Memory for License Plates

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Abstract

The ability of an eyewitness to recall a briefly-viewed license plate is an under-studied issue with great practical significance. Using large samples of adult participants (total \( N = 1859 \)), we assessed the memory implications of a current proposal (EZ-ID, n.d.) to include a nameable symbol, such as a triangle or heart, on standard-issue license plates. In two experiments, no overall memory benefit was observed for license plates with symbols compared to standard designs. Although symbols conveyed no memory advantage, we show that, under certain conditions, including symbols can reduce the number of matching plates when a plate is partially remembered, enhancing the ability of investigators to identify the specific vehicle involved in a crime. We also assessed recall performance for license plates viewed under a range of conditions. Exposure time and the time delay to report have both real-world relevance and clearly predicted effects grounded in the basic memory literature. Memory increased with exposure time, but there was no effect of study-test delay. We also manipulated viewing orientation, to allow comparison of memory given a standard view with the mirror-reversed view that a witness might experience while driving. Memory was significantly worse for mirror-reversed plates.
United States Commonwealth of Massachusetts Senate Bill 2387 (Bill S.2387, 2012) is a call to redesign motor vehicle license plates. In Massachusetts, standard issue license plate numbers currently consist solely of 6 characters (i.e., digits and letters). The bill includes the proposal that general issue license plates could include a “commonly recognizable symbol”, such as a triangle or circle\(^1\). As will be discussed below, including symbols can reduce the number of matching plates when a plate is partially remembered, enhancing the ability of investigators to identify the specific vehicle involved in a crime. Symbols may also be remembered differently than other characters. As described by the organization sponsoring the bill, a large part of the motivation behind including symbols is that “random numbers and letters on license plates are too difficult to remember in a time of crisis” (EZ-ID, n.d.). The assumption is that the inclusion of symbols would aid in license plate recognition and recall. Although the intuition behind this premise is reasonable, we could find no published studies that test this assumption. The main goal of this paper is to test the idea that the addition of a symbol would improve memory for license plates.

The vast eyewitness memory literature includes hundreds of studies on witnesses' ability to describe or recognize the perpetrator of a crime (a PsychLit search with "eyewitness identification" revealed 428 peer-reviewed journal articles; 122 were returned for "eyewitness AND description"). In contrast, we found only five studies on memory for another forensically-relevant detail of a crime, namely license plate numbers, in the psychological literature. Given that a partially remembered plate is much more likely to be useful than an impoverished description of a suspect, surprisingly little research has been published in the psychological literature on the memorability of license plates. The

\(^1\) To our knowledge, no U.S. state currently includes a symbol in standard issue license plates. Vanity plates in some states do allow limited use of some symbols (Knuth, 2011).
studies that have been done, while valuable, are of limited scope. Two studies presented subjects with a series of slides depicting an actor who appeared to load stolen goods into a car and then drive away (Mende, MacKinnon, & Geiselman, 1987; MacKinnon, O'Reilly, & Geiselman, 1990). These studies (see also Emmett, Clifford, Young, Kandova, & Potton, 2006) primarily focused on interview techniques that might enhance recall. Consequently, they did not manipulate many encoding factors. Mende et al. did vary the presentation rate for the slides, finding that longer exposure time (5 sec/slide) yielded higher recall than shorter exposures (2 sec/slide; Mende et al., 1987), and about 3-3.5 characters were typically reported correctly (MacKinnon et al., 1990). A single license plate was used in each of these experiments (either 640VYE or 1MJT407), leaving open the possibility that memory could be better or worse for other plates. Indeed, Baerwald, Karmeier, and Herrington (1960) reported that recall exceeded 4 characters for plates comprised only of digits, and was typically about 3 characters for plates with mixed letters and digits like 640VYE. One reason for recall differences across plates appears to be that grouping letters and numbers (as in 640VYE, but not 6V4Y0E) allows the information to be more easily chunked; fewer alternations between letters and numbers yields enhanced recall (Schraagen & van Dongen, 2005). Although Al-Haboubi (1999) also manipulated study time, that study, like Schraagen and van Dongen's (2005), focused on the design of the license number. These studies both asked which particular grouping of letters and numbers yield better recall, finding that fewer alternations between letters and numbers was ideal.

Previous memory research suggests that adding a symbol to license plates might help memory, if we assume that symbols are encoded and represented differently than characters (Paivio, 1963). This differential representation could result in the cognitive compartmentalization of symbols and characters resulting in either less cross-class interference or improved encoding strategies (e.g., "chunking").

Item pairs from different stimulus classes did not interfere with one another in an associative recognition task (Criss & Shiffrin, 2004). Participants were shown a series of item pairs. Each pair
consisted either of two words (WW), two faces (FF), or one word and one face (WF). During study, the participants were asked to judge the degree of association between items in each pair. Immediately following study, participants were given a surprise memory test. The test pairs consisted of intact (i.e., identical to a study pair) or rearranged (i.e., items from two different study pairs) pairs, and participants were asked to determine if each of the test pairs was seen during study. The number of study pairs was kept constant across participants, but the proportion of pairs of each class varied. For example, in one condition, there were 40 WF, 40 WW, and 40 FF study pairs, whereas another condition had 80 WF, 20 WW, and 20 FF study pairs. The key result was that, as the proportion of a particular pair class decreased, performance for that class improved. For example, even though the total number of pairs was kept constant, associative recognition for WF pairs was better when there were 40 WF pairs than when there were 80 WF pairs. Criss and Shiffrin (2004) concluded that different classes of pairs do not interfere with each other during retrieval.

Gillund and Shiffrin (1981) performed a similar study using a free recall task for single items. Participants were presented with study lists consisting of a series of individual words and pictures. The absolute and relative number of each item class on the study list was manipulated. For example, a base study list consisted of 10 words or 10 pictures. A longer study list could then be created by adding 10 words or 10 pictures to the base list, creating lists with 20 words, 20 pictures, or 10 pictures and 10 words. Note that, for the longer lists, list length is constant, but the proportion of words and pictures varies. Consistent with research on the list-length effect (e.g., Shiffrin, 1973), recall decreased as list length increased. Furthermore, performance also decreased whether items of the same class or items of the other class was added to the base list. It is important to note, however, that in the majority of conditions, adding items of a different class decreased performance less than adding items of the same class. For example, memory for pictures was better in the 10-picture, 10-word condition than in the

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2 The authors did not perform statistical tests to assess this claim, which is based on the results in Figure 3 of Gillund & Shiffrin (1981).
20-picture, 0-word condition, again suggesting that mixing classes of items may improve performance.

There are two intuitive information categories on current license plates: letters and digits. Recall that, as the proportion of a class decreased, performance for that class improved. Because a symbol would take the place of a letter or digit, reducing the number of elements of that class, the addition of symbols could improve memory. For example, consider the plate M6C83, which has 3 digits and 2 letters. Replacing the 6 with a symbol, e.g., ★, produces the plate M★C83. The number of digits has been reduced, potentially increasing memory for the digits in the plate.

*Chunking*, or the grouping of items into meaningful units, is a well known way to improve memory (e.g., Bower & Springston, 1970). Like the faces, pictures, and words used in Shiffrin's studies (Gillund & Shiffrin, 1981; Criss & Shiffrin, 2004), digits and letters form natural classes of information. Schraagen and van Dongen (2005) demonstrated that grouping those item classes together can benefit memory for license plates. Following previous research (e.g., Broadbent & Gregory, 1964; Sanders & Schroots, 1968; Hull, 1976), they hypothesized that memory for a license plate would decrease as the number of alternations between letters and digits in a chunk increased. They presented participants with license plates with 0 (e.g., ABC-123), 1 (e.g., A12-BCD), 2 (e.g., A1-BC2-3), 3 (e.g., A1-B2-C3), and 4 (e.g., A1B-2C3) alternations between letters and digits within the chunks, defined by the spatially separated groups. The idea is that the spatial separation creates groups of items and that these groups would be more meaningful, and therefore easier to remember, if the items within a group were all of the same class (i.e., all letters or all numbers). Participants studied each plate for approximately 500ms and then recalled the plate after a 6 second delay. The central result was that memory performance was higher for license plates with fewer alternations, suggesting that grouping items of the same class aids memory. Note that the alternations are defined within the spaced character groups, e.g., A12 and BCD in A12-BCD.

Symbols may form an efficient way to group license plate characters, akin to a space, but
containing meaningful, identifying information. For example, the triangle, ▲, in the plate AB▲123 may create a natural grouping, e.g., AB-▲-123. Thus, the inclusion of a symbol could help observers chunk the plate characters while at the same time serving as one of the to-be-remembered items. Our primary goal is to assess whether the inclusion of a nameable symbol enhances memory for a license plate.

The second goal of this research is to explore the effect of three "real world" factors that may influence how well a license plate is remembered outside the lab: exposure time, test delay, and viewing orientation. Almost nothing is known about how these factors influence memory for license plates, although we can make some basic predictions based on the memory literature. Consider a witness to a hit-and-run incident. During the event, the witness may get anywhere from a glimpse of the plate to many seconds of viewing time. This exposure time seems likely to influence how well a plate is remembered. As in standard memory experiments that manipulate stimulus duration (e.g., Hintzman, 1970), longer viewing time provides the participant with more time to encode the license plate, which yields better recall (Mende et al., 1987; Al-Haboubi, 1999). The relative discriminability and identifiability of symbols and characters has not been explored, so it is unclear whether symbols can be encoded more quickly than characters. If they are encoded relatively quickly, then higher recall accuracy for symbols rather than characters should occur at shorter viewing times. The second factor is the recall delay, i.e., the length of time between when the plate was viewed and the participant is asked to recall the plate. Short-term memory typically declines quickly (e.g., Brown, 1958), so we expect that a longer delay will result in poorer recall. Again, it is unknown how the recall of symbols will fare relative to characters as the delay is increased. To enhance realism in our experiments, the recall delay period will be filled with a video that simulates driving down a road with the radio playing. The third factor we considered is viewing orientation, i.e., whether the plate is viewed normally or reversed as if seen in a car's rear-view mirror. Most license plates are almost surely viewed normally, but it is
possible, particularly for cars behind a driving witness, to be viewed in a mirror. Because the recognition of many non-character symbols has the advantage of being less affected by variation in orientation, the recall of symbols may be better preserved when viewed as in a mirror.

Experiment 1

The main goal of Experiment 1 is to determine whether a symbol would improve memory for a license plate (either for the symbol itself or for the plate in general). Participants viewed a license plate situated on the back of a car and then, after a short delay, were asked to recall as much of the plate as possible. Because knowledge of car color, in addition to partial plate recall, can greatly reduce the number of matching cars that would need to be investigated, participants were also asked to recall the car color. To achieve an upper-bound on memory performance, participants were explicitly instructed to attend to the license plate and car color.

Because the inclusion of a symbol increases the number of total possible plate combinations, in principle, license plates that include a symbol can be shorter than those that do not.³ For example, the current standard-issue, Massachusetts license plate has 6 characters, theoretically yielding more than 2.2 billion different possible plates (36⁶, 36 characters in 6 positions).⁴ If only 5 characters are used, the number of possible plates is drastically reduced to 60.5 million (36⁵). With the addition of one symbol from a set of 20, however, a 5 position plate (i.e., 4 characters + 1 symbol) yields 168.0 million different plates (36⁴×20×5, 36 characters in 4 positions and 1 of 20 symbols in 1 of 5 positions).

The inclusion of a symbol makes a 5-position plate feasible, so our experiments compare memory for license plates with 6 characters (as are currently in use) and with 4 characters and 1 symbol

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³ Whether the plate length can be reduced in practice would depend on the number of available symbols and the desirability of completely randomly-ordered digits and letters, among other considerations.

⁴ This value is an upper bound, as it ignores certain aspects of license plate design. For example, in MA the final digit is not randomly-chosen: it indicates the month of vehicle registration. Furthermore, not all letters and digits are used. In addition, not all random sequences of letters and numbers are used.
(a proposed design). Any observed benefit for the plates with symbols could be due to having fewer
details to remember, however. For this reason, we also include a length-matched control: 5-character
license plates that do not include a symbol. We also manipulated exposure time, study-test delay, and
viewing orientation to assess their affects on recall performance. To prevent interference from repeated
study of multiple license plates, each subject was presented and tested on exactly one plate.

Method

Participants. The 619 participants (371 male, 233 female, remainder unreported) were
recruited from Amazon Mechanical Turk (https://www.mturk.com/mturk/) and were required to be
fluent English speakers between the ages of 18 and 74 currently in the United States. A number of
studies suggest that, given proper experimental design, data collected using Mechanical Turk is
comparable to traditional collection techniques (e.g., Mason & Suri, 2012). Payment was $0.30.

Stimuli. Each stimulus was a short video comprised of three main sections: a 3-second 'Get
Ready' prompt, the critical view of the license plate, and a filler segment.

The license plate display segment was a static image of the rear of a sedan that was displayed
for 1, 2, or 3 seconds with the license plate clearly visible. See Figure 1 for an example. The color of
the car was randomly chosen from 4 possibilities: white, black, red, or blue. The plate was modeled on
the current, standard-issue Massachusetts license plate with the state name replaced by “America” and
the state motto replaced by “A State in America”. This image was presented either with a normal view,
as in Figure 1, or with the entire image left-right mirror reversed. The plate consisted either of 6
characters (letters or digits; 6 char), 5 characters (5 char), or 4 characters plus one symbol (4 char +
sym). The symbols were sampled from this set: ★ (star), ⬤ (circle), ♦ (heart), ■ (square), or
△ (triangle). Because the Massachusetts bill does not identify any specific symbols, these experiments used very simple symbols that should be both easily recognized and consistently named by most people. Twenty plates were randomly generated for each of the 6 char, 5 char, and 4 char + sym conditions. The characters were sampled randomly from the letters A-Z, exclusive of I, O, and Q, and the digits 2-9 (i.e., not 0 or 1). The excluded characters were removed to reduce reporting confusion, e.g., mistaking the letter I for a number 1. To roughly equalize the probability of sampling a letter and digit, the digits were oversampled by a factor of two. In the 4 char + sym condition, each symbol occupied 4 different license plate positions and there were 4 plates each with a symbol in positions 1-5. By inspection, any plates with recognizable patterns (e.g., words, repeated characters) were removed and replaced with a new, random plate. The full set of license plates is provided in the Appendix. Font size was held constant across all conditions.

The filler segment of the video was filmed from the inside of a moving car driving down a country road, looking through the front window (UMass Arbella Insurance Human Performance Laboratory, n.d.). No license plate was visible during this part of the video. An original blues song was played in the background (Starns, 2011, track 1). The filler segment lasted either 15 or 30 seconds.

**Design.** All factors were manipulated between subjects. The full design was 3 (license condition: 6 char, 5 char, or 4 char + sym) x 3 (exposure duration: 1, 2, or 3s) x 2 (orientation: normal or mirror) x 2 (study-test delay: 15 or 30s) x 4 (car color: white, black, red, or blue) x 20 (license number). Participants were randomly assigned to conditions.

**Procedure.** First, the participant was informed of the entire procedure. In particular, the participant was told to expect a short video, and was asked to remember the color of the car and the

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5 Given that a large number of participants were tested and that a video had to be created for each plate in each condition, it was infeasible to create a random plate for each subject.
license plate number shown at the start of the video. The participant was told that the plate might be 
viewed normally or reversed, as in a mirror, but that, if the plate is reversed, it should be recalled as if 
the plate were not in a mirror. The participant was informed that the plate might consist of letters, 
numbers, and/or symbols. Finally, the participant was told that the plate might only be visible for a 
very short period of time. The full set of instructions is provided in the Appendix.

Second, one complete video was shown (including plate display and filler interval), as 
described in the Stimuli section.

Third, to simulate dialing '911' to report a crime, the participant was asked to type '822' into a 
text box after the end of the video.

Fourth, the participant was asked to recall the car color and plate number by selecting radio 
buttons positioned next to response options. There was one set of response options for each license 
plate position and another for the car color; these options were displayed vertically on the screen. Each 
license plate position included response options for the letters A-Z, the digits 0-9, and, if the plate 
contained a symbol, the symbols ★, ●, ▼, □, or ▲. Five possible car colors (i.e., white, black, red, 
blue, and green), were displayed in a single column. For all responses, the participant could also select 
“Don't Know”. To ensure that the results are not contingent on the response methodology, in the 
Discussion we present a follow-up experiment that used a different ("fill in the blank") response 
method.

Finally, the participant was asked their age range (e.g., 18-24, 25-34, ..., 65-74) and gender.

The entire procedure (including reading and signing the consent form) took, on average, 
approximately 2 minutes and 15 seconds.

Results
The data from all participants were used. All data were collapsed across the 20 different license plates in each condition, yielding a mean of 17.19 (SD = 4.14) participants in each combination of license condition, orientation, exposure duration, and filler delay condition. All analyses were performed in R (R Core Team, 2013).

**Overall number correct.** We report the maximum number of license plate positions recalled correctly in position. There are many ways that a response could be considered correct, so we used several strategies to compute number correct and selected the maximum correct for each participant.

To describe our different estimates of recall accuracy, we will assume that the displayed license plate was ▲-A-B-1-2 and that the response was ▲-A-A-2-DON'T KNOW. In this case, positions 1 and 2 are recalled correctly, for a total of 2 correct responses. For the mirror orientation condition, we were concerned that some participants might have misunderstood the instructions. That is, they may have had perfect memory for the plate, but reported the characters in mirror order, not reading order. To check for this type of reporting error, we also computed the number correct based on the responses given in the opposite order. In our example, the plate is compared to DON'T KNOW-2-A-A-▲. No positions match, so there are 0 correct responses. To avoid artificially biasing performance in the mirror condition compared to the normal condition, this approach was adopted for both orientation conditions. Our third strategy assumed that participants may have disregarded symbols in the first position, as will be discussed later. Such a participant, with otherwise perfect recall, would respond A-B-1-2. To avoid penalizing the symbol condition for this type of error, all responses were also compared to the plate with the first position removed. In this example, the response, ▲-A-A-2-DON'T KNOW, was compared to A-B-1-2. Only position 4 matches, for a total of 1 correct response. Again, this comparison was applied to all conditions. The maximum number correct from these different comparisons was used. In this example, the maximum was the straightforward match between the plate
and the response, or 2 correct responses. Whether or not a single character was reported correctly was also determined from this maximum comparison.

Across all conditions, the mean number of correct responses was 3.20 ($sd = 1.82$); this recall level closely replicates previous results (Karmeier et al., 1960; Mende et al., 1987). Given that testing was done under ideal conditions, it is somewhat surprising that memory was relatively low. The mean number of correct responses for each license plate condition is shown in Figure 2 (error bars represent the between-subjects SEM throughout). To test the effect of license condition, orientation, exposure duration, study-test delay, age, and gender on the number of correct responses, we performed an ANOVA with these six variables as factors. Due to the large number of comparisons and tests, unless otherwise noted, all analyses assumed an $\alpha$ of .01.

Critically, the number of correct responses did not differ across license conditions, $F(2, 384) = 1.23, p = .29, MSE = 2.83, \eta^2_p = 0.01$: Performance in the symbol and non-symbol license conditions was essentially identical. Predictably, performance in the mirror condition was significantly worse than in the normal viewing condition, $F(1, 384) = 47.69, p < .001, MSE = 2.83, \eta^2_p = 0.11$, and exposure duration influenced performance, $F(2, 384) = 26.00, p < .001, MSE = 2.83, \eta^2_p = 0.12$. Replicating previous studies, longer exposure led to better recall (Mende et al., 1987; Al-Haboubi, 1999), although there was only a very small difference between exposure times of 2 and 3 seconds. Surprisingly, there was no significant effect of study-test delay on performance, $F(1, 384) = 0.16, p = .69, MSE = 2.83, \eta^2_p = 0.00$. Increasing the delay from 15s to 30s did not reduce performance to a noticeable degree. There was no effect of the subjects' age category, $F(5, 384) = 1.35, p = .24, MSE = 2.83, \eta^2_p = 0.02$, or gender, $F(1, 384) = 0.10, p = .75, MSE = 2.83, \eta^2_p = 0.00$, on the number of correct responses. No interactions were significant.
Model for Position, Symbols, and Symmetry. To determine the effect of character position, symbols vs. characters, and character symmetry on the probability of recall, we ran a logistic linear mixed-effects model (Bates, Maechler, Bolker, & Walker, 2013) on recall of each character (incorrect=0, correct=1) with the following fixed effects: main effects of license condition, orientation, exposure duration, study-test delay, position, symbol (i.e., whether the character was a symbol or not), and symmetry (i.e., whether the character was symmetric); all two-way interactions of license condition with orientation, exposure duration, study-test delay, and position; all two-way interactions of position with orientation, exposure duration, study-test delay, and symbol; all two-way interactions of symbol with orientation, exposure duration, and study-test delay; and the two-way interaction of symmetry and orientation. Subjects were included as a random-effect factor with random intercepts.

License condition was coded as a set of two contrasts. The first contrast (license condition-5v6) compares the 5-position (5 char and 4 char + sym) and 6-position (6 char) plates. The second contrast (license condition-5v4) compares the 5 char and 4 char + sym conditions. Symbol (coded as -0.5, 0.5), symmetry (-0.5, 0.5), orientation (-0.5, 0.5), exposure duration (-0.5, 0.0, 0.5), and study-test delay (-0.5, 0.5) were coded as centered variables. Position (-2, -1, 0, 1, 2, 3) was centered on Position 3 (for the 5-position plates).

The complete results for the fixed effect variables are provided in Table 1. This analysis supports the major results from the previous ANOVA. Performance is better for license plates viewed in a normal orientation and for longer exposure durations. Although the ANOVA showed no difference across license conditions, this analysis shows that recall is better for the shorter (5-character) plates. The reason for this difference is that, whereas the ANOVA looked at total number correct, this analysis considers performance in each position separately. That is, although performance in each position of the 6 char condition is lower than in the 5-position plates (see Figure 3), there is an additional chance for recall in the 6 char condition (i.e., the 6th position), which increases the total number of recalled
characters. The effects of position, symbols, and symmetry will be discussed separately.

Effect of Position. Figure 3 shows the probability of recall as a function of condition and position within the plate (i.e., 1st, 2nd, etc). Earlier positions are clearly recalled better than later positions. This observation is supported by a significant main effect of position in the linear mixed-effects model. Position also interacts with license condition and exposure duration. In particular, as position increases (i.e., toward the right-hand end of the plate number), performance decreases faster for the shorter exposure durations and for the 6-position plates compared to the 5-position plates. That is, decreasing exposure time or increasing the number of characters to remember reduces the chance to encode and/or recall all of the license plate details. Because we read from left-to-right, recall of the rightward positions suffers the most.

Effect of Symbols vs. Characters. The relationship between recall of symbols and recall of characters across different license positions is shown in Figure 4 as a function of license condition and viewing orientation. For ease of comparison, the data in the figure are restricted to the license plates with 5 elements (i.e., the 5 char and 4 char + sym conditions). In the figure, the data are divided into three groups: the probability of recalling the characters in the 5 char condition (solid lines) or in the 4 char + sym condition (open circles, dashed lines), and the probability of recalling the symbols in the 4 char + sym condition (filled circles, dashed lines). In the analysis, all license conditions were included.

The key result is a non-significant main effect of symbol. That is, recall performance was neither harmed nor improved by including symbols on the license plates. Although there was no symbol-by-position interaction, the performance differences across positions in Figure 4 are highly

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6 Including the three-way interaction of license condition, exposure duration, and position in the model did not change the results and the interaction was not significant.

7 Recall that position was centered on the third character, where there is little change in performance.
suggestive. We ran two post-hoc tests comparing the recall of symbols and characters at the first and second position within the 4 char + sym license plates (using a Bonferroni adjusted significance level of .005). In the first position, symbols were recalled significantly worse than characters, $t(37) = 3.00, p = .005, d = -0.67$. In the second position, symbols were (marginally) recalled better than characters, $t(77) = 2.81, p = .006, d = 0.41$. For completeness, none of the other positions showed a difference ($p > .1$).

Effect of Symmetry. Because they are invariant to changes in orientation, symmetric characters (e.g., A) may be better recognized than asymmetric characters (e.g., B) in the mirror condition. However, there was no overall difference in the probability of correctly responding to a symmetric character or symbol (0.61) or an asymmetric character (0.61). There was also no interaction of symmetry and viewing orientation. Symmetric characters were not recalled better than asymmetric characters in the mirror condition.

Effect of Chunking. Recall that previous research (e.g., Schraagen and van Dongen, 2005) found that the number of letter-digit alternations within a pre-defined chunk decreased memory. Although the current experiment did not expressly manipulate chunks or alternations, it is nonetheless informative to look at the effect of alternations on recall. First, the number of alternations was determined for each plate. An alternation was defined as a switch from a letter, digit, or symbol to a member of a different class. For example, the plate E98■2 has 3 switches (E9, 8■, and ■2). Second, the number of correct responses was regressed on the number of switches, license condition, orientation, exposure duration, study-test delay, and all interactions. License condition, orientation, exposure duration, and study-test delay were centered as described previously. Because there were between 0 and 4 switches in the
plates, the number of switches was centered on 2 switches (-2, -1, 0, 1, 2).

There were significant main effects of orientation (est. = -0.70, S.E. = 0.19, \( t \)-value = 3.71, \( Pr(>|t|) < .001 \)) and exposure duration (est. = 1.21, S.E. = 0.23, \( t \)-value = 5.18, \( Pr(>|t|) < .001 \)), consistent with the analyses reported previously. The main effect of number of switches was only marginally significant (est. = 0.23, S.E. = 0.11, \( t \)-value = 2.15, \( Pr(>|t|) = .032 \)), but number of switches interacted with viewing orientation and exposure duration (est. = 1.33, S.E. = 0.51, \( t \)-value = 2.59, \( Pr(>|t|) = .01 \)). Finally, there was an interaction of orientation, exposure duration, filler condition, and number of switches (est. = -3.30 S.E. = 1.02, \( t \)-value = 3.22, \( Pr(>|t|) = .001 \)) which we do not interpret. No other effects were significant (\( p > .01 \)).

To further explore the interaction of orientation, exposure duration, and number of switches, we performed a post-hoc regression analyses of number correct on the number of switches for each combination of orientation and exposure duration. There are 6 such tests (using a Bonferroni correction, \( \alpha = .0017 \)). The only significant effect of number of switches was for plates in the normal orientation with a 1 second exposure (est. = 0.74, S.E. = 0.21, \( t \)-value = 3.53, \( Pr(>|t|) < .001 \)). Note that this condition best matches the conditions in the Schraagen and van Dongen (2005) study, which involved normally oriented plates shown for approximately 500ms.

**Color.** The car color was reported correctly on 53% of the trials. Some of the colors were relatively dark and may have been poorly represented on participants' monitors, so we looked at how often each color was confused with each other color. By far, the largest confusion was responding "black" to a blue car, i.e., \( P(\text{Black} | \text{Blue}) = 0.54 \). The next highest was confusing black for red, i.e., \( P(\text{Red} | \text{Black}) = 0.13 \). When blue and black cars and responses are collapsed, the mean percent correct is 68%. Given the high confusion rate, all subsequent color analyses collapse over the blue and
black categories. An ANOVA was run with license condition, orientation, exposure duration, study-test delay, age, and gender as factors.

Car color was reported more accurately in the normal viewing condition (75%) than in the mirror condition (61%), $F(1, 384) = 15.49, p < .001, MSE = 0.21, \eta_p^2 = 0.04$. There was no effect of license condition, $F(2, 384) = 3.08, p = .05, MSE = 0.21, \eta_p^2 = 0.02$, exposure time, $F(2, 384) = 1.806, p = .17, MSE = 0.21, \eta_p^2 = 0.01$, or study-test delay, $F(1, 384) = 0.28, p = .59, MSE = 0.21, \eta_p^2 = 0.00$, on the recall of car color. There was a significant interaction of orientation and age, $F(5, 384) = 3.69, p = .003, MSE = 0.21, \eta_p^2 = 0.05$. Performance for older participants was lower in the mirror condition, suggesting that older participants may have had more trouble attending to both the plate and car color when the plate was in the more difficult mirror orientation. No other interactions were significant.

**Reporting Errors.** Witnesses reporting a license plate can make two types of errors. An error of omission is a simple failure to report, or a "don't know" response about a particular position within the plate (46% of the errors in the current experiment). An error of commission is a mis-recalled character or symbol. We considered these errors separately.

A logistic linear mixed-effects model was run to test for the effect of condition on omission errors. The model was the same as the previous linear mixed-effects model except for the following differences. The dependent measure was whether a response was “don't know” (1) or not (0). The previously non-significant interactions of license condition with orientation, exposure duration, and study-test delay were removed. The complete results are given in Table 2.

More "don't know" responses were given in the mirror orientation (1.35) than in the normal viewing orientation (0.67). Longer exposure time decreased the number of "don't know" responses.

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8 The model did not converge with these interactions included. Numerous model variations were tried, all with nearly identical results.
from 1.57 in the 1s exposure condition to 0.75 and 0.72 in the 2 and 3s exposure conditions, respectively. The number of “don't know” responses increased with position. The only other significant result was an interaction of exposure duration and position. The increase in omission errors with position was greater for the 1s exposure duration (the slope from simple linear regression of error on position is 0.12) than the 2s (slope = 0.06) or 3s (slope = 0.05) exposures. This pattern of results is completely consistent with our analysis of accurate responses by position.

The same model was run with error of commission as the dependent variable (0=no error, 1=error of commission). The intercept was the only significant factor.

Discussion

Our key finding is that the inclusion of a symbol did not result in a significant change in the number of correctly recalled elements of the license plate: the same amount of information was reported from each of the plate conditions. Furthermore, there was no overall memory advantage for symbols relative to other characters. Given the large number of participants in this study, the results strongly suggest that any recall difference between symbols and characters is likely to be very small. Indeed, the effect size for the overall effect of license plate condition was only 0.01 in this experiment.

Memory for symbols did interact with position: recall of symbols in the first position was significantly worse than recall of characters in the first position. We suspect that our participants may not have viewed a symbol in the first position as part of the license plate, for two main reasons. First, symbols are a novelty in license plates and thus unfamiliar to our participants. It would be more difficult to ignore symbols embedded within other characters. Perhaps equally importantly, specialty plates (e.g., "Invest in Children", "New England Patriots") are common in the United States, and those
plates tend to have small logos that are positioned to the left of the plate number. The first-position symbols may also have been confused with such logos. Experience with license plates with symbols may alleviate this issue. Memory for symbols in the second position, however, was somewhat higher than for characters in the second position. We have no explanation for this modest benefit. Neither of these effects of symbol position was anticipated, so we will assess their replicability with planned comparisons in Experiment 2.

Other factors also affected plate recall. Longer exposure time improved memory, consistent with many studies in the basic memory literature as well as two studies of memory for license plates (Mende et al., 1987; Al-Haboubi, 1999). The improvement was most pronounced between 1 and 2 seconds. There was no significant decrease in memory as a function of study-test delay, even though the interval was filled. It appears that, once the plate characters were encoded, rehearsing them for 30s was no more difficult than rehearsing for 15s. The use of a more active filler task that prohibits rehearsal would be more likely to cause decreased recall with increased delay, and might be more representative of some eyewitness situations. Because it takes more effort to identify and encode mirror-reversed characters, memory for mirror-reversed plates was relatively low.

Performance increased with the number of alternations between characters, digits, and symbols, but only for normally-oriented, briefly-presented stimuli. In Schraagen and van Dongen (2005), performance decreased with the number of alternations within a chunk. It is important to note that, unlike the prior research, there were no pre-defined chunks in the current study. Without a clearly defined chunk, the alternations themselves may have aided in the creation of chunks, improving memory performance. For example, the plate E98■2 could be chunked as E98, ■2. It is possible that additional alternations increase the possible ways a plate can be chunked, which, in turn, improves recall. Given the absence of an effect of number of alternations at longer exposures and for mirror-reversed plates, the conditions under which this mechanism applies may be restricted; the issue
deserves additional empirical study.

To ensure that the main results were not due to the response method, a follow-up experiment, Experiment 1b, was run in which participants typed their position-by-position responses rather than selecting them from a list of options. For plates that included symbols, they were asked to type the name (i.e., "circle") in the appropriate position. In particular, 192 additional Mechanical Turk participants (54 in 6 char, 78 in 5 char, and 60 in 4 char + sym) were shown one of the same stimuli in the same manner as in Experiment 1. To simplify the design, we restricted the viewing conditions to the 2s exposure time, normal orientation, and 15s delay condition; our focus was solely on the method of reporting the license plate from memory. Each participant viewed a single plate: one of the 20 plates in the 6 char and 5 char conditions was selected at random. To further simplify the design, the 4 char + sym plates were sampled at random from those with symbols in the 4th position. The results of Experiment 1b did not differ qualitatively or quantitatively from the corresponding conditions in Experiment 1. For example, in Experiment 1, the overall mean number of characters recalled was 4.04 (s=1.67), and in Experiment 1b, the mean number of characters recalled was 4.08 (s=1.59). Likewise, an ANOVA on license plate conditions in Experiment 1b shows no difference in number of correctly recalled characters across license conditions, $F(2, 189)=2.02, p=.14, MSE=2.50, \eta^2=0.02$, replicating Experiment 1. Of course, the critical comparison is the relative memory for the character or symbol in the 4th position. In Experiment 1b, the proportion of correct responses in the 4th position in the 6 char, 5 char, and 4 char + sym conditions were .69, .72, and .75, respectively. As in Experiment 1, accuracy of recall for the 4th position information does not differ between the 5 char and 4 char + sym conditions, $t(129)=0.42, p=.67, d=-0.07$. Thus, symbols are not recalled better than characters. Given the consistency of the data across these different response formats, we feel confident that the results of Experiment 1 are not due to the response format. In addition, there is nothing in these data to suggest that the recall task asked of "real" witnesses would yield a different conclusion.
Experiment 2

There were 20 different, randomly-selected plates in each license condition of Experiment 1. Although this design allows for the generalization of results to other plates, it does present certain challenges for the comparison of memory for characters and symbols. Specifically, comparing performance within a plate (e.g., comparing memory for the ■ to memory for the characters E, 9, 8, and 2 in E98■2, both within the same plate) fails to control for position effects, which Experiment 1 revealed to be quite strong. We could (and did) eliminate that position confound by making comparisons on the same position across different license plates (e.g., the ■ in E98■2 to the 8 in JC58M, both on Position 4), but that approach fails to control for the fact that some plates may simply be easier to remember than others. That is, the symbol-to-character comparisons were not precisely controlled. In the current experiment, the plates in the different license conditions were matched on all positions except the symbol location. For example, using the plates M6C83 (5 char) and M★C83 (4 char + sym), the ★ in M★C83 can be compared to the 6 or to other characters in M6C83. Note that the M, C, 8, and 3 in Positions 1, 3, 4, and 5 are now fixed across plates; only the symbol changes. To collect sufficient data per condition, only 2 different plate classes were used (Plate 1 and Plate 2). Although conclusions based on these data will be restricted to the plates used, it allows for a cleaner comparison of memory for symbols and characters.

In Experiment 1, recall for symbols in Positions 1 and 2, but not in Positions 3-5, was different than for characters in the same positions. Those effects were not anticipated and were tested with post-hoc analyses. An additional benefit of our matched-plate design in Experiment 2 is that we can readily plan comparisons of recall for symbols and characters as a function of position. We chose to focus our analyses on the two positions that yielded significant recall differences in Experiment 1 (namely,
Positions 1 and 2) and a single position (4) that previously provided a non-significant memory difference; this focus increases our statistical power. As in Experiment 1, we manipulated the viewing orientation (normal or mirror-reversed), but we eliminated the factors of exposure time, study-test delay, and car color.

Method

Participants. 1048 people (689 male, 340 female, remainder unreported) participated through Amazon Mechanical Turk, 535 in the Plate 1 condition and 513 in the Plate 2 condition. Each participant was paid $0.30.

Design and procedure. The design and procedure were identical to Experiment 1 with the following exceptions. The number of different plates was greatly reduced. In the Plate 1 condition, the plates were M6C83R in the 6 char condition, M6C83 in the 5 char condition, and ★6C83, M★C83, and M6C★3 in the 3 versions of the 4 char + sym condition. In the Plate 2 condition, the plates were T62XR7 in the 6 char condition, T62XR in the 5 char condition, and ▲62XR, T▲2XR, and T62▲R in the 3 versions of the 4 char + sym condition. Note that, for better comparison across conditions, the plates are identical except for the exclusion of 6th position in the shorter plate conditions and the replacement of one character with a symbol in the 4 char + sym condition. Also note that, because symbols in Positions 3, 4, and 5 yielded similar recall in Experiment 1, the symbols in the 4 char + sym condition only occupy Positions 1, 2, and 4. All subjects viewed the plate for 2 seconds with a study-test delay time of 15 seconds, and all cars were black. Both normal and mirror viewing were included.

Results
A mean of 52.4 (SD = 18.02) participants viewed each combination of basic license condition (6 char, 5 char, 4 char + sym), orientation condition (normal or mirror), and plate condition (Plate 1 or 2).

**Overall number correct.** The number correct for each participant was calculated using the same method as in Experiment 1; the results are shown in Figure 5 as a function of viewing orientation and the five different license conditions (6 char, 5 char, and the 3 versions of the 4 char + sym). Across all conditions, the mean number of correct responses was 3.38 (sd = 1.68). An ANOVA was run with the total number of correct responses as the dependent variable and license condition (collapsing the three different 4 char + sym conditions9), plate condition, orientation condition, age, and gender as factors. Consistent with Experiment 1, the only significant effect was a main effect of orientation, $F(1, 920) = 89.91, p < .001, MSE = 2.51, \eta^2_p = 0.09$: more items were remembered when the plate was oriented normally. There was no effect of license condition, $F(2, 920) = 3.22, p = .04, MSE = 2.51, \eta^2_p = 0.01$. Because there was no effect of plate condition (i.e., Plate 1 v. 2), $F(1, 920) = 3.16, p = .08, MSE = 2.51, \eta^2_p = 0.00$, and plate condition did not interact with any other factors, all graphs collapse the two plate conditions.

**Memory for Symbols vs. Characters.** Figure 6 shows the probability of recall as a function of license plate position, orientation condition, and license condition; recall for the symbols (filled dots) is plotted separately from recall for the characters (open dots, as in Figure 4 for Exp. 1). To assess memory for symbols relative to memory for characters, we ran a logistic, linear mixed-effects model similar to the one from Experiment 1. The factors were main effects of license condition, orientation,

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9 The results are qualitatively similar if the five license conditions are left separate. The effect of license condition is $F(4, 862) = 2.65, p = .03, MSE = 2.50, \eta^2_p = 0.01$. 

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plate condition, position, and symbol and all possible interactions. (Note that, because symbols do not appear in all license conditions, interactions including these two factors are not possible.) Subjects were included as a random-effect factor with random intercepts. License condition, orientation, position, and symbol were centered and coded as before. Plate conditions 1 and 2 were coded as -0.5 and 0.5, respectively.

Because the results are nearly identical to Experiment 1, only significant and critical results are presented. Recall performance was better for the 5 character plates, est. = -0.85, S.E. = 0.22, z-value = -3.93, Pr(>|z|) < .001, and for license plates viewed with the normal orientation , est. = 1.19, S.E. = 0.35, z-value = -3.41, Pr(>|z|) < .001. There was a main effect of position, such that recall was lower for rightward characters in the plates, est. = -0.38, S.E. = 0.10, z-value = -3.83, Pr(>|z|) < .001. Finally, there was a license length (5v6) by position interaction, est. = -0.48, S.E. = 0.09, z-value = -5.48, Pr(>|z|) < .001. No other effects reached significance. In particular, the main effect of symbol was not significant, est. = -0.21, S.E. = 0.22, z-value = -0.93, Pr(>|z|) < .35. The effect of plate condition (Plate 1 v. 2) approached significance, est. = 0.21, S.E. = 0.09, z-value = 2.46, Pr(>|z|) = 0.014, hinting at plate specific performance.

Planned comparisons between symbols and their associated characters in the 5-character plates were run. For example, the ★ in Plate ★6C83 was compared to the M in Plate M6C83. Replicating Experiment 1, symbols impaired memory in the first position, t(326) = 4.27, p < .001, d = -0.46. In contrast, the modest memory benefit for symbols in the second position was not replicated, t(358) = 1.90, p = .06, d = 0.18. There was no effect of symbols v. characters in the fourth position, t(347) = 1.42, p = .16, d = 0.15.

Discussion
The results of this experiment replicate and extend the results of Experiment 1 in a more powerful and focused design. In particular, as in Experiment 1, there was no overall memory advantage for symbols, and, indeed, recall for symbols was substantially worse than recall for characters in the left-most position on the license plate. Recall was better for plates viewed in a normal orientation than a mirror-reversed orientation. Later positions were remembered worse than earlier positions, especially for the 6-character plates. Perhaps not surprisingly, recall varied somewhat across the two plate conditions, suggesting that some plates are inherently easier to remember than others.

General Discussion

Our experiments replicate the basic findings of the mean number of recalled elements of a license plate – around 3.5 to 4 characters – as well as the observation that longer exposure time improves recall accuracy. Our data also extend those general results in important ways. For example, in Experiment 1 we used a wide variety of randomly-generated license plates, which reduces the possibility that the previous results were idiosyncratic to the particular plate tested. Also in Experiment 1, we found no memory decrement as the study-test lag increased from 15 to 30 seconds, although we predict that a more cognitively demanding filler interval would reveal a negative effect of increased delay. More critically, our data reveal the magnitude of the memory impairment that occurs when a witness views a license plate in a mirror, as could occur when driving or riding in a car: participants in the mirror viewing condition recalled about 1 fewer elements from the plate number than participants who viewed the plate from a normal perspective. Finally, our experiments tested a specific hypothesis that motivates a proposal to include a nameable symbol on license plates, namely that doing so would enhance recall of the plate number. Our data are quite conclusive that there is no overall memory
benefit associated with the inclusion of a symbol, nor is memory for the symbol itself better (or worse) than memory for a letter or number.

Although our experiments were not designed to explicitly test the effect of chunking and within-class interference on memory for license plates, preliminary observations can be made. Under certain conditions, i.e., brief exposure times, memory did improve with the number of alterations between different character types (digits, letters, and symbols) in the plate. This result is consistent with previous research (Schraagen and van Dongen, 2005), reinforcing the idea that chunking may have a limited effect on license plate recall. There was no evidence of interference on memory. The inclusion of a symbol increased the number of information classes from 2 (digits and letters) to 3 (digits, letters, and symbols). At the same time, when comparing the 5 char and 4 char + sym conditions, inclusion of symbols reduced the number of digits or letters in the plate. There was, however, no overall memory advantage when symbols were present, suggesting that this reduction did not have an effect. These conclusions are speculative, however, and future research is needed to specifically address these issues.

Perhaps surprisingly, the average number of correctly recalled license plate elements did not differ as a function of license plate length. Participants recalled about 3.5-4 items regardless of whether the license plate had 5 or 6 elements. Similarly, MacKinnon et al. (1990, Exp. 1) found that their participants correctly reported an average of 3.5 characters from the particular 7-character plate they tested. This result suggests that working memory capacity may play a strong role in the consistency of recalled information across different plate lengths (e.g., Nelson, 2010).

An interesting consequence of the relatively constant number of recalled elements is that participants recall a higher fraction of the total information from a shorter license plate. That proportional increase could potentially reduce the search space for a team investigating a crime. Imagine that Witness A reports 2 characters from a 6-character plate and Witness B reports 2 characters from a 5-character plate. Because there are fewer plates that will match those two characters, Witness B
has provided more valuable information. This benefit comes directly from there being fewer positions to match in the 5-character plate. Now compare Witness B to Witness C, who reports 2 characters (or a character and a symbol) from a 4-character + symbol plate. Both of the license plates have 5 positions, but as we described in the introduction, there are many more possible 5-character plates with a symbol than without a symbol. Consequently, the characters recalled by Witness C are less likely to match the “wrong” plate and so are more likely to narrow down the set of possible cars to investigate. Indeed, this motivation has been used to argue for the inclusion of a symbol on license plates (EZ-ID, n.d.).

To more precisely address the practical implications of plate type on the number of partially matched plates, we ran a simulation with the following characteristics. As in our experiments, the simulated plates were of 3 types: 6 characters, 5 characters, or 4 characters plus a symbol. The characters and symbols were selected from sets of size 9 and 5, respectively, yielding a total of $9^6 = 531,441$ and $9^5 = 59,049$ possible plates in the 6 char and 5 char conditions, and $9^4 \times 5\text{ symbols}\times 5\text{ positions} = 164,025$ possible plates in the 4 char + sym condition.\(^{10}\) We chose the set size values to equate the ratio of symbols to characters in plates with 36 possible characters and the 20 possible symbols proposed by EZ-ID (i.e., 20 symbols / 36 characters = 5 symbols / 9 characters = 0.56 symbols/characters). Next, we assumed that 5241 plates were issued, simulating "cars on the road." This value is approximately 1% of all possible plates with 9 characters and 6 positions, a fraction similar to the percentage of general issue Massachusetts plates currently in use (U.S. Dept. of Transportation, Federal Highway Administration, n.d.). Finally, we assumed that the plates were either issued sequentially (e.g., 000000, 000001, etc) or in a random order. Once the simulated plates were generated, we estimated the number of cars to be investigated by randomly sampling one plate at random and assuming that 1, 2, 3, 4, 5, or 6 of the plate's elements were reported.

\(^{10}\) Given the huge number of possible plates, running simulations with 36 characters and 20 symbols was not computationally feasible. Different numbers of characters and symbols were tried and the same basic results was observed for all simulations.
The number of issued plates that matched the recalled characters is plotted in Figure 7\textsuperscript{11}. There are two main results. First, it is clearly better to generate plate numbers randomly than sequentially\textsuperscript{12}. The number of partially matching plates in the ordered conditions were 3 to 4 times higher than in the random conditions. This informational advantage for random plates occurs because plates issued in order tend to have considerable overlap (e.g., 00001, 00002, 00003, etc); the same characters tend to occupy the same position on many plates. Worse, the overlapping positions are actually those that human witnesses recall with highest probability (see Figures 3 and 6). The second main result of these simulations is, as Figure 7 shows, that there is a small advantage for the 4-char + sym plates that is dependent on the manner in which the plate numbers are created. For the randomly-generated plates, the 4-char + sym plates show an informational advantage regardless of how many elements are recalled. In contrast, for the ordered plates, the number of partially-matching 4-char + sym and 5-char plates were essentially identical. Note that the advantage for randomly-generated 4 char + sym plates remains intact across the range of remembered characters, including the experimental mean of 3 to 4 items (see the inset of Figure 7).

In summary, adult participants recalled about 3 elements from a license plate studied for 1 second, and about 4 items from a plate studied for 2-3 seconds. Viewing a mirror-reversed plate decreased recall by about one character, and nameable symbols were recalled with accuracy similar to numbers and letters. Additional studies to assess other viewing conditions, such as nighttime or foggy conditions, situational factors such as cognitively-demanding filler tasks, longer delays, and participant factors, such as child witnesses or high stress levels, will continue to flesh out the slender literature on memory for license plates. Because participants were instructed to memorize the plates, these results place an upper-bound on memory performance. Future experiments are needed to address memory for

\textsuperscript{11} Only recalled license plate details were considered, not other identifying information such as car color or make.

\textsuperscript{12} This advantage only occurs when the number of plates on the road is far lower than the number of possible plates. To see why, consider an extreme example: if all possible plates are issued, then, whether or not the plates were issued in order or randomly, exactly the same plates are on the road.
plates when learning is incidental. There was no overall memory advantage or decrement associated with the addition of symbols to the license plate. The one strong exception were symbols in the first position; further research is needed to determine whether exposure to such plates would ameliorate this difficulty. Finally, if plate numbers were generated at random, rather than sequentially, then the addition of a symbol could improve the ability of police to identify a vehicle involved in a crime by reducing the number of similar license plates to consider.

Finally, we offer a post-script on the current status of the Massachusetts Senate Bill that prompted these experiments. After extensive discussion, an amended version of the Bill was recently passed. The amendments shifted the focus from one of immediate license plate redesign and implementation to the creation of a special task force to study the costs and benefits of any such changes. The task force is charged, among other things, with studying the visual and cognitive processing of license plates (including those with symbols), the cost and benefit of implementation of any changes to current plate design, as well as the broader impact on law enforcement at the local, state, and federal levels. We hope that their study will include 1) an evaluation of the memory factors outlined previously, 2) consideration of variables that influence perception of the plates (font style and size, symbol selection, visual contrast effects, etc.), and 3) an assessment of the reduction in search space from assigning license plate numbers in a random order, which Figure 7 shows would benefit law enforcement regardless of whether symbols are included. We believe that this amended Bill offers the best possible interplay of public policy, law enforcement, and psychological research.
References


Author Note

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Appendix

Instructions:

When the experiment starts, you will be asked to do the following:
- You will view a short video. Please attend to the entire video.
- At the start of the video you will see a car. Try to remember the car color and license plate number.
- After the video, you will type the number 822 into a text box. You will be reminded of this number at that time.
- You will then be asked to recall the car color and license plate number.
- Finally, there will be some short demographics questions.

Notes:
- The license plate may or may not be reversed (as if you were looking at it in a rear-view mirror). You will be asked to recall the license number in reading order (the order when the license is looked at normally, i.e., not in a mirror).
- The license plate may or may not be shown for a very short time, so pay attention to the video right away.
- The license may consist of letters, numbers, and/or symbols.
- Payment is not contingent on perfect performance, so please don't use the browser back button or write or record anything. Just do your best.
- Please attend to the entire video as best you can.
- The video has sound, so please turn your sound on.
Table A1. Experiment 1 license plates.

<table>
<thead>
<tr>
<th>License condition</th>
<th>6 Characters</th>
<th>5 Characters</th>
<th>4 Characters + Symbol</th>
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<tr>
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<td>F6UX3</td>
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<td>6 ★8DA</td>
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<td>ASW9 □</td>
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<td>GZ ▼3V</td>
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<td>6XGG ★</td>
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<td>YRAH9A</td>
<td>E8P8U</td>
<td>▼6VKC</td>
<td></td>
</tr>
</tbody>
</table>
Table 1.

Fixed-effect results from the logistic linear mixed-effects model for the effects of position, symbol, and symmetry in Experiment 1.

|                          | estimate | S.E.  | z-value | Pr(>|z|) |
|--------------------------|----------|-------|---------|---------|
| (intercept)              | 0.870    | 0.130 | 6.681   | 0.000   |
| license condition-5v6    | -0.465   | 0.129 | -3.614  | 0.000   |
| license condition-5v4    | -0.009   | 0.120 | -0.073  | 0.942   |
| orientation              | -1.356   | 0.262 | -5.176  | 0.000   |
| exposure duration        | 1.331    | 0.319 | 4.169   | 0.000   |
| position                 | -0.449   | 0.082 | -5.512  | 0.000   |
| symbol                   | -0.003   | 0.223 | -0.013  | 0.989   |
| symmetry                 | -0.112   | 0.118 | -0.950  | 0.342   |
| license condition-5v6:orientation | 0.133 | 0.258 | 0.514   | 0.607   |
| license condition-5v4:orientation | 0.098 | 0.243 | 0.404   | 0.687   |
| license condition-5v6:exposure duration | -0.279 | 0.320 | -0.869  | 0.385   |
| license condition-5v4:exposure duration | -0.206 | 0.295 | -0.700  | 0.484   |
| license condition-5v6:study-test delay | -0.510 | 0.257 | -1.981  | 0.048   |
| license condition-5v4:study-test delay | -0.269 | 0.241 | -1.118  | 0.264   |
| license condition-5v6:position | -0.146 | 0.045 | -3.242  | 0.001   |
| license condition-5v4:position | 0.078 | 0.047 | 1.666   | 0.096   |
| orientation:position     | -0.089   | 0.064 | -1.379  | 0.168   |
| exposure duration:position | 0.377 | 0.080 | 4.722   | 0.000   |
| study-test delay:position | -0.006  | 0.063 | -0.095  | 0.924   |
| orientation:orientation  | 0.373    | 0.449 | 0.830   | 0.406   |
| exposure duration:symbol  | -0.628   | 0.513 | -1.223  | 0.221   |
| study-test delay:symbol   | 0.923    | 0.412 | 2.241   | 0.025   |
| position:symbol           | -0.091   | 0.169 | -0.539  | 0.590   |
| orientation:symmetry     | -0.302   | 0.230 | -1.314  | 0.189   |

Note: All effects for which Pr(>|z|) < .01 are in bold.
Table 2.

Fixed-effect results from the logistic linear mixed-effects model for omission errors in Experiment 1.

|                                | estimate | S.E.  | z-value | Pr(>|z|) |
|--------------------------------|----------|-------|---------|----------|
| (intercept)                    | -4.865   | 0.294 | -16.544 | 0.000    |
| license condition-5v6          | 0.671    | 0.297 | 2.261   | 0.024    |
| license condition-5v4          | 0.095    | 0.294 | 0.322   | 0.747    |
| orientation                   | 2.366    | 0.564 | 4.194   | 0.000    |
| exposure duration              | -2.078   | 0.647 | -3.211  | 0.001    |
| study-test delay               | -0.597   | 0.543 | -1.100  | 0.271    |
| position                       | 1.069    | 0.147 | 7.277   | 0.000    |
| symbol                         | -0.055   | 0.424 | -0.130  | 0.896    |
| symmetry                       | -0.143   | 0.210 | -0.681  | 0.496    |
| license condition-5v6:position | 0.097    | 0.086 | 1.125   | 0.260    |
| license condition-5v4:position | -0.084   | 0.096 | -0.875  | 0.382    |
| orientation:position           | 0.033    | 0.132 | 0.255   | 0.799    |
| exposure duration:position     | -0.664   | 0.147 | -4.510  | 0.000    |
| study-test delay:position      | 0.070    | 0.122 | 0.577   | 0.564    |
| orientation:symbol             | -0.020   | 0.790 | -0.025  | 0.980    |
| exposure duration:symbol        | 0.541    | 0.794 | 0.682   | 0.495    |
| study-test delay:symbol         | -1.183   | 0.713 | -1.658  | 0.097    |
| position:symbol                | 0.220    | 0.296 | 0.741   | 0.459    |
| orientation:symmetry           | 0.411    | 0.412 | 0.996   | 0.319    |

Note: All effects for which Pr(>|z|) < .01 are in bold.
Figure captions

Figure 1. A close-up of a sample license plate stimulus from Experiment 1. Participants saw more of the car. The original stimulus was in color.

Figure 2. Number of correct responses in each condition of Experiment 1.

Figure 3. Probability of recall at each license plate position in each condition of Experiment 1.

Figure 4. Probability of recall at each license plate position across license conditions and at each orientation in Experiment 1 separated by non-symbols in the 5 character and 4 character + symbol conditions and symbols in the 4 character + symbol condition.

Figure 5. Number of correct responses in each license condition and orientation of Experiment 2.

Figure 6. Probability of recall at each license plate position in each license condition and orientation of Experiment 2.

Figure 7. Simulation results of the number of plates that match a partially recalled plate as a function of the number of characters recalled for different plate types. The inset magnifies the region from 3-4 recalled characters.
Figure 1
Figure 2
Figure 3
Figure 4
Figure 5
Figure 6
Figure 7