Eye Movement During Skill Acquisition: More Evidence for the Information-Reduction Hypothesis

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Two experiments tested H. Haider and P. A. Frensch's (1996) information-reduction hypothesis that people learn, with practice, to distinguish between task-relevant and task-redundant information and to limit their processing to task-relevant information. Participants verified alphabetic strings (e.g., "E [4] J K L") containing task-relevant and task-redundant information. In Experiment 1, the positioning of task-relevant information within the strings and the consistency of positioning were manipulated. Degree of information reduction as reflected in reduced reaction times was not affected by the positioning of the relevant information and was only slightly affected by consistency of the positioning. In Experiment 2, eye movements were recorded. Results suggest that task-redundant information is ignored at a perceptual rather than a conceptual level of processing. Thus, existing theories of skill acquisition should include mechanisms that capture the practice-related increase in the selective use of information.

Practice improves both the speed and quality of performance. This relation between task practice and performance appears to hold across a wide variety of cognitive (e.g., Anderson, 1982, 1983, 1987, 1992, 1993; Lassaline & Logan, 1993; Logan & Etherton, 1994; Logan & Klapp, 1991) and motor (e.g., K. Newell, 1991; Schmidt, 1987) tasks; frequently, speed-of-performance improvements follow a power law of practice (e.g., A. Newell & Rosenbloom, 1981). Typically, the relation between task practice and task improvement is explained with reference to practice-related (a) qualitative changes in the effective task structure (i.e., strategy changes; Cheng, 1985; Logan, 1988, 1990, 1992), (b) increases in the efficiency of performing individual task components (e.g., the concept of strengthening in Anderson's 1982, 1987, and 1992 ACT* theory), (c) increases in the efficiency of performing sequences of task components (e.g., Anderson's 1982 and 1987 composition mechanism; see also Frensch, 1991, 1994; A. Newell & Rosenbloom's chunking mechanism), or (d) combinations of these mechanisms (e.g., Anderson, 1987).

We (Haider & Frensch, 1996) recently reintroduced a theoretical explanation for practice-related performance improvements that differs from those mentioned above. Specifically, we argued that changes in the speed and quality of performance are partially due to a reduction in the amount of task information that is processed. This information-reduction hypothesis holds that people learn, with practice, to become selective in their use of information, that is, to distinguish between task-relevant and task-redundant information and limit their processing to task-relevant information. Improvements in task performance, in this view, reflect an increased knowledge about which information has to, and which information does not have to, be processed.

The theoretical notion of information reduction (for related proposals, see Anderson, Matessa, & Douglass, 1995; Logan & Etherton, 1994) is rooted in the traditional belief that selection of information is a necessary prerequisite for action (e.g., J. J. Gibson, 1979; Hoffmann, 1993; Neisser, 1976; Neumann, 1985, 1990; van der Heijden, 1992) and has been introduced in many different areas of psychology. It can be found in the literature on perception (e.g., E. J. Gibson, 1963; J. J. Gibson & Gibson, 1955; Kaptein, Theeuwes, & van der Heijden, 1995), concept formation (e.g., Regehr & Brooks, 1993), educational psychology (e.g., Bransford, Sherwood, Vye, & Rieser, 1986; Gaeth & Shanteau, 1984), and expertise (e.g., Shanteau, 1992; Shapiro & Raymond, 1989). Moreover, the idea of information reduction is consistent with empirical results observed in various areas of psychology (e.g., Christensen et al., 1981; Fisher & Tanner, 1992; Holding, 1985; LaBerge & Samuels, 1974; Lambert, Spencer, & Mohindra, 1987; Myles-Worsley, Johnston, & Simons, 1988; Strayer & Kramer, 1994a, 1994b).

To test the information-reduction hypothesis for the domain of cognitive-skill acquisition, we asked participants to verify alphabetic letter strings (Haider & Frensch, 1996). Strings consisted of an initial letter–digit–letter triplet and a
consistent with arguments that have been made in other information reduction, even when instructions are given the task that contain redundant information. Additional support for the latter view comes from a new series of experiments in which participants were asked to attend to and perceive those structural components of the strings that may be the result of a conscious and voluntary decision to notice or not notice the task-redundant information. The main results of these experiments are as follows:

1. The magnitude of the string-length effect for correct strings is always correct and was redundant for the verification task. Therefore, letters in String Positions 4 and higher were always correct and were redundant for the verification task required of participants.

Because the total number of letters varies across strings in the alphabet verification task, one can infer whether or not participants ignore the task-irrelevant information from the magnitude of the string-length effect for correct strings. If participants verify the entire string, then verification time should increase systematically with string length. If, on the other hand, participants have learned to limit their task processing to the relevant letter-digit-letter triplet, then verification time should be independent of string length. The magnitude of the string-length effect for correct strings is thus an indirect measure of the degree to which task-irrelevant information is ignored.

Three main results were reported in the initial set of experiments (Haider & Frensch, 1995). First, the effect of string length on the verification times for correct strings disappeared altogether after approximately 500 trials. Second, when errors were suddenly introduced at the formerly redundant string positions, participants’ error rates correlated positively with the amount of practice they had received on the original task. Third, the magnitude of the string-length effect was unaffected by changes in the stimulus material (i.e., new letters).

These results are suggestive of a two-phase information-reduction process, in which task-relevant and task-redundant information are identified in the first phase. In the second phase, task-relevant information is actively selected for processing (e.g., Allport, 1987; Neumann, 1990), and task-redundant information is actively ignored (e.g., Neisser & Becklen, 1975). Primarily on the basis of the first and third main results summarized above, we reasoned that noticing the distinction between relevant and redundant information may be driven by both bottom-up and top-down processes (i.e., that it may be the result of implicit or, explicit learning mechanisms, or both), whereas the active selection of relevant information and ignoring of redundant information may be the result of a conscious and voluntary decision to no longer attend to and perceive those structural components of the task that contain redundant information. Additional support for the latter view comes from a new series of experiments (Haider & Frensch, in press), in which it was shown that speed and accuracy instructions affect the rate of information reduction, even when instructions are given halfway through training. In general, the two-phase view is consistent with arguments that have been made in other psychological contexts (e.g., J. J. Gibson & Gibson, 1955; Neisser, 1976; Trabasso & Bower, 1968).

The primary goal of the present set of experiments was to examine the effect of consistency of positioning. For this purpose, participants in a third condition received strings in which the task-relevant information (i.e., the triplet) could randomly occur either at the beginning or the end of the strings.1

1 Another potentially interesting task parameter that could have favored the occurrence of information reduction is the difference in difficulty and perceptual salience between the task-relevant and task-redundant information. Lincourt, Hoyer, and Cerella (1997) equalized the complexity and perceptual salience of the task-relevant information and task-redundant information in the alpha-
EXPERIMENT 1

Experiment 1 consisted of three experimental conditions in which participants evaluated alphabetic strings of the type used by Haider and Frensch (1996). In the fixed relevant-first condition, the task-relevant information (i.e., the letter-digit-letter triplets) was consistently presented at the beginning of the alphabetic strings; in the fixed relevant-last condition, the task-relevant information was consistently presented at the end of the strings; and in the relevant-mixed condition, the task-relevant information randomly occurred either at the beginning or end of the strings. For all participants, the experiment was divided into two phases, a training phase and a transfer phase. The two phases were not distinguishable for participants and differed only in terms of the location at which errors in incorrect strings occurred. Errors in the training phase (i.e., Trial Blocks 1–7) occurred only at the unique digit-letter transition of the string; errors in the transfer phase occurred either inside the triplet or, on some trials, in the formerly redundant letters.

Degree of information reduction was assessed in two ways in all three conditions—first, in terms of the string-length effect for correct strings, which was expected to decline with practice, and, second, in terms of the error rate for incorrect strings with errors outside the triplet. The latter was expected to be higher than the error rate for incorrect strings with errors inside the triplet during the transfer phase. More specifically, the expected findings for Experiment 1 were as follows.

Positioning of Task-Relevant Information

First, if information reduction is unaffected by the positioning of the task-relevant information, then participants in the relevant-first and the relevant-last conditions should show a similarly declining string-length effect for correct strings in the training phase but should differ in terms of their string-length effects for incorrect alphabetic strings. Because of the fixed location of errors in incorrect strings at the last string position, participants in the relevant-last condition should show a declining string-length effect for incorrect strings as well as for correct strings. In contrast, participants in the relevant-first condition should show no string-length effect for incorrect alphabetic strings because in this condition errors occurred always at the third string position. Second, regardless of positioning of task-relevant information, the error rate for incorrect strings with errors outside the triplet (e.g., the transfer phase) should be higher than the error rate for incorrect strings with errors inside the triplet during the transfer phase. Alternatively, if indeed information reduction depends on locating task-relevant information at the beginning of the strings, then the effects described above should be found only for participants in the relevant-first condition.

Consistency of Positioning

Comparing performance in the two fixed positioning conditions with that in the two types of positioning within the relevant-mixed condition makes possible a fair assessment of the influence of consistency of positioning that is unconfounded by potential positioning effects. If consistency of positioning is not a necessary precondition for information reduction, then we should find a similar decline of the string-length effect in the two fixed positioning conditions and the relevant-mixed condition. In addition, the error rate for incorrect strings with errors outside the triplet (the transfer phase) should not differ between conditions. If, on the other hand, information reduction depends on consistency of positioning, then the effects described above should be found only for participants in the two fixed conditions.

Method

Participants

One hundred seven male students at the University of the Armed Forces, Hamburg, Germany, served as participants in the experiment. Participants ranged in age from 20 to 27 years (M = 24.1, SD = 1.96) and received course credit in introductory psychology.

Stimuli and Apparatus

In total, 50 correct and 70 incorrect alphabetic strings were used in the experiment. Correct strings contained a letter-digit-letter triplet (e.g., “E [4] J”) that began with 1 of 10 letters, E, F, G, H, I, J, K, L, M, or N. The 10 possible correct triplets were either followed (relevant-first condition) or preceded (relevant-last condition) or, within each block, followed in half of the trials and preceded in the other half of the trials (relevant-mixed condition) by 0, 1, 2, 3, or 4 additional letters such that the entire string followed the alphabet. The digit in brackets was always equal to 4. In all three experimental conditions, there were thus 5 × 10 = 50 correct letter strings that varied in total length from three to seven symbols.

The construction of 50 of the 70 incorrect letter strings was identical to the construction of the correct letter strings, except that the letter immediately following the digit 4 was the letter that followed the correct one in the alphabet (e.g., “E [4] K” instead of “E [4] J”). In addition, 20 incorrect strings were constructed that contained the error outside the triplet (five errors at each of the four logically possible string positions in the two fixed positioning conditions and two to three errors at each of the eight logically possible positions in the relevant-mixed condition).

Strings were presented at the center of a 17-in. (43.2-cm) diagonal video screen controlled by a PC-AT80386. The letters were approximately 1.0 × 0.8 cm. Consecutive letters appeared approximately 0.8 cm apart on the screen. Response keys were the “<” or the “—” key on the second row from the bottom on a PC-AT keyboard. Half of the participants were instructed to use the “<” key to indicate that a string was correct and the “—” key to indicate that the string was incorrect; for the other half, the key assignment was reversed.
Procedure

Participants were randomly assigned to one of the three experimental conditions, fixed relevant-first, fixed relevant-last, and relevant-mixed, and were tested in groups of up to 3 people in a moderately lit room containing three PC-ATs. The experiment began with computerized instructions. Participants were instructed that their task was to verify alphabetic strings. They were told what constituted a correct string and were shown examples of correct and incorrect strings. Then, a short practice session followed in which participants evaluated 10 strings. For the practice strings, errors in incorrect strings occurred inside as well as outside the letter-digit-letter triplet. If participants made more than three errors on the practice strings, the instructions and practice session were repeated.

When they had successfully completed the practice session, participants received additional instructions and began with the training phase. They were told to pay attention to the entire string because errors could occur anywhere in the string. Both speed and accuracy of responding were stressed. During the training phase, in all conditions the 50 correct and 50 incorrect alphabetic strings were presented seven times each, once in each of seven training blocks.

The transfer phase consisted of a single block of trials and immediately followed the training phase without further instructions. Here, the 50 correct strings, 30 of the 50 incorrect strings of the practice phase and 20 incorrect strings with errors outside the triplet, were presented. The order of strings was randomly determined for each participant in each trial block.

Each trial began with the presentation of a fixation cross at the center of the screen for 500 ms. The disappearance of the fixation cross was followed by the presentation of a string that remained on the screen until a response was made. A 440-Hz tone was sounded for 1,000 ms, and the next fixation cross appeared. When the participants responded incorrectly, an error prompt with a 600-ms duration appeared on the screen and the 440-Hz tone was sounded.

In the transfer phase, only half of the participants in the relevant-first and the relevant-last conditions and all participants in the relevant-mixed condition received error feedback for trials in which errors occurred outside the letter-digit-letter triplet. The remaining participants did not receive feedback.

After every trial block, participants received feedback about their mean response time and their error rate for the preceding trial block and were allowed to take a short break. For all conditions, the summary feedback given for the transfer block included mistakes for incorrect strings with errors outside the triplet. The entire experiment lasted between 90 and 120 min.

Design

Dependent variables were the individual median reaction times (RTs) and the mean error rates per trial block. The only between-subjects factor was triplet position (relevant-first vs. relevant-last vs. relevant-mixed). Within-subjects factors were trial block (1 through 8), string length (3 through 7), string type (correct vs. incorrect), and error type (inside vs. outside triplet).

Results

For each participant and each trial block, mean error rates were computed first to ensure that only participants with reasonable error rates in the training were entered in the data analysis. Two participants showed error rates higher than 10% in each training block (the a priori criterion for excluding participants) and were excluded from further data analyses. There were 45 participants in the relevant-first condition, 38 participants in the relevant-last condition, and 22 participants in the relevant-mixed condition. Mean error rates per trial block were generally low (Ms = 3.5%, 3.8%, and 3.4% in the relevant-first, the relevant-last, and the relevant-mixed conditions, respectively). For all participants, median RTs for correct responses to correct and incorrect strings were computed separately for each trial block and each string length.

In all analyses reported here and in Experiment 2, the adopted significance level was .05. For significant effects, individual probability values are not reported.

The discussion of the main results is divided into two sections. First, we describe the overall learning effects in the training phase of the experiment. Second, we discuss the findings obtained for the transfer phase.

Training Phase

Overall RTs

Figure 1A (fixed relevant-first vs. fixed relevant-last conditions) and Figure 1B (relevant-first vs. relevant-last strings of the relevant-mixed condition) display the mean RTs per trial block for correct and incorrect strings as a function of triplet position.2 As can be seen from Figure 1A, the two fixed triplet conditions showed very similar RT declines over training. A closer look reveals that the difference between correct and incorrect strings differed for these two conditions, at least for the first few trial blocks. Specifically, in the relevant-first condition, incorrect strings were initially verified more quickly than correct strings. In contrast, in the relevant-last condition, correct strings were initially verified more quickly than incorrect strings. The differences between correct and incorrect strings gradually disappeared, however, in both conditions. Moreover, comparison of Figures 1A and 1B shows that the relevant-mixed condition produced longer latencies for both relevant-first and relevant-last strings than the two fixed position conditions.

To examine the effect of positioning of the task-relevant information and of consistency of positioning on overall RTs, we computed a 2 (triplet position: relevant-first vs. relevant-last) × 7 (training block: 1–7) × 2 (string type: correct vs. incorrect strings) mixed-design analysis of variance (ANOVA) and two separate 2 (consistency: fixed relevant-first vs. mixed relevant-first and fixed relevant-last vs. mixed relevant-last) × 7 (training block: 1–7) × 2 (string type: correct vs. incorrect strings) mixed-design ANOVAs.

Positioning of task-relevant information. The fixed positioning ANOVA yielded significant main effects of training block, \( F(6, 486) = 218.3, MSE = 703,404 \), and of string type, \( F(1, 81) = 5.33, MSE = 132,290 \). In addition, the interaction between triplet position and string type, \( F(1, 81) = \)

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2 The confidence intervals shown here and in subsequent figures were constructed separately for each experimental group (Loftus & Masson, 1994).
Figure 1. Mean RTs (reaction times) for correct and incorrect strings in Experiment 1 (A: fixed conditions; B: mixed conditions). The error bars represent 95% within-subject confidence intervals as defined by Loftus and Masson, 1994.

28.43, MSE = 132,290, and the interaction between practice block and string type, F(6, 486) = 4.88, MSE = 33,488, were significant, as was the three-way interaction, F(6, 486) = 4.26, MSE = 33,488. At present, we do not have a reasonable explanation for the puzzling three-way interaction but interpret the overall results of this initial analysis as demonstrating few clear-cut differences between the two fixed triplet position conditions.

Consistency of positioning. Both the relevant-first string and the relevant-last string ANOVAs revealed significant main effects of consistency, F(1, 65) = 10.46, MSE = 9,759,054, and F(1, 58) = 7.71, MSE = 12,559,836, for the two relevant-first and the two relevant-last conditions, respectively, and of practice block, F(6, 390) = 134.8, MSE = 742,662, and F(1, 58) = 116.99, MSE = 762,427, for the two relevant-first and the two relevant-last conditions, respectively. In addition, the relevant-first string ANOVA yielded an additional significant interaction between practice block and string type, F(6, 390) = 10.1, MSE = 41,107. In contrast, the relevant-last string ANOVA revealed a significant main effect of string type, F(1, 58) = 5.97, MSE = 136,463, as well as significant interactions between consistency and string type, F(1, 58) = 14.01, MSE = 136,463; between practice block and string type, F(6, 348) = 4.57, MSE = 44,104; and between consistency, string type, and practice block, F(6, 348) = 2.21, MSE = 44,104. Thus, consistency of positioning affected the overall latencies in that varying the triplet position slowed down participants' verification times. More important, neither the two relevant-first conditions nor the two relevant-last conditions differed substantially with regard to their practice-related decline of overall latencies, indicating that consistency of positioning appears to have had, at best, minor effects on learning rate.

String-Length Effect

In order to capture the effects of the string-length manipulation, we computed the slopes of the best fitting linear regression lines across the five string lengths separately for each participant in each trial block (see Haider & Frensch, 1996).

Positioning of task-relevant information. As mentioned above, if the positioning of the task-relevant information does not affect information reduction, then the mean slopes for correct strings should not differ between the fixed relevant-first and the fixed relevant-last conditions. In addition, in the fixed relevant-last condition, the mean slopes for incorrect strings should be similar to the slopes for correct strings; in the fixed relevant-first condition, however, they...
should be flatter and, ideally, should not change with practice. The reason for this expected difference is that participants in the fixed relevant-first condition, for whom errors always occurred at String Position 3, should stop their processing of the incorrect strings as soon as they discover the errors. Therefore, a string-length effect should not develop in this condition. For participants in the fixed relevant-last condition, in contrast, errors in incorrect strings occurred at the very last string position. Thus, early in training, the entire string had to be processed regardless of whether the string turned out to be correct or incorrect. Consequently, a string-length effect should be observed in this condition early in practice but then should disappear, because participants should increasingly be able to distinguish task-relevant from task-redundant information.

Figure 2A displays the average slopes for correct and incorrect strings over the seven training blocks for the fixed relevant-first and the fixed relevant-last conditions. With the exception of the first training block, the general pattern of results depicted in Figure 2A fits the predictions outlined above. As can be seen, three of the four functions for the two fixed-position conditions were very similar to each other and show a decline over practice; the fourth function (i.e., incorrect strings in the fixed relevant-first condition) was comparatively less affected by practice. As can be seen from Figure 2B, the slopes of the relevant-first and the relevant-last strings in the relevant-mixed condition also declined with training (again, with the exception of the first training block). This decline, however, was somewhat flatter than that observed for the two fixed positioning conditions. In addition, the effect of positioning of task-relevant information on the difference between correct and incorrect strings was less pronounced than for the two fixed positioning conditions. Because three of the four conditions showed unexpectedly flat slopes in the first training block, this block was excluded from all following analyses.

The effect of positioning of the task-relevant information on information reduction was assessed by a 2 (triplet position: fixed relevant-first vs. fixed relevant-last) X 6 (training block) X 2 (string type) mixed-design ANOVA on participants' slope values. This ANOVA yielded significant main effects of triplet position, $F(1, 81) = 9.87, MSE = 36,057.7$; training block, $F(5, 405) = 27.5, MSE = 9,278.2$; and string type, $F(1, 81) = 21.75, MSE = 11,327.5$. In addition, the interactions between triplet position and string type, $F(1, 81) = 7.93, MSE = 11,327.5$, and between training block and string type, $F(5, 405) = 4.79, MSE =$

![Figure 2A](image1.png)

![Figure 2B](image2.png)

*Figure 2.* Means of best fitting regression slopes for correct and incorrect strings in Experiment 1 (A: fixed conditions; B: mixed conditions). The error bars represent 95% within-subject confidence intervals as defined by Loftus and Masson, 1994.
To more cleanly assess the effect of the task-relevant information on information reduction, we computed a Linear × Linear Interaction contrast between triplet position and training block for correct strings only. This analysis yielded no significant effect, $F(1, 81) = 2.61, \text{MSE} = 9,984, p = .11$, indicating that positioning had only a negligible effect on the decline of the slopes for correct strings.

On the whole, the pattern of results from the two fixed positioning conditions is consistent with the assumption that the positioning of the triplets itself had little effect on information reduction. Participants in the fixed relevant-first and the fixed relevant-last conditions showed similar declines of the string-length effect over practice for correct strings but differed with regard to their performance on incorrect strings, $F(1, 81) = 15.91, \text{MSE} = 26,476$, indicating that task processing of the incorrect strings was affected by error position. If errors occurred at String Position 3, as was the case in the relevant-first condition, participants were able to stop processing of the incorrect strings as soon as they discovered the errors. If, in contrast, errors occurred at the very last position of the strings, as was the case in the relevant-last condition, the entire string had to be processed until participants were able to distinguish relevant from redundant task information. Therefore, the string-length effect should not develop in the relevant-first condition and should have declined in the relevant-last condition, which is exactly what was observed.

Consistency of positioning. To assess the effect of consistency of positioning on degree of information reduction, we conducted two separate 2 (consistency; fixed relevant-first vs. mixed relevant-first and fixed relevant-last vs. mixed relevant-last) × 6 (training block) × 2 (string type) mixed-design ANOVAs on participants’ slope values. The relevant-first ANOVA revealed that error rates for strings with errors inside the triplet were smaller than in the two fixed positioning conditions, $F(1, 65) = 23.57, \text{MSE} = 21,250.1$; of practice block, $F(5, 325) = 16.37, \text{MSE} = 9,082.7$; and of string type, $F(1, 65) = 26.01, \text{MSE} = 21,552.4$. In addition, the interaction between practice block and string type was significant, $F(6, 325) = 6.41, \text{MSE} = 8,736.9$ (all other $p > .1$). The relevant-last ANOVA revealed that error rates for strings with errors inside the triplet were significantly higher than the error rate for incorrect strings with errors inside the triplet. Table 1 shows, first, that error rates for strings with errors inside the triplet did not differ between conditions.

Second, and more important, in all conditions the error rate for strings with errors outside the triplet was significantly higher than the error rate for strings with errors inside the triplet, although this difference was affected by feedback. Third, although positioning of task-relevant information itself did not affect error rates, neither with nor without feedback, consistency of positioning did. Error rates in the relevant-mixed condition were smaller than in the two fixed positioning conditions with feedback, particularly for relevant-last strings.

The discussion of the main results from the transfer phase is divided into two sections. First, the effect of errors in the formerly redundant letters on overall error rates is reported. Second, we discuss the correlation between error rate and string-length effect.

Whereas all participants in the mixed-relevant condition and about half of the participants in the two fixed positioning conditions (23 participants in the relevant-first and 15 participants in the relevant-last conditions) consistently received error feedback in the transfer phase, the remaining half of the participants in the two fixed-relevant conditions did not receive error feedback when they erroneously accepted a string with an error outside the triplet as correct. The omission of error feedback in the transfer block was deliberately because we were concerned that error feedback might artificially reduce the theoretically important error rate.

Overall Error Rate

Table 1 contains the mean error rates for the last training block and the transfer block for the two error types (errors occurring inside vs. outside the triplet). The error rates are reported separately for the three feedback conditions (relevant-first, relevant-last, and mixed-relevant) and the two no-feedback conditions (fixed relevant-first and fixed relevant-last). As argued above, occurrence of information reduction can be inferred if the error rate for incorrect strings with errors outside the triplet is higher than the error rate for incorrect strings with errors inside the triplet. Table 1 shows, first, that error rates for strings with errors inside the triplet did not differ between conditions.

Second, and more important, in all conditions the error rate for strings with errors outside the triplet was significantly higher than the error rate for strings with errors inside the triplet, although this difference was affected by feedback. Third, although positioning of task-relevant information itself did not affect error rates, neither with nor without feedback, consistency of positioning did. Error rates in the relevant-mixed condition were smaller than in the two fixed positioning conditions with feedback, particularly for relevant-last strings.

Table 1

<table>
<thead>
<tr>
<th>Condition</th>
<th>Last training block (inside triplet)</th>
<th>Transfer block (inside triplet)</th>
<th>Transfer block (outside triplet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevant-first/feedback</td>
<td>2.56</td>
<td>2.93</td>
<td>28.91</td>
</tr>
<tr>
<td>Relevant-last/feedback</td>
<td>2.73</td>
<td>3.31</td>
<td>36.00</td>
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<tr>
<td>Mixed-first/feedback</td>
<td>2.91</td>
<td>3.07</td>
<td>28.64</td>
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<tr>
<td>Mixed-last/feedback</td>
<td>3.09</td>
<td>3.18</td>
<td>15.00</td>
</tr>
<tr>
<td>Relevant-first/no feedback</td>
<td>2.59</td>
<td>3.01</td>
<td>63.86</td>
</tr>
<tr>
<td>Relevant-last/no feedback</td>
<td>2.96</td>
<td>2.45</td>
<td>57.39</td>
</tr>
</tbody>
</table>
Two 2 (consistency: fixed relevant-first vs. mixed relevant-first and fixed relevant-last vs. mixed relevant-last; all conditions with feedback) × 3 (type of error: inside-triplet/last-training-block vs. inside-triplet/transfer-block vs. outside-triplet/transfer-block) mixed-design ANOVAs were computed separately. The relevant-first ANOVA yielded a reliable main effect only of error type, \(F(2, 86) = 61.3, \text{MSE} = 164.19\). The relevant-last ANOVA, however, revealed reliable main effects of consistency, \(F(1, 35) = 5.44, \text{MSE} = 235.64\), and of error type, \(F(2, 70) = 28.23, \text{MSE} = 211.82\), as well as a significant interaction between consistency and error type, \(F(2, 70) = 6.26, \text{MSE} = 211.82\).

A third 2 (triplet position: relevant-first vs. relevant-last; both conditions without feedback) × 3 (type of error) mixed-design ANOVA on participants' error rates revealed a significant main effect only of type of error, \(F(2, 86) = 80.17, \text{MSE} = 626.40\). Neither the main effect of triplet position nor the two-way interaction was significant in this analysis.

Taken together, the error rate data support the results obtained above with overall RTs and the string-length effect, namely, that consistency of positioning reduces degree of information reduction.

**Error Rate Distribution for Errors Outside Triplets**

The fact that half of the participants in the fixed relevant-first and the fixed relevant-last conditions received no feedback in the transfer block allows for an additional analysis, the correlation between error rates for strings with errors outside the triplet and the magnitude of the string-length effect for correct strings. If indeed the error rate for strings with errors outside the triplet and the magnitude of the string-length effect are both measures of information reduction, as we have argued previously (Haider & Frensch, 1996), then the two measures ought to be correlated.

Figure 3 relates the string-length effect for correct strings (averaged over the two last blocks of the training phase) to the error rate in the transfer phase. As can be seen, the relation between string-length effect and error rate was significant in both conditions, \(r(22) = -0.49\) and \(r(23) = -0.73\) for the relevant-first and the relevant-last conditions, respectively.

Nevertheless, the results were, at first glance at least, quite surprising. First, the error rate frequency distributions were quite different for the two experimental conditions. Specifically, participants in the relevant-last condition could be divided into two groups. Of the 23 participants in this condition, 10 committed a maximum of 10% errors on incorrect strings with errors in the redundant string part and showed virtually no string-length effect by the end of the training phase. Twelve participants committed a minimum of 95% errors on the same strings and exhibited rather large string-length effects by the end of training. The error rate for 1 participant lay in between the two peaks of the distribution.

Participants in the relevant-last condition thus behaved in one of two ways: First, information reducers \((n = 12)\) recognized the relevant and redundant task information with task practice and, consequently, selected the relevant information for processing and ignored the redundant information altogether. Second, nonreducers \((n = 10)\), in contrast, processed rather consistently the entire task information throughout the experiment.

By comparison, in the relevant-first condition, the relation between string-length effect and error rate was relatively linear, but the distribution of error rate was much more

![Figure 3](image-url)
continuous. As Figure 3 shows, the extreme upper end of the error rate distribution (i.e., 100%) was oversampled relative to the remainder of the distribution. That is, there were 9 participants with error rates of 100% who, for the most part, exhibited relatively small string-length effects. In addition, the lower end of the distribution was undersampled relative to the relevant-last condition.

Participants in the relevant-first condition thus behaved in one of three different ways. First, some participants were information reducers (those participants who showed error rates close to 100%; \( n = 9 \)). Second, some were nonreducers (those who showed error rates close to 0%; \( n = 3 \)). Third, some were mixed reducers (\( n = 10 \)), who initially ignored redundant information but who at some time during the transfer phase began noticing the errors in the formerly redundant task component. Once noticed, the formerly redundant information was no longer ignored. Eight of the 10 participants in this group behaved in this way, if one takes the rather crude measure of correctly identifying three consecutive errors in the formerly redundant task component as a measure of when participants first noticed that the redundant information had become relevant. The 2 remaining participants behaved erratically; for a while, they performed as if they knew that the information outside of the triplets was relevant, but then they returned to ignoring this information nevertheless.

Discussion

Experiment 1 produced three main results regarding the question of generalizability of previously obtained findings on information reduction (Haider & Frensch, 1996). First, varying the positioning of task-relevant information (i.e., the letter-digit-letter triplet) within the strings between subjects had little effect on overall response times, the initial magnitude of the string-length effect, and the overall likelihood of participants’ making mistakes when errors in the formerly redundant task part were suddenly introduced.

Second, varying the positioning of task-relevant information within subjects appears to reduce information reduction. The results obtained for the relevant-mixed condition suggest that manipulating positioning of task-relevant information within blocks reduced the decline of slopes over practice and the overall likelihood of errors on strings with errors outside the triplet relative to the two “pure” conditions. Nevertheless, and worth noting, information reduction still operates under mixed positioning conditions. In six additional single-case studies, we trained participants over 30 practice blocks (Haider & Frensch, 1997). Three of these participants received consistently relevant-last strings, and 3 received either relevant-first or relevant-last strings (randomly varied from trial to trial). The results confirmed that information reduction occurs with both consistent and mixed positioning of task-relevant information, although it was again reduced in the mixed positioning condition.

Third, the distribution of errors for new incorrect strings in the transfer phase differed for the relevant-first and the relevant-last conditions. The main difference between the error distributions for the two conditions lies in the finding that, in the transfer phase, a substantial number of participants in the relevant-first condition, but only 1 participant in the relevant-last condition, initially ignored redundant information but eventually came to process it. There are several possible reasons for this finding. For example, the difference between the relevant-first and the relevant-last conditions might have been due to overlearned left-to-right reading habits, making it very difficult for participants in the relevant-first condition to abruptly stop their processing of the strings once the relevant task component had been processed. This difficulty might not have existed in the relevant-last condition because there the relevant task information was located at the end of the strings, and right-to-left movement of eye fixations might have required extra effort.

Whatever the reason for this difference in error pattern, the results of Experiment 1 give very little support to the assumption that the positioning of the task-relevant information at the beginning of the strings might be necessary for inducing information reduction. Indeed, with the exception of the error distributions, there were no hints in our data indicating that positioning itself had any effect on information reduction.

EXPERIMENT 2

The main issue addressed in Experiment 2 was whether information reduction operates at a perceptual or later conceptual level. According to the information-reduction hypothesis (Haider & Frensch, 1996), redundant information, once identified, is no longer perceived and consequently is not processed any longer at any level of the cognitive system. However, there exist no data as of yet that would refute the alternative argument, namely, that information recognized as redundant continues to be perceived but is ignored at a later processing stage.

The main focus of Experiment 2, therefore, was on participants’ eye fixations while they were performing the alphabet evaluation task. More specifically, the emphasis was on the frequency and duration of participants’ eye fixations on both the task-relevant and task-redundant information. If redundant information, once identified, is no longer perceived, then we should find that participants’ eye fixation frequencies show a clear decrease for the redundant positions of the strings with increasing practice. Alternatively, if redundant information is ignored at a later stage of processing, then participants’ eye fixation frequencies should not show a decline for redundant string positions, although fixation durations might well show such an effect.

Experiment 2 was essentially a replication of the two fixed positioning conditions used in Experiment 1. Participants in the relevant-first condition received strings in which the relevant letter–digit–letter triplet was positioned consistently at the beginning of the strings (i.e., String Positions 1–3). Participants in the relevant-last condition evaluated strings in which the relevant information always occurred at the end of the strings. In contrast to Experiment 1, no transfer block was given in Experiment 2.

Consistent with our finding little support for the effects of positioning on information reduction in Experiment 1, we
expected the string-length effect, as our main measure of information reduction in Experiment 2, to be predicted by the number of times with which participants fixated the redundant task components. Participants showing small string-length effects should fixate the task-redundant component less often than participants showing large string-length effects, irrespective of triplet position. In contrast, we expected the string-length effect to be less well predicted by the duration of the eye fixations.

Method

Participants

Participants were 16 male and 14 female students at the University of Göttingen, Germany, who were paid DM 20 ($12) for participating in the experiment. The participants ranged in age from 19 to 37 years (M = 24.2, SD = 4.69). All participants had normal or corrected-to-normal vision. Because of technical problems concerning the calibration of eye movements, the data from 2 participants had to be discarded.

Materials

Apparatus

A projection screen (70 × 45 cm) was placed about 1.5 m in front of the participants. Presentation of strings was controlled by a Power Macintosh computer. Participants' responses and response times were assessed and stored by the Power-Mac. Eye movements were monitored by a DEMEL-Recorder (Debic 84) and recorded on a PC-AT80386 that was attached to the Power-Mac. The DEMEL-Recorder generated 50 samples per second.

Stimulus Materials

Thirty correct and 30 incorrect alphabetic strings were used. As in Experiment 1, these strings were composed by 10 different correct and 10 different incorrect letter-digit-letter triplets and were either followed (relevant-first condition) or preceded (relevant-last condition) by 0, 2, or 4 additional letters.

Strings were displayed at the center of the screen. Letters were approximately 2.8 cm in length and 3.8 cm in height. Consecutive letters appeared approximately 6 cm apart. The horizontal visual angle between two consecutive letters was equal to 3°. Participants responded by pressing either the left or right key on an external keypad with two keys. Half of the participants were instructed to use the right key to indicate that a string was correct and the left key to indicate that the string was incorrect; for the other half, the key assignment was reversed.

Procedure

Participants were randomly assigned to one of the two experimental conditions, relevant-first and relevant-last, and were individually tested in a dimly lit room that contained the video screen. Each participant was seated in a movable reclining chair with a headrest. The headrest was adjusted for each participant in order to reduce head movements.

The experimental session began with computerized instructions followed by a short practice session (see Experiment 1). After participants successfully completed this part of the experiment, their eye fixations were calibrated at 20 points of the screen determining the upper, lower, left, and right boundaries of the screen. During the entire experimental session, the calibration of participants' eye fixations was observed on-line by a trained experimenter. If accuracy of calibration fell below a prespecified threshold, participants' eye fixations were recalibrated. This occurred only two times during the entire experiment, once for each of 2 participants.

After calibration, the training phase began. The training phase contained 240 correct and 240 incorrect alphabetic strings that were equally divided into eight blocks of 60 strings each. In each of the training blocks, the 30 correct and 30 incorrect strings were presented once, randomly ordered for each participant in each training block. Eye movements were registered from the appearance of the letter string until the response was given.

After every trial block, participants were given feedback about how well they were doing in terms of their mean response time and their error rate for the preceding trial block and were allowed to take a short break. The entire experiment lasted between 60 and 90 min.

Design

As in Experiment 1, the main dependent variables were the median response time per trial block and the mean error rate per trial block. Concerning the eye movements, the main dependent variables were the mean number and mean duration of fixations on the relevant and redundant string positions. There were four independent variables, triplet position (relevant-first vs. relevant-last; between-subjects), string type (correct vs. incorrect strings; within-subjects), trial block (1–8; within-subjects), and string length (3, 5, 7; within-subjects).

Preliminary Data Analysis of Eye Movements

The coordinates of all stored eye fixations were first transformed into video screen positions. Then, absolute eye fixation screen positions were converted to string positions. Figure 4 summarizes the assignment of absolute screen positions to string letters. The unit of analysis was defined as fixations that fell into one of the seven position categories and had a minimum duration of 80 ms (cf. Rayner, Slowiaczek, Clifton, & Bertera, 1983).

Results

As in Experiment 1, a first check ensured that only participants with reasonable error rates were entered in the data analysis. Therefore, mean error rates were computed for

3 Letter boundaries were constructed such that they were not exactly in between adjacent letters. The reason for this was that a pilot study had shown that after training, participants did not fixate the letters themselves any longer but rather the space between adjacent letters.

Figure 4. Assignment of absolute eye-fixation screen positions to string letters in Experiment 2.
each participant and each trial block. No participant showed consistently high error rates (higher than 10% errors in each training block). Mean error rates per training block were 4.7% and 4.8% in the two experimental conditions, relevant-first and relevant-last, respectively. There were 12 participants in the relevant-first condition and 16 participants in the relevant-last condition. For all participants, median RTs for correct responses to correct and incorrect strings were computed separately for each trial block and each string length.

The discussion of the results is divided into two main sections. First, we describe the results of the string-length effect analysis. Then, we report the results of the eye-fixation analysis.

**String-Length Effect**

As in Experiment 1, the slopes of the best fitting regression lines across the three string lengths were computed for each participant and each trial block. Figure 5 displays the average slopes in the two triplet position conditions for correct and incorrect strings over the eight training blocks. As can be seen in the figure, the results closely replicated those reported for the two fixed positioning conditions of Experiment 1 (cf. Figure 2). Three of the four slopes were very similar to each other and declined with training. The fourth slope, for incorrect strings in the relevant-first condition, was considerably smaller than the remaining ones and was relatively unaffected by practice.

A 2 (triplet position) × 8 (training block) × 2 (string type) mixed-design ANOVA on participants' slope values yielded significant main effects of triplet position, $F(1, 26) = 11.01$, $MSE = 72,864.76$; training block, $F(7, 182) = 6.29$, $MSE = 15,888.5$; and string type, $F(1, 26) = 10.77$, $MSE = 20,287.48$. In addition, the interaction between triplet position and string type was significant, $F(1, 26) = 10.01$, $MSE = 20,287.48$. Because of the relatively small sample size in Experiment 2, the three-way interaction was not significant. Nevertheless, the pattern of results depicted in Figure 5 was sufficiently similar to the pattern depicted in Figure 2 to indicate replication of the findings obtained in Experiment 1.

**Eye-Fixation Analyses**

**Training Effects: Eye-Fixation Frequency**

Figures 6A and 6B display the frequency of eye fixations on the relevant and redundant string components across the eight blocks of training in the two experimental conditions, separately for correct (Figure 6A) and incorrect (Figure 6B) strings. The data are averaged over string length and exclude incorrect responses. As stated above, fixations were counted only if they (a) fell into one of the seven position categories displayed in Figure 4 and (b) had a minimum duration of 80 ms. As can be seen, the patterns of results were very similar for correct and incorrect strings. The main finding conveyed by the two figures is that the fixation frequencies for the relevant-last condition showed the exact pattern we had expected. That is, the fixation frequencies were initially identical for task-relevant and task-redundant information, but with increasing training participants fixated the redundant information less frequently than the relevant information. The pattern in the relevant-first condition was less clear. Here, the fixation frequencies differed markedly for the first block of training already, and the decline over training was roughly parallel for task-relevant and task-redundant information.

A 2 (triplet position) × 2 (relevance: relevant vs. redundant) × 8 (training block) × 2 (string type: correct vs. incorrect strings) mixed-design ANOVA on participants' eye-fixation frequencies yielded results consistent with the impressions conveyed by Figures 6A and 6B. The main effects of training block, $F(7, 182) = 39.64$, $MSE = 0.11$; of relevance, $F(1, 26) = 50.54$, $MSE = 0.797$; and of string type, $F(1, 26) = 25.46$, $MSE = 0.04$, were all significant, as were the interactions between triplet position and relevance, $F(1, 26) = 13.8$, $MSE = 0.797$; between triplet position and string type, $F(1, 26) = 29.82$, $MSE = 0.04$; and between...
Figure 6. Means of eye-fixation frequencies for relevant (triplet) and redundant (letters) task components for correct strings (A) and for incorrect strings (B) in Experiment 2. The error bars represent 95% within-subject confidence intervals as defined by Loftus and Masson, 1994.

relevance and string type, $F(1, 26) = 60.94, MSE = 0.03$. In addition, the three-way interactions between triplet position, relevance, and string type, $F(1, 26) = 36.38, MSE = 0.03$, and between triplet position, training block, and relevance, $F(7, 182) = 6.96, MSE = 0.064$, were significant.

Separate follow-up analyses for the relevant-first and the relevant-last condition indicated significant interactions between relevance and training block in both the relevant-first, $F(7, 77) = 4.57, MSE = 0.061$, and the relevant-last condition, $F(7, 105) = 3.28, MSE = 0.067$. However, as can be seen in Figures 6A and 6B, the pattern of results underlying the significant interactions differed for the two conditions. In the relevant-last condition, the interaction was due to a steeper decline of the fixation frequencies for task-redundant than task-relevant information; in contrast, the interaction in the relevant-first condition was due to a steeper decline of the fixation frequencies for task-relevant information.

There are at least two different possible explanations for our not finding the pattern of results we had expected in the relevant-first condition. First, it is conceivable that the mechanisms underlying information reduction are different in the two triplet position conditions. For example, it might be that participants in the relevant-first condition, due to overlearned left-to-right reading habits, found it difficult to not fixate the redundant task information at all and instead tried to minimize the amount of time spent looking at the redundant letters. If this is the case, then the analysis of eye fixation durations presented below should reveal this.

Second, it also seems plausible that the pattern underlying the interaction between relevance and training block in the relevant-first condition might have been caused by a floor effect for eye fixations on task-redundant information. Given that the fixation frequency on task-redundant information in that condition was very low in the first training block already, there simply was not much room left for a decline.

Concerning the latter, the floor-effect argument, the two experimental conditions were divided, by means of a median split, into those showing large (nonreducers) and those showing small string-length effects (reducers) by the end of the training phase (Block 8). Figures 7A and 7B display the mean fixation frequencies on the redundant and the relevant task component for reducers and nonreducers in the relevant-first (Figure 7A) and relevant-last (Figure 7B) conditions (correct alphabetic strings only). As can be seen, the data presented are indeed consistent with this argument.
In the relevant-first condition, the fixation frequencies for relevant information (i.e., the triplet) were very similar for reducers and nonreducers. The fixation frequencies for redundant information, in contrast, diverged for reducers and nonreducers, beginning with Block 4. Put differently, the difference between fixating relevant and fixating redundant task information was more pronounced for reducers by the end of the training phase than for nonreducers.

Similarly, and as shown in Figure 7B, in the relevant-last condition, nonreducers showed basically no difference for eye fixations on task-redundant and task-relevant information; reducers, however, did. Taken together, these findings suggest that the reason for our not finding the expected pattern of results in the relevant-first condition might indeed have been a floor effect in that condition.

**Training Effects: Eye-Fixation Duration**

Figures 8A and 8B display the mean duration of eye fixations on the relevant and redundant task components across the eight blocks of training in the two experimental conditions, separately for correct (Figure 8A) and incorrect (Figure 8B) alphabetic strings. The mean fixation durations shown are the averages of the individual duration means, which, in turn, were based on fixations to the seven categories shown in Figure 4 lasting at least 80 ms. It is important to note that the mean durations were computed on the basis of eye fixations; they were thus not affected by fixation frequency. The data are averaged over string length and exclude incorrect responses, and again the patterns of results were essentially identical for correct (Figure 8A) and incorrect (Figure 8B) strings.

Three aspects of Figures 8A and 8B are important. First, in both conditions the mean duration of eye fixations for task-redundant information was much shorter than the mean duration for task-relevant information. Second, the mean duration for task-relevant information was longer in the relevant-last than the relevant-first condition. Third, and most important, in both conditions training did not decrease the eye fixation durations more for redundant than for relevant task information.

A 2 (triplet position) × 2 (string type: correct vs. incorrect strings) × 8 (training block) × 2 (relevance: relevant vs. redundant) mixed-design ANOVA on participants’ fixation durations yielded significant main effects of training block, \( F(7, 182) = 33.05, MSE = 15,083.8 \); of relevance, \( F(1, 26) = 75.27, MSE = 244,018.2 \); and of string type, \( F(1, 26) = 5.82, MSE = 10,546.9 \). Furthermore, the interactions between triplet position and relevance, \( F(1, 26) = 6.24, MSE = 15,083.8 \).
**Figure 8.** Means of eye-fixation durations for relevant (triplet) and redundant (letters) task components for correct strings (A) and for incorrect strings (B) in Experiment 2. The error bars represent 95% within-subject confidence intervals as defined by Loftus and Masson, 1994.

\[MSE = 244,018.2; \text{ between training block and relevance, } F(7, 182) = 8.1, MSE = 10,875; \text{ and between relevance and string type, } F(1, 26) = 4.86, MSE = 3,248, \text{ were significant, as was the three-way interaction, } F(1, 26) = 12.96, MSE = 3,248.\]

The findings conveyed by Figures 8A and 8B point to the following interpretation. First, the mean duration for task-relevant information might have been consistently longer than for task-redundant information because of a difference in complexity for the two types of information. It was simply more demanding to process the triplet than the additional letter strings. Second, the shorter duration of triplets in the relevant-first condition is consistent with the higher fixation frequency found for this condition and points to a possible strategy difference between the relevant-first and relevant-last conditions mentioned above. Third, and most important, there was no evidence in support of the view that eye-fixation durations decline differentially with training for task-relevant and task-redundant information.

**Predicting the Magnitude of the String-Length Effect**

Of primary importance in Experiment 2 was the prediction of participants’ string-length effects on the basis of their eye-fixation frequencies and durations for task-relevant and task-redundant information. Figures 7A and 7B, of course, demonstrate already that the fixation frequency for task-redundant information was related to the magnitude of the string-length effect. To address this issue more directly, we fitted two separate multiple regression models to the data from the relevant-first and the relevant-last condition (correct and incorrect alphabetic strings were both included). Predictors in both models were participants’ mean eye-fixation frequencies for task-relevant and task-redundant information (averaged over Blocks 7 and 8) and their mean fixation durations for task-relevant and task-redundant information, also averaged over Blocks 7 and 8. The dependent variable was participants’ mean string-length effect (averaged over Blocks 7 and 8), expressed as the slope of the individual best fitting linear regression across the three string lengths. The results of the two analyses are summarized in Table 2.

As can be seen in the table, the string-length effect was, in both conditions, significantly predicted by participants’ eye-fixation frequencies on task-redundant information. The direction of the beta weights was as one would expect. That is, the lesser the frequency with which participants fixated the task-redundant information, the smaller were their string-length effects. In the relevant-last condition, a second
were again divided, by means of a median split, into those
position. What Figures 9A and 9B each trial fixated the first, second, third, and so forth string
9A (correct strings) and 9B (incorrect strings). These figures
display the mean of first-gaze frequencies across the seven
figures display how many times participants' first gaze on
participants' string-length effect was driven mainly by their
result of the regression analyses is consistent with the findings for
relevant-first condition, is impressively underscored by Figures
Participants in each of the two experimental conditions
were again divided, by means of a median split, into those
show is a clear shift in the preferred first-gaze position for
participants in the relevant-last condition for early to late
in training, but only for reducers. These participants initially
fixated the beginning of the strings but by the end of the
training phase had come to fixate primarily the end of the
sequence, that is, the task-relevant information. Nonreducers
in the same experimental condition did not show such a
shift. In addition, participants in the relevant-first condition
did not show such an effect either, as indeed they should not
have. This finding underscores the interpretation that small
string-length effects reflect the perceptual ignoring of task-
redundant information rather than the inhibition of processing
task-redundant information at a later cognitive processing

Discussion

The main goal of Experiment 2 was to assess whether
information, once identified as redundant, is ignored at the
perceptual level or is "suppressed" at a later processing
stage. The most important conclusion suggested by the
results of Experiment 2 is that task-redundant information
appears to be ignored at the perceptual level. This conclu-
sion is most impressively demonstrated by the findings for
the relevant-last condition in which participants seem to
initially have processed the task information in a strictly
serial manner, moving from the first to the last string
position. After practice, they behaved in complete accor-
dance with the information-reduction view, and, as in
Experiment 1, neatly fell into one of two categories.
Participants showing small string-length effects by the end
of the training phase did not fixate task-redundant informa-
tion any longer; instead, they concentrated exclusively on
the task-relevant information. Participants who still showed
large string-length effects by the end of the training phase, in
contrast, fixated task-relevant and task-redundant informa-
tion proportionally to exactly the same extent as they did at
the beginning of training.

The conclusion that task-redundant information is ignored
at the perceptual level is somewhat less well supported for
the relevant-first condition. Participants in the relevant-first
condition, although they clearly "noticed" the task-
redundant information at some level, did not show the
expected Relevance \times Training Block pattern for fixation
frequencies overall, although the interaction became visible
when information reducers and nonreducers were separated.
We have argued that the weaker pattern in this condition
might have been due to a floor effect that, in turn, might have
been caused by the influence of highly overlearned left-to-
right reading habits on participants' behavior in the alphabet
verification task.

**GENERAL DISCUSSION**

Haider and Frensch (1996) argued that practice-related
changes in the speed and quality of task performance are
partially due to a reduction in the amount of information that
is processed. The information-reduction hypothesis holds
that participants learn, with practice, to distinguish between

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<tr>
<td><strong>Results of Regression Analyses Predicting Individual String-Length Effect</strong></td>
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<tr>
<td>Condition</td>
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<td>Gaze frequency</td>
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<td>Triplet</td>
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<td>Gaze duration</td>
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<td>Accumulated eye-fixation durations</td>
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*Note. Numbers are standardized regression coefficients. *p < .05.
task-relevant and task-redundant information and to limit their processing to task-relevant information. The present experiments address two issues raised by previous research: (a) the generalizability of the original findings and (b) the question of whether task-redundant information is ignored at a perceptual or conceptual level of processing.

Taken together, the results from Experiment 1 indicate that the positioning of the task-relevant information within the alphabetic strings evaluated by participants in the Haider and Frensch (1996) task does not affect information reduction. In addition, inconsistency of positioning appears to slow down, but does not completely eliminate, the process of information reduction. Thus, the findings reported earlier by Haider and Frensch can be said to be, to some extent, general effects that do not depend on the specifics of the task as it was used earlier.

In addition, and perhaps more important, the findings of Experiment 2 indicate that task-redundant information ap-
pears to be ignored at the perceptual level. These findings do not necessarily imply, of course, that task-redundant information is exclusively ignored at the perceptual level; rather, they suggest that redundant information is perceptually ignored whenever this is possible. Our current thinking is that participants, once they have identified redundant information, try to minimize the amount of processing they extend to this information. Preferably, they do so by not perceiving redundancies anymore. If this is not a viable option, they might use a different strategy, such as minimizing the duration of time spent on the redundant information.

This view suggests that how participants deal with redundant information is based on a conscious strategic decision. A similar argument has been recently advanced by Strayer and Kramer (1994a, 1994b), who have argued that participants can strategically adjust their response criteria, that is, how much of the information given by a task is verified before a response is selected (e.g., Fisk & Schneider, 1983; LaBerge & Samuels, 1974; Strayer & Kramer, 1994a, 1994b). Alternatively, one could assume, of course, that information reduction is dealt with implicitly, that is, by way of some automatic (e.g., Jacoby, 1991) learning mechanism, perhaps one similar to the mechanism that is responsible for the overshadowing or blocking effect in Pavlovian conditioning experiments (e.g., Kamin, 1969; Rescorla, 1968). A stimulus–response association in the blocking paradigm is not learned if it does not contain information beyond that inherent in another stimulus–response compound that has been learned earlier (e.g., Hinchly, Lovibond, & Ter-Horst, 1995; Lovibond, Siddle, & Bond, 1988). The blocking effect does not occur if both stimuli carry unique information regarding the appearance of the unconditioned stimulus.

Because participants in the present experiments did not know at the beginning of training that the strings contained redundant information, they had to process both the redundant and the relevant task information initially. Thus, at least at the beginning of training, the redundant letters carried unique information for the required response beyond that given by the triplet. At the present time, we therefore believe it to be unlikely that a blocking-like learning mechanism, and in general, any nonconscious, nonstrategic mechanism, could account for the findings presented here and in the earlier Haider and Frensch (1996) article, although such a possibility cannot and should not be excluded at the present time. For instance, one could argue that an automatic implicit strengthening of attention occurs that eventually reaches a level at which participants become consciously aware of the attentional shift. Nevertheless, it is noteworthy that only 7 (out of 36) participants with large string-length effects in the fixed relevant-first and the fixed relevant-last conditions of Experiment 1 (the two conditions without feedback in the transfer block) reported that they had noticed the redundant information and yet continued checking the redundant letters because they expected errors to occur. In contrast, all participants with close-to-zero string-length effects by the end of the training phase (n = 37) reported that they had discovered that errors occurred only in the triplet and, therefore, had stopped checking the additional letters.

The results of the present experiments show that one important effect of practice is that task processing becomes more selective as has been suggested by, among many others, J. J. Gibson and Gibson (1955). Put differently, the results of Experiments 1 and 2 support the contention that the rate of acquiring a skill is dependent on the amount of, and ability to, limit processing to relevant information. The effect of information reduction on learning rate cannot be explained by assuming that participants optimize their task processing by means of a transition from algorithmic-based to memory-based processing (e.g., Logan, 1988, 1992) or by optimizing the sequence of procedures used to process the task (e.g., Anderson, 1982, 1987, 1992).

On the other hand, however, information reduction in and by itself cannot be the sole explanatory mechanism underlying skill acquisition. Task information can be safely ignored only when it is redundant. Otherwise, information reduction must lead to incorrect task solutions. Clearly, many tasks in our daily lives, such as pure mental arithmetic tasks (Frensch & Geary, 1993), for instance, do not contain redundant information, yet they are learned. Thus, it is obvious that any effects of practice that are observed with these tasks cannot be due to information reduction.

This is to say that it is necessary to extend the theoretical mechanisms introduced by Anderson and his colleagues and by Logan and his colleagues to incorporate the present findings. For example, Anderson et al. (1995) recently argued that “information gathering” should be considered a “procedure” (p. 64). Similarly, Logan and Etherton (1994; Lassaline & Logan, 1993) have shown that what is learned during skill acquisition is dependent on what is attended to. Thus, although the main focuses of existing theories of skill acquisition are different from the phenomenon that we have concentrated on, it is clear that existing theories are, at least in principle, capable of explaining information reduction—if they are extended to incorporate mechanisms that capture the practice-related increase in the selective use of information.

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5 We are grateful to Bill Whitlow for pointing out this possibility.

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