrelations between the factors ($r < 0.28$, $p =$ NS) and low variance inflation factors (< 1.12) indicated that there was no problem with multicollinearity. This suggests that the standardized coefficient for the factors can be reliably interpreted as the degree to which the factors contributed to memory performance. Using a stepwise, forward and backward regression analysis it was found that the factor alternations had the highest standardized coefficient ($\beta_a = 0.34$, $p < 0.001$), followed by the factors equality of group size ($\beta_e = 0.12$, $p < 0.001$) and letter:digit ratio ($\beta_r = 0.11$, $p < 0.001$), which did not differ in the degree to which they contributed to memory performance.

4. Discussion

It has been shown that memory performance is better: 1) when character arrangements have fewer alternations between characters of different categories; 2) when character arrangements have a lower letter:digit ratio, that is, consist of fewer letters and more digits; and 3) when character arrangements consist of groups of equal sizes, except in cases when the letter:digit ratio is low, in which case it does not seem to matter whether groups have equal sizes. It has been shown that objective measures of memorability correlate highly with subjective measures, confirming the validity of the measures. This is not to say that, in the future, researchers can do away with objective measures and use subjective measures instead. In some cases, for instance, with the types AB-CD-EF and A12-BCD, relatively large discrepancies occurred between subjective and objective measures. If the difference among the various alternative character arrangements is small, in terms of mean number of errors, and the ergonomics practitioner needs to be accurate, the best measure is still the objective one.

In comparing the degree to which each factor influences memory performance it can be concluded that the number of alternations between characters of different categories affects memory performance the most. The letter:digit ratio and equality of group size affect memory performance to a lesser degree and do not seem to differ in the degree to which they contribute to memory performance. As has already been stated, the primary function of licence plates is to display the information necessary for fast and accurate identification of automobiles. When designing character arrangements for licence plates for memorability it seems to be most important to avoid alternations between characters from different categories within the spatially separated groups. Given that the set size for the letters for any given position is much larger than for numbers, one might have expected *a priori* the letter:digit ratio to be a more important factor. If this had been the case, then all six-letter combinations would have been the worst to recall. This was clearly not the case, as can be seen in table 3. In fact, the three arrangements that were the most difficult to recall all contained a large number of alternations between letters and digits, with no more than four letters.

The results of the current study may have a wider applicability than licence plates. Postal or zip codes would be one obvious example that comes to mind. Codes with a large number of alternations between letters and digits, such as in the Canadian system (A1B 2C3) or to lesser extent in the British system (AB1 2CD), are less optimal, from a memorability point of view, than the Dutch system (1234 AB) (Ten Hoopen 1978).

Given the findings above, the customer, the Centre for Transport Technology and Information in The Netherlands, has been advised, given the constraints of the current physical layout of Dutch licence plates, that licence plates of the type 12-ABC-3 or 123-ABC would be optimal from a memorability point of view (AB-12-CD and AB-CD-12 also yielded very few errors but had to be excluded as these are the types that are currently in use and need to be replaced). Based on these recommendations, the Centre has selected the type 12-ABC-3 as the future character arrangement for Dutch vehicles.

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