The Statistics of the Environment Affect the Functional Architecture of Vision in Adulthood: A Reduced Alphanumeric Category Effect in Canadian Mail Sorters

Thad A. Polk
Department of Psychology
University of Pennsylvania
3815 Walnut Street
Philadelphia, PA 19104-6196
polk@psych.upenn.edu

Martha J. Farah
Department of Psychology
University of Pennsylvania
3815 Walnut Street
Philadelphia, PA 19104-6196
mfarah@psych.upenn.edu

Abstract

Letters are detected more efficiently among digits than among letters. This alphanumeric category effect suggests an architectural distinction between letter and number representation in human vision and dissociations between letter and number recognition following brain damage support this interpretation. Because letter and number recognition are not innate, this implies that experience can shape the functional architecture of vision. A possible explanation is that letters co-occur with letters in the environment while numbers co-occur with numbers; such statistics cause segregation of letter and number representations in artificial neural networks. To test the general hypothesis that environmental statistics affect the architecture of vision, and the specific hypothesis that within-category co-occurrence causes the alphanumeric category effect, we measured the effect in foreign mail sorters who process Canadian zip codes (which violate the co-occurrence statistics) and in control subjects. As predicted, foreign mail sorters showed a smaller category effect.

The Alphanumeric Category Effect and the Co-Occurrence Hypothesis

A central goal of cognitive psychology is to characterize the functional architecture, that is, the set of information-processing subsystems underlying cognition. In the case of vision, a productive behavioral approach to elucidating the architecture has been to study pop-out effects. A visual target is said to pop-out if it is detected quickly and without serial search (i.e., response time is relatively independent of the number of distractors). Treisman and colleagues (Treisman, 1988; Treisman & Gelade, 1980) have shown that targets that differ from distractors by the presence of certain, so-called primitive, visual features (e.g., color, orientation, motion) pop-out, while targets that differ by the presence of other features do not (i.e., they require slower, serial search). Treisman and Gelade (1980) proposed an influential feature-integration theory in which primitive features are processed automatically and in parallel in specialized modules, called feature maps. This hypothesis is consistent with neuroscientific evidence for spatially segregated, cortical areas that are specialized for processing such features (Cowey, 1979; Van Essen & Maunsell, 1983).

A similar pop-out effect occurs for letters and digits: A letter target is detected more quickly and accurately among digit distractors than among distinct letter distractors and vice versa (Duncan, 1980; Duncan, 1983a; Egeth, Jonides, & Wall, 1972; Jonides & Gleitman, 1972; Merikle, 1980; Schneider & Shiffrin, 1977; von Wright, 1972). Although this alphanumeric category effect can disappear when using letter-digit pairs that are matched for visual similarity (Cardosi, 1986; Krueger, 1984), this approach makes between category items (letters and digits) more visually similar, on average, than within category items (different letters) and hence may mask the effect; when both between and within category similarity are controlled, the category effect reemerges (Dixon & Shedden, 1987).

This evidence suggests that category information about alphanumeric stimuli is computed automatically, rapidly and in parallel in much the same way information about primitive visual features is processed. Consistent with this hypothesis, brain-damaged patients can be selectively impaired at letter recognition relative to number recognition (Gardner, 1974; Hecaen & Kremin, 1976) and vice-versa (Cipolotti, 1995), suggesting that letter and digit recognition are carried out by distinct modules or maps.

Although it is natural to assume that the visual processing of color, motion, and other primitive features are innate, letter and digit recognition certainly are not: They are not phylogenetically old, they are not shared by all normal adults, and they require systematic training to develop. If the functional architecture of vision (in normal adult readers) includes maps devoted to letter and digit recognition, as the behavioral and neuropsychological data suggest, then the environment must be playing a role in shaping that architecture. How might it do so?

The fact that neural learning is fundamentally correlation-based suggests that temporal correlations in the environment may provide an answer. For example, stimuli within a category (e.g., letters) tend to occur in close temporal proximity (e.g., in text), but stimuli between categories (e.g., letters and digits) occur in such close temporal proximity much less often. This statistical feature of the environment could interact with correlation-based learning in the brain to lead to maps for letter and digit recognition. Polk and Farah (1993, 1995) implemented this hypothesis in a simple neural network model that used a Hebbian learning rule. When this network was presented with inputs that satisfy these co-occurrence statistics, it spontaneously self-organized to produce maps for letters and digits.

An Empirical Test of the Co-Occurrence Hypothesis

If the development of such maps is due to the co-occurrence of letters with letters and digits with digits, then the alphanu-

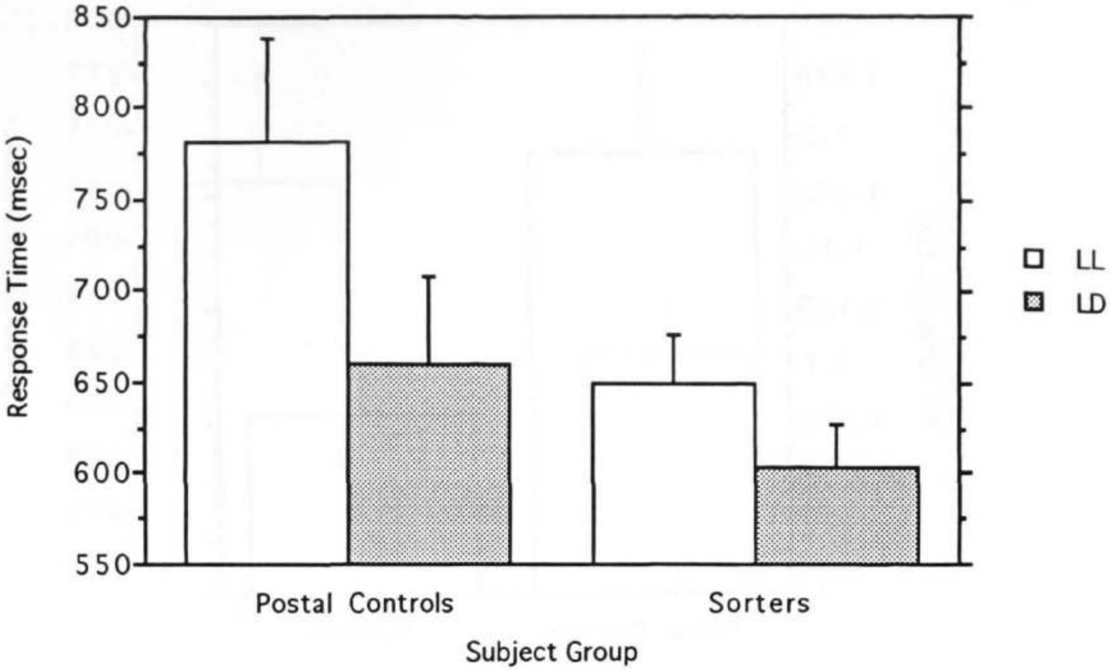

Figure 1: Mean reaction time (with standard error bars) for correct responses on target-present trials for the foreign mail sorters and postal controls in both the letter-among-letters (LL) and letter-among-digits (LD) conditions.

meric category effect should be smaller in subjects who regularly see letters and digits together. Such subjects should have less segregated maps and, as a result, letters should not pop out from digits as much as they do for control subjects. This prediction offers the appealing possibility of directly observing the effects of environmental co-occurrence on the functional architecture of vision.

To test this prediction we compared the alphanumeric category effect in foreign mail sorters with that in postal worker controls. Foreign mail sorters spend roughly 4 hours per day processing Canadian zip codes in which letters and digits occur together (they alternate).

Method

Subjects. 10 foreign mail sorters and 16 postal controls from the Philadelphia Air Mail Facility were paid $20 for their participation. The foreign mail sorters had all been operating the Letter Sorting Machine for at least 6 months prior to their participation.

Task. The experiment was run on a Macintosh IIsi computer with a 14" screen. Displays were made up of digits and uppercase letters from the Geneva typeface in 10 point font. The task and procedure were modeled on those of Duncan (1983b), experiment 1.

On each trial, the computer first presented the target letter in the center of the screen (either an A or a Z, randomly chosen). Once the subject pressed the spacebar indicating they were ready to proceed, the screen went blank for 1600 msec and then presented a fixation point at the center of the screen. After 400 msec the fixation point was replaced by a circular array of two, four, or six characters whose diameter subtended a visual angle of 3.4 degrees and which was centered on the fixation point. On half the trials, this array included the target letter, on half the trials it did not. In the letter-among-digit (LD) trials, the distractors were selected randomly from the set 3, 5, 6, 8, 9. In the letter-among-letter (LL) trials, the distractors were selected randomly from the set C, E, F, H, J, K, L, N, P, R, S, T, U, V, X, Y. The subjects pressed a key with their right index finger if the target was present and with their left index finger if the target was absent. After the response, the screen went blank for 2 sec followed by the target for the next trial.

There were 12 possible positions in the circular array in which characters could appear, arranged like a clock. The positions in the array were grouped into six pairs (12 and 1 o'clock, 2 and 3 o'clock, ..., 10 and 11 o'clock). Characters appeared in random positions in the array except that two characters never appeared in the same group and at least one pair of characters appeared in diametrically opposite groups (e.g., one character in the 12-1 o'clock group and one character in the 6-7 o'clock group).

Procedure. After being instructed, each subject received a block of LD trials and a block of LL trials with the order randomized across subjects. Each block consisted of 24 practice trials (not analyzed), a break, and 108 test trials.

Within each set of 108 test trials, the following factors were varied orthogonally: 3 (two, four, or six characters) x 2 (target present vs. absent) x 6 (target positions; a dummy variable for target absent trials) x 2 (A or Z). Otherwise, trial sequences were randomized for each block and subject.

Results

Figure 1 shows the mean reaction time for correct responses on target-present trials for the foreign mail sorters and postal con-

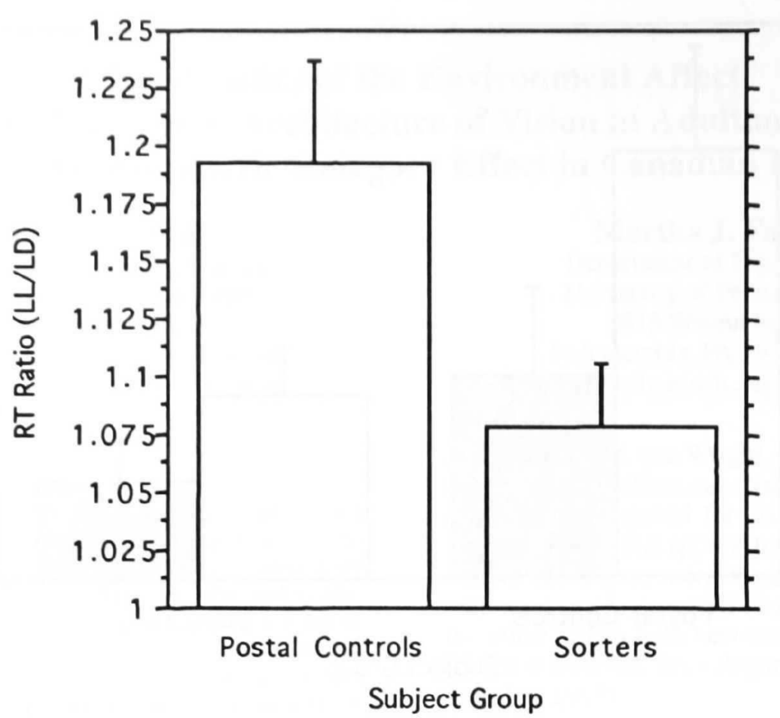

Figure 2: Mean ratio of reaction times (with standard error bars) in the two conditions (LL/LD) for the two subject groups.

trols in both the letter-among-letters (LL) and letter-among-digits (LD) conditions. In keeping with the traditional category effect, there was a main effect for condition, with LD trials being reliably faster than LL trials, $t(25) = 4.367$, $p < .001$, one-tailed. Although the foreign mail sorters were on average faster than controls (627 msec vs. 721 msec) this effect did not achieve significance, $t(24) = 1.429$, $p > .15$, two-tailed. The interaction between subject group and condition, however, was significant; the foreign mail sorters showed a smaller difference between the LL and LD conditions than did the controls (i.e., a reduced category effect as measured by LL-LD difference), $t(24) = 1.816$, $p < .05$, one-tailed.

Figure 2 shows the mean ratio of reaction times in the two conditions (LL/LD) for the two subject groups. The foreign mail sorters also showed a reduced category effect as measured by the LL/LD ratio, $t(24) = 1.864$, $p < .05$, one-tailed.

Figure 3 shows the mean reaction times for the two subject groups when the three slowest controls are excluded, thus making their average response time in the LD condition faster than that for the sorters. In keeping with the overall results, the LD condition was significantly faster than the LL condition, $t(22) = 4.785$, $p < .001$, one-tailed, and the foreign mail sorters showed a reduced category effect as measured by the LL-LD difference, $t(21) = 1.881$, $p < .05$, one-tailed, and by the LL/LD ratio, $t(21) = 2.060$, $p < .05$, one-tailed. There was a cross-over interaction in this case, with control subjects responding faster than sorters in the LD condition, but slower than sorters in the LL condition. There was not a significant main effect for subject group, $t(21) = 0.583$, $p > .50$, two-tailed.

Figure 4 shows the same results with a set of 8 college graduates in place of the postal controls. Once again, the LD condition was significantly faster than the LL condition, $t(17) = 3.208$, $p < .01$, one-tailed, and the foreign mail sorters showed a reduced category effect as measured by the LL-LD difference, $t(16) = 2.271$, $p < .05$, one-tailed, and by the LL/LD ratio, $t(16) = 2.792$, $p < .01$, one-tailed. Again, this was a cross-over interaction with controls responding faster than sorters in the LD condition, but slower than sorters in the LL condition. There was not a significant main effect for subject group, $t(16) = -0.438$, $p > .50$, two-tailed.

Discussion

In keeping with the prediction of the co-occurrence hypothesis, foreign mail sorters showed a reduced category effect as measured by the absolute difference in response times (RT in the letter-among-letter [LL] condition - RT in the letter-among-digit [LD] condition, Figure 1) and by the ratio of response times ((RT in LL)/(RT in LD), Figure 2). To ensure that these results were not the result of a floor effect (RT for the sorters in the LD condition approaching a floor and therefore reducing the effect), we excluded the three slowest postal worker controls for one analysis (Figure 3) and used college graduates whose RTs were faster for another (Figure 4). In both cases, the control group showed a larger category effect than the foreign mail sorters, even though both these groups were faster than the sorters in the LD condition. These cross-over interactions eliminate any obvious interpretations based on artifacts.

The co-occurrence hypothesis may also explain other examples of environmental influences on the functional architecture. There is evidence for the neural segregation of handwriting vs. other manual control tasks (Alexander, Fischer, & Friedman, 1992) (and even script and print can be selectively impaired by brain damage, Kinsbourne and Hiltbrunner, personal communication), of melody recognition vs. the recognition of other sounds (Peretz, 1993), and of each language in bilinguals (Ojemann, 1983). These examples also involve

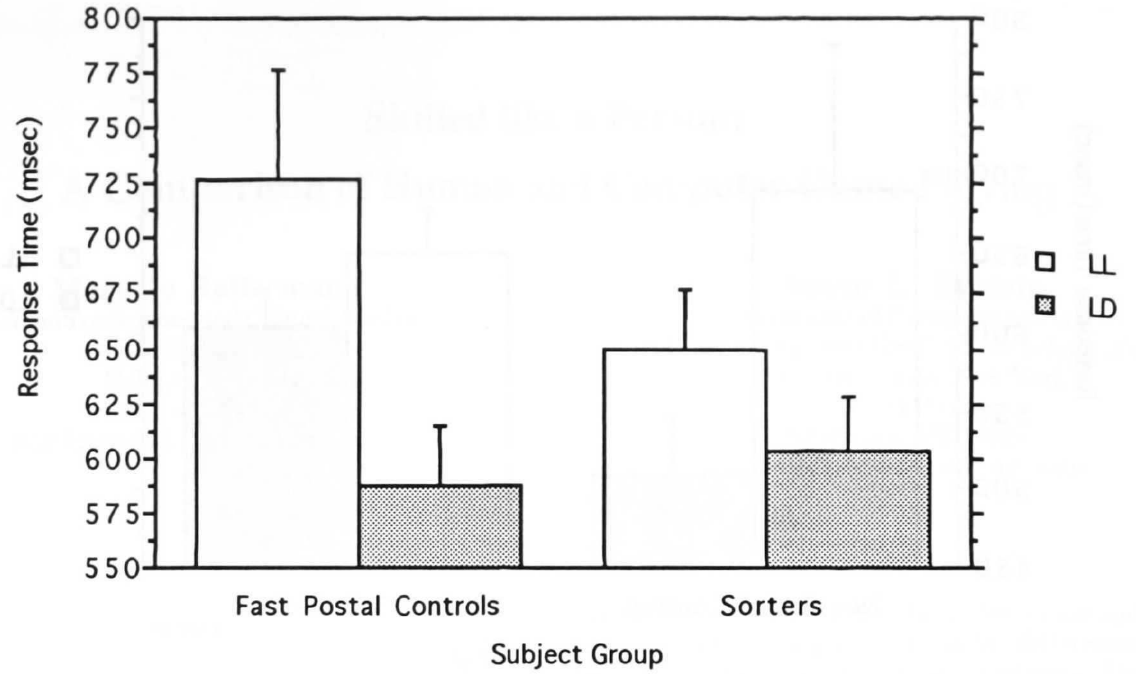

Figure 3: Mean reaction times (with standard error bars) for the two subject groups when the three slowest controls are excluded.

influences on the functional architecture that are presumably not innate. And in keeping with the co-occurrence hypothesis, stimuli within these categories often occur in close temporal proximity: Handwriting a character is usually immediately preceded and followed by writing another character (and script characters are temporally correlated with other script characters, but print characters are correlated with print), musical sounds tend to co-occur with other musical sounds, and spoken words tend to co-occur with spoken words from the same language. Conversely, stimuli between different categories (e.g., script and print) occur in such close temporal proximity less often.

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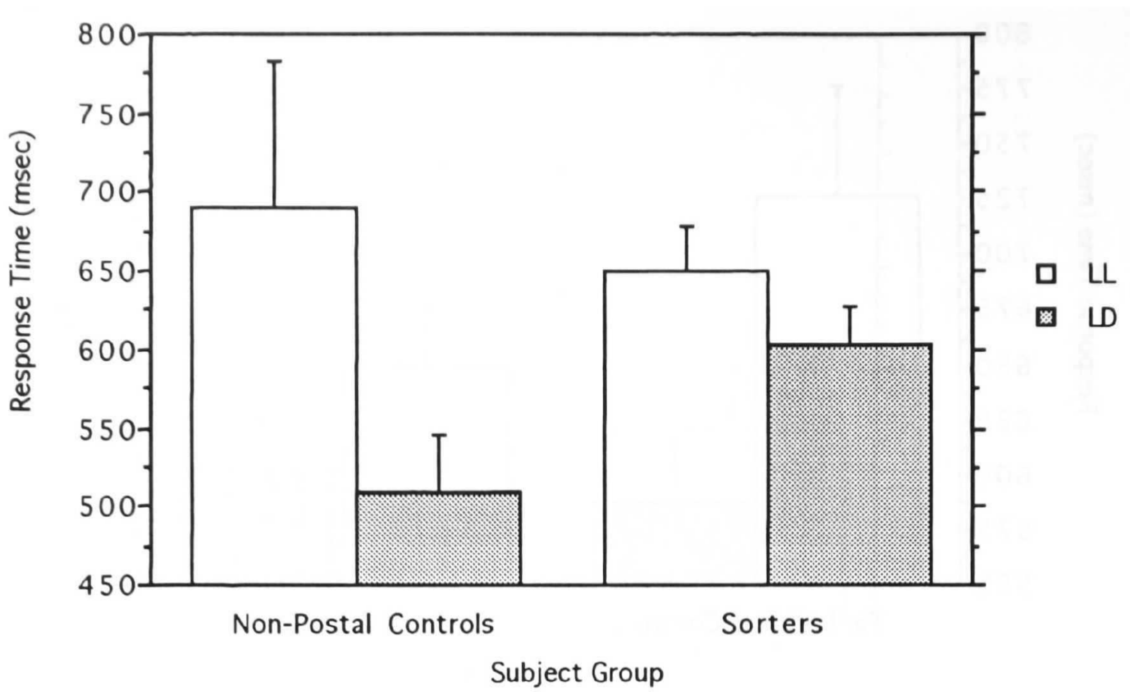

Figure 4: Mean reaction times (with standard error bars) with a set of 8 college graduates in place of the postal controls.

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