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IMPLICIT LEARNING FROM ONE'S MISTAKES

The negative choice aftereffect

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Introduction

Imagine you are writing an e-mail to your friend and typing very quickly. While you are checking for the overall meaning of the message you probably become less attentive to the grammar and make a couple of mistakes. They are corrected automatically by the text editor and you might not notice the correction. Next time you type similar words you might notice that you are repeating the same mistake: for example, typing "spychology" instead of "psychology". You smile, correct yourself and forget about it. To your great surprise you might find yourself repeating the "spychology" mistake long after you thought you initially caught it, which makes it a recurring error. Somehow a certain stimulus and a certain erroneous response to this stimulus stick together and prevent us from correcting the error. How does this situation come to be? Does it depend on overall performance, that is, do recurring mistakes happen only when we perform poorly in the task, or is it possible for such errors to continue to occur even when overall performance is good?

Dunlap (according to Yates, 1959) described three models that could be used to explain the occurrence of recurring mistakes even in the presence of correct answers. The "Alpha" model states that a response to a given stimulus pattern increases the probability that on the recurrence of the same stimulus pattern, the same response will occur. The "Beta" model states that there is no connection between the probability of stimulus occurrence and the response to it. The "Gamma" model, in contrast to the Alpha model, states that certain responses decrease the probability of future co-occurrence of the stimulus–response association (Peak, 1941; Yates, 1959). If we consider these three models in an attempt to account for recurring mistakes, then the Gamma model tells us that every time we make a mistake, we are trying to correct our behavior and switch to the other response. In this case no recurring mistakes are possible. The Beta model disconnects the stimulus from the response, so any type of co-occurrence might be coincidental. Taking this into account, the proportion of recurring mistakes must be equivalent to the proportion of non-recurring mistakes in the task. The Alpha model describes a situation where a correct response, once given, will be repeated. At the same time, a mistake, once made, will also tend to be repeated, as shown in the example above. The Alpha model essentially states that we memorize not only correct responses, but also erroneous responses. The mandatory association of both errors and correct responses to a given stimulus allows for a high level of performance together with a certain level of recurring errors in the same task. For example, the Alpha model makes it possible to explain why one would persistently misspell some word like "psychology" over and over again even though one is otherwise proficient at writing. This is the perspective we will use in this chapter.

With the Alpha model in mind, we suggest that *recurring mistakes happen because we learn to make them*. One might consistently misspell "spychology" for "psychology"[1] because one has probably learned a certain manner of typing, or an irrelevant representation of the task, an "undesirable pattern of response" (Yates, 1959), or a "nonrepresentative rule" (Reber, 1989). Reber points out that "if subjects emerge from the learning phase with rules (either explicit or implicit) that are not accurate reflections of the grammar, this knowledge base will consistently lead them to misclassify particular items" (Reber, 1989, p.227). Recurring errors result from explicit or, which is more plausible, implicit learning of irrelevant or distracting information that might either be present or not in the stimulus sequence.

This is, while somewhat paradoxical or ironic, overall not surprising. There are many examples showing that people automatically memorize distracting or irrelevant information. For example, in a visual search, observers remember the features of distracting stimuli (Chetverikov, Campana, and Kristjánsson, 2016; Kristjánsson and Campana, 2010; Maljkovic and Nakayama, 1996) resulting in changes in search efficiency. Importantly, the repetition of task-irrelevant features also affects future trials (Huang, Holcombe, and Pashler, 2004; Burnham, 2015), and repetition effects are moderated by task context (Thomson and Milliken, 2013). These results indicate that even when people do not *have* to learn some aspects of the task, they nevertheless do it, even if it harms future performance. Such automatic learning could exist in parallel to more controlled or explicit learning (Maljkovic and Nakayama, 1996; 2000; Perruchet, 1985; 2015) and become a source of recurring errors.

On the other hand, the erroneous response pattern may not seem erroneous or irrelevant from a subjective perspective. "Error", as a term, is always relative to a particular frame of reference. The action that is considered a mistake from the experimenter's point of view could be a correct behavior from the subject's viewpoint. Recurring errors often appear in experimental designs that do not provide any feedback to a subject (Reber, 1989). Thus, a subject who has made a mistake might be quite confident that she is doing everything right and keep her behavior consistent. Dienes and Scott (2005) illustrated that consistency of errors might be associated with conscious efforts to do the task. In their experiment, the participants were asked to report on the source of their decisions in an artificial grammar learning task. Judgments of responses to be based on "guess" and on "intuition" did not correlate with high level of recurring errors ("consistent errors" in the authors' terms). It is only when subjects attributed their decisions to "rules" or "memory", i.e. made a special effort to control the task performance, that the proportion of recurring errors in comparison to non-recurring errors increased.

To summarize briefly described evidence, recurring errors may appear (1) when we make a conscious effort, (2) repeat the task several times and (3) fail to receive feedback about the accuracy of our previous judgments. Even so, some questions arise. If we consider the Alpha model, we need to consider the fact that our memory stores correct and incorrect responses together. How do we differentiate between an actually correct response and a response that seems to be correct? If recurring mistakes are stored in memory together with correct responses they might have an origin different from non-recurring mistakes. Is it so?

The "negative choice" framework

V. M. Allakhverdov, working in the former Soviet Union in 1974, not only developed a framework that accounts for the differences between correct and erroneous responses, but also described recurring errors as a consequence of a purported "negative choice" mechanism. In this chapter, we will first describe this approach and the main findings obtained. We will then compare studies carried out by V. M. Allakhverdov's group to similar effects observed in a variety of studies conducted elsewhere.

"Negative choice" is a hypothetical mechanism based on the idea of sustained unawareness. Allakhverdov (1993, 2000) reasoned that, just as is the case for all human information processing, the selection of information available for responses is subject to learning. Hence, it is possible that the "choice" to ignore some information might be implicitly remembered and later negatively affect the likelihood of the same information being used on the next encounters (see description of the theoretical context in Chapter 3 of this volume). This mechanism was used to explain a number of effects, such as recurring errors, the inability to recognize the second meaning of a reversible figure or difficulties in the retrieval of well-known information.

Crucially for the present treatment of recurring errors, the information necessary for a correct decision can be "negatively chosen". Allakhverdov (1993, 2000) states that, for example, if we fail to retrieve some information in a memory task, we still remember it, but with a tag stating "not to be retrieved". This tag keeps the information in memory, although it prevents us from reporting it until the context of the task is changed and predictions about the stimulus pattern and response are changed as well. This "negative choice" framework explains the Alpha model (Peak, 1941) discussed above: a response to a given stimulus pattern increases the probability that on the recurrence of the same stimulus pattern, the same response will occur because it is stored in memory with an extra information about its previous usage.

Thus, according to the "negative choice" hypothesis, our memory stores previously chosen and non-chosen responses to the stimulus together with their identification as "to be retrieved" or "not to be retrieved" or, if we take a wider approach, with an identification as "to be aware" or "not to be aware". This label or tag makes recurring mistakes different from non-recurring mistakes because it assumes that the element is activated in memory together with its tag.

Allakhverdov (1993) further suggested that a pattern of responses is kept unchanged only as long as the context of the cognitive task or the task itself remains the same. Once the context changes, the tag/label structure of stimulus–response associations also changes. Moreover, the tag "not to be retrieved" is not applied anymore and the stimulus remains activated in memory. That is why the information that is now stored without a tag starts to pop up in your mind and may become a source of reminiscence-like effects as well as a source of non-recurring mistakes.

Let us consider our example about misspelling the word "psychology" again. According to the idea of "negative choice", when we first encounter the task of spelling the word, we implicitly form an association between the representation of the word and our particular response. The first spelling mistake may occur because of some external/internal factors. Once it is made, however, the erroneous response is stored in memory together with the representation of the word. The correct response is also stored in memory, but with the tag "not to be retrieved" or "not to be used". Because the association is formed between the erroneous response and a representation of the word, we tend to repeat this erroneous response each time we encounter the word "psychology" (as in the Alpha model). We also tend to "negatively choose" the correct spelling. It is important to mention that "negative choice" is a result of unconscious implicit learning and does not imply conscious control over task performance. We can continuously make the same mistake until the task or the context changes, and this change breaks the former association of a word representation and the erroneous response. We may also correct the mistake once feedback gives us an opportunity to become aware of such an association.

In summary, the "negative choice" framework proposes two main statements about recurring mistakes:

1) A previously "negatively chosen" item can become continuously "negatively chosen", i.e. every mistake can become a recurring mistake if the task includes repetitive actions with the same set of stimuli.[2] Due to the fact that the recurring mistake is stored in memory it elicits faster responses and higher levels of confidence ratings in comparison with non-recurring mistakes.
2) A continuously "negatively chosen" item may lose its tag "not to be retrieved" when the task or the context of the task changes. After that, information about the "negatively chosen" item starts to pop up in mind in the form of a non-recurring mistake or reminiscence-like association.

These two statements were coined as the "negative choice aftereffect" (Allakhverdov, 1993).

Further in this chapter we present experimental evidence of this phenomenon.

Experiments on "negative choice aftereffect"

How to measure a "negative choice aftereffect"

The very first experiments on the "negative choice aftereffect" were conducted in 1974 as a part of doctoral dissertation by V. M. Allakhverdov (1974). Here we present some of the data from a 1977 study that was later partially described in a book (Allakhverdov, 1993).

On each trial (out of 700), participants were briefly shown a semicircle scale that looks like a speedometer (Figure 4.1) with an arrow that points in a certain position. This scale ranged from 0.1 to 5.0 and was divided into fifty increments. The time of presentation ranged around 300 msec. After presentation participants tried to manually match the position of the arrow with the one they had previously seen. For example, when the arrow pointed to 3.4, participants had to position a test arrow into the same location. The error was calculated as the absolute deviation of the response as compared to the original position. The task required a lot of practice and only three subjects carried out all 700 trials.

The goal of the study was to test whether any given response of the subject is dependent on the previous responses that were associated with this very stimulus. In other words if I made a mistake when trying to position an arrow into the "3.4" location, will I tend to make the same mistake again when I am presented with the same position a second time? If yes, then this will be a recurring mistake.

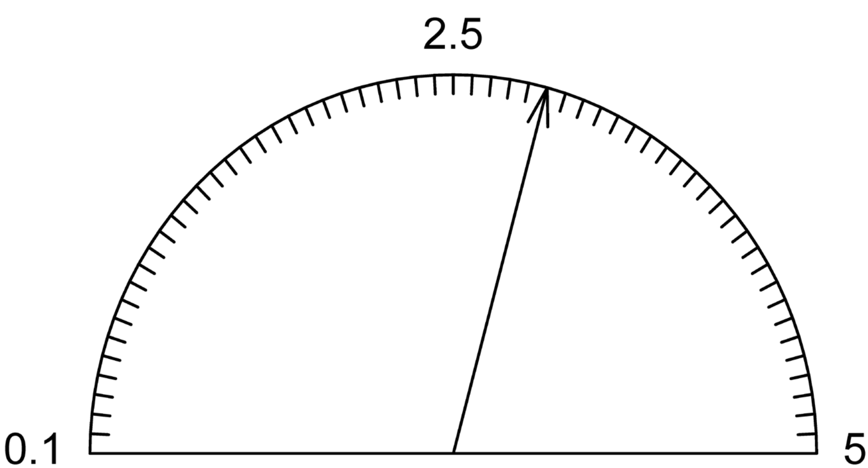

FIGURE 4.1 Semicircle scale that was used in the 1977 experiment of V. M. Allakhverdov in the study of the negative choice aftereffect.

In this experiment, the probability of a mistake across the subjects was 0.29.

The probability of making a mistake the next time the same stimulus was shown was found to be 0.43.[3] This result was confirmed when recalculated per each subject independently. The probability of a recurring mistake was calculated as the quotient of the number of recurring mistakes for this stimulus and the sum of recurring and non-recurring mistakes for the same stimulus. Table 4.1 presents a piece of raw data from the experiment where "0" stands for a correct response and any other number stands for an error measured as a deviation from the correct response. On the first trial, as we can see, the probability of a mistake is 0.5 (6 mistakes out of 12 presented arrow locations). On the second trial the probability of making a mistake is 0.6 (8 mistakes out of 12 presented arrow locations) but the probability of a recurring mistake is 0.5 (4 recurring mistakes out of 8 mistakes of all kinds). The third trial shows an increase of the recurring mistakes probability. Now it is 0.85 (6 recurring mistakes out of seven mistakes of all kinds) whereas the probability of any mistake becomes smaller (0.58).

A skeptical reader may consider such a result an artifact. Reading a set of briefly presented numbers on a semicircle scale can be quite hard. Subjects tend to make most of their mistakes on certain positions, i.e. close to the end of the scale, whereas the center of the scale and increments marked with numbers are usually

TABLE 4.1 Deviations from the reading on the scale pooled for subject and type of stimuli. "x" shows that the protocol marked the response as an incorrect but didn't specify the deviation from the reading on the scale.

Marks on the scale	*0.1*	*0.2*	*1.7*	*1.7*	*1.7*	*2.4*	*3.1*	*3.3*	*3.7*	*4.4*	*4.6*	*4.6*
Subjects' ID Trial number	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*
1	0	0	0	0	0	0	−1	−1	−1	−1	+1	+2
2	+1	0	x	+1	+1	+1	−1	−1	0	+1	−1	0
3	+1	0	+1	+1	+1	+1	−1	0	0	−4	0	0
4	+1	+1	+1	0	x	+1	0	0	0	+2	0	0
5	+1	+2	1	+1	0	0	−1	−1	0	+2	0	+2
6	+1	+1	+1	+1	0	+1	0	−1	+1	−1	0	+2
7	+1	+1	0	+1	0	0	0	−1	0	+2	+2	0
8	+1	+1	0	0	0	0	0	0	0	+2	+2	+2
9	+2	+1	0	0	x	0	−1	−1	−1	−1	0	+2
10	+1	+1	0	0	0	0	0	−1	−1	+3	+2	0
11	+1	+1	0	0	0	0	−1	−1	0	0	0	0
12	0	+1	0	+1	+1	−1	0	0	0	+1	x	0
13	0	0	x	+1	+1	−1	−1	−1	0	0	x	+1
14	0	0	0	+1	0	0	0	−1	+1	0	x	0
15	0	0	0	0	0	0	x	0	−2	0	x	+1

remembered better. Thus we might suspect that errors recur only in locations where lots of mistakes are made and do not recur when the task is easy.

If this assumption were true, we should observe a tendency to repeat one's own mistakes as a result of a systematic bias rather than any other reason. Then if we take cases with overall poor performance, we might find more recurring errors there. To check for this assumption, only the cases (locations of the arrow pointer) with more than 50% of incorrect responses were analyzed.

If a skeptical point of view is correct, then these cases should show an increased probability of making a recurring mistake in comparison with a probability of making a non-recurring mistake. The probability of making a mistake in low performance cases was 0.61, while the probability of making a recurring mistake was 0.58. We do not see an increase of recurring mistakes in this case. On the other hand, if we take only the cases in which performance accuracy varies from 50% to 80% of correct responses, we can observe a different picture. The probability of making a mistake in high performance cases was 0.37, while the probability of making a recurring mistake was 0.53. Thus this comparison showed that we cannot associate a recurring mistake's effect with poor quality of task performance.

We can also consider the amplitude of mistakes, i.e. the deviation from the reading on the scale. Most of the time a subject's response deviates not more than a couple of units (increments). Table 4.1 shows these response deviations pooled for subjects and stimuli. This table illustrates that mistakes go together in some pattern of a similar deviation. One can assume that an observed pattern is a result of a systematic shift. If a subject tends to make a mistake of a certain type (for example a deviation is always larger than the reading on the scale) then a recurring mistake should be of the same type. Table 4.1 shows that the most common deviation for all three subjects is an increase in the reading on the scale.

To test this we can take only the pairs of mistakes that deviate from the correct response by one unit (those marked by + 1 in Table 4.1). For example, Subject 1 in the second and third trials made the same mistake by recognizing "0.1" reading on the scale as "0.2". Such mistakes were pretty common; they amount to more than 80% of all mistakes. At first, we calculated a theoretical and empirical probability of making two mistakes in a row with the same deviation. Then we calculated the probability of two mistakes with the same deviation but with some number of correct responses between them. The result can be seen in Table 4.2. When the same stimulus is shown, there is a strong tendency to repeat one's own mistakes. This tendency is clear for the very next presentation of the stimulus and becomes less clear for subsequent presentations. Thus we can conclude that a systematic shift, if any, happens for certain stimuli and depends on the previous response to the stimuli. It's important to mention that this systematic shift is not caused by overall poor performance on the task but rather happens when the overall accuracy is above 50%.

The data presented so far serve the purpose of illustration of the first statement of V. M. Allakhverdov's framework, i.e. that i.e. every mistake can become a recurring mistake if the task includes repetitive actions with the same set of stimuli.

TABLE 4.2 Probability of making a mistake when it happens right after the first mistake or with some gap. All mistakes are calculated for the same stimulus. The last column represents data pooled across three subjects.

	Subject 1	*Subject 2*	*Subject 3*	*Across subjects*
Empirical probability of a mistake	0.56	0.54	0.51	0.54
Empirical probability of two mistakes in a row	0.84	0.85	0.79	0.83
Empirical probability when two mistakes are separated by some number of correct responses	0.63	0.67	0.6	0.63

This statement assumes that recurring mistakes unlike single non-recurring mistakes are stored in memory for a longer period of time. If they are stored in memory we might find some evidence of it, for example, facilitated reactions to mistakes that repeat over several trials.

Negative choice aftereffect processing: analysis of reaction times and confidence ratings of recurring mistakes

Erroneous responses are often accompanied by uncertainty and failures of control over the task. In general, mistakes increase response time as compared to correct answers, although results for the tasks with the time pressure seem to be different (see Pleskac and Busemeyer, 2010).

If the subject hesitates to respond then the hesitation may increase the time of processing and the probability of producing a mistake. The change in response time might also correlate with overall response frequency. In simple cognitive tasks, correct responses outnumber mistakes and hence become a more frequent type of answer, which elicits shorter response times (RTs) (Notebaert et. al., 2009; Nunez Castellar et. al., 2010). For example, Rabbitt and Rodgers (1977) showed that post-error slowing is not observed when subjects are making the same type of response which they should have made on a previous trial. This means that the more frequent the error is, the shorter the response latency can be.

In the 1977 experiment, V. M. Allakhverdov noticed that the response latency in the case of a correct response was much shorter than in the case of a single mistake. But this was not the case with recurring mistakes. If the subject repeated her/his own mistake, the response latency decreased in 52% of cases out of all recurring error cases.

Another example of a change in response latencies was shown in one of the experiments of V. M. Allakhverdov's students – N. Andriyanova – conducted in 2015. We will present a more formal description of her experiment here.

Clock faces experiment

Participants

Sixty observers (43 females, 18–28 years old) at Saint Petersburg State University voluntarily participated in the experiment. They were not paid for participation. All reported normal or corrected-to-normal visual acuity.

Procedure and design

A number of analogue clock faces were presented (Figure 4.2). All stimuli were shown on the 19-inch computer screen using PsychoPy (Peirce, 2007). Every clock face appeared on a screen for 200 ms. The task was to memorize the time shown and write a response in a response box once the stimulus had disappeared. A total of 120 trials were grouped into 10 blocks. In each series, the same 12 stimuli were presented in a different order. During the course of the tasks, responses and response latencies were recorded. A recurring mistake was considered to be a mistake made in response to the same stimulus. For example, a case when a subject saw 1:30 p.m. on a clock face and repeatedly mistook the reading for something else was considered a recurring mistake.

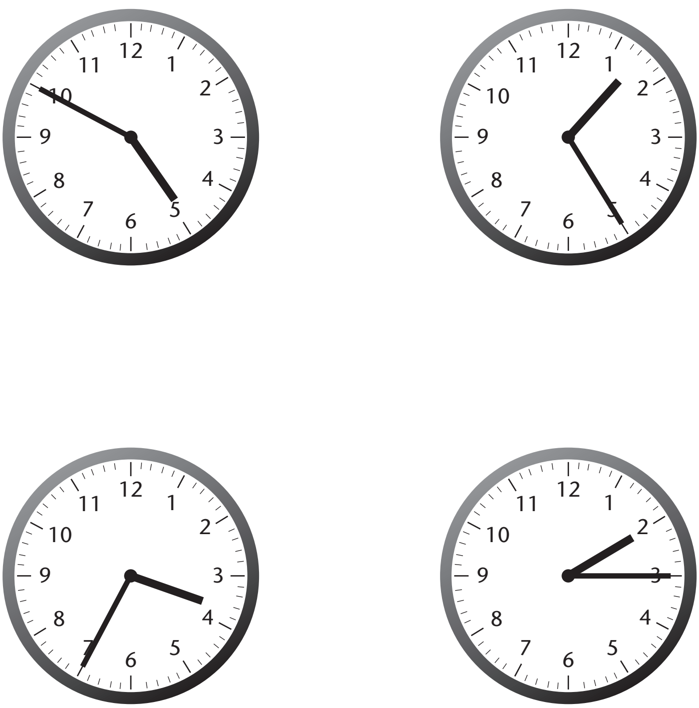

FIGURE 4.2 Analogue clock faces that were presented one per trial in the experiment of N. Andriyanova.

We hypothesized that error latencies might decrease over the course of learning the association between a certain stimulus and response in the task. Thus, reaction latency to a single error (which will become a recurring error) at the beginning of the task should be longer than the average reaction latency to a recurring error.

In our analysis we compared (i) latencies of correct responses, (ii) latencies of single errors, (iii) latencies of single errors (which will become recurring errors) and (iv) latencies of recurring errors. Half of the participants in each experiment were required to estimate confidence in their answers after each trial. We used a one to five confidence rating scale ("one" identified the least confident response and "five" identified the highest level of confidence in a given response).

Results

Mean RTs for different types of answers are presented in Table 4.3. Our data showed that RTs for single errors (M = 7077 ms, SD = 1872) were significantly longer than for correct answers (M = 5298 ms, SD = 1378) and for recurring errors (M = 5564 ms, SD = 1448), $t(49) = 9.506$. $p < .01$. Surprisingly, there was no significant difference between RTs for correct answers and recurring errors, $t(49) = 1.148$; $p > .1$ assuming that there is probably no post-error adjustment in recurring errors (as in Danielmeier and Ullsperger, 2011) (Table 4.3).

RT for a single error (which will become a recurring error) (M = 6092 ms, SD = 1794) was significantly longer than for a repeated mistake, $t(49) = 2.95$; $p < .05$, but significantly shorter when compared to a single error reaction, $t(49) = 7.202$; $p < .01$.

The analysis of the confidence data showed statistically significant differences in evaluation of correct and incorrect responses, Wilcoxon $V(29) = 450$; $p < .01$, i.e. participants were more confident in their correct answers, than they were in the incorrect ones. Confidence levels for repeated errors were nevertheless higher than for single errors, $V(29) = 400$; $p < .01$ (Table 4.4) which might be evidence of recurring errors being processed differently from single ones.

RTs correlated with confidence of the response: RTs were significantly shorter for the confident answers, $t(27) = 4.759$; $p < .01$. However, even when responses were the least confident (from one to three on a scale) we still observed the difference between repeated errors (M = 6134 ms, SD = 2254) and single errors (M = 7746 ms, SD = 2038), $t(27) = 4.007$; $p < .01$.

TABLE 4.3 Mean response times (SD in parenthesis).

Type of answer	*Mean response times (ms)*
Correct response	5298 (1378)
Recurring error	5564 (1448)
Single error (that will become a recurring error)	6092 (1794)
Single error	7077 (1872)

TABLE 4.4 Medians of confidence ratings (range in parentheses).

Type of response	*Medians of confidence ratings*
Correct response	4.3 (1.9)
Recurring error	4 (2.3)
Single error (which will become a recurring error)	3.8 (2.5)
Single error	3.5 (2.3)

Discussion

The experiment described above shows that recurring errors might elicit shorter reaction latencies as well as higher confidence ratings. This result can be interpreted in terms of learning an association between the stimulus and response. When the association is not established (when a mistake is made for the first time) the reaction time reflects an error processing/procedural control operations. When the same stimulus elicits the same erroneous response multiple times the established association between a stimulus and response makes the time of processing shorter and comparable to correct responses. On the other hand the absence of a visible post-error adjustment in recurring mistakes indicates that subjectively they are not perceived as errors.

The status of a single mistake that will become a recurring error is vague. Our data shows that it is processed faster than the single mistake which could be an artifact result. To interpret this we need to assume that the association between the particular stimulus and particular response might be established at the very first presentation of the stimulus. This association might distinguish recurring errors from the single ones and lead to impaired procedural control over former responses and shorten the time of processing.

According to V. M. Allakhverdov, response latency depends on the diversity of the responses (Allakhverdov, 1993). This effect reminds one of the Hick's law (Hyman, 1953) that states that response latency depends on the number and diversity of the signal. Thus, predominant correct responses should elicit the shortest reaction and single errors as the more rare response should elicit longer reaction (Notebaert et. al., 2009; Nunez Castellar et. al., 2010). Recurring errors as a more frequent type of error then should be somewhat between correct responses and single error responses. This is exactly what was confirmed in the experiment of N. Andriyanova.

Robustness of negative choice aftereffect with time and context

As was stated before, the negative choice aftereffect manifests itself in two forms:

1. Every mistake may become a recurring mistake if the task includes repetitive actions with the same set of stimuli.

2. A mistake may cease to be recurring mistakes when the task itself or the context of the task changes. After that the previously stored information starts to pop up in mind in a form of a non-recurring mistake (Allakhverdov, 2000).

Experiments described above illustrated the first statement. Here we want to present two experiments that illustrate the second statement. The first study was conducted by one of the members of V. M. Allakhverdov's research group – M. Filippova. Her experiment aimed at testing robustness of recurring mistakes with time. The second study was conducted by one of the students of V. M. Allakhverdov – A. Odainic. His experiment was aimed at testing the robustness of recurring mistakes with change of task context.

Toy car experiment

Participants

Eighteen observers (11 females, 18–56 years old, age Mdn = 29) at Saint Petersburg State University voluntarily participated in the experiment. They were not paid for participation. All reported normal or corrected-to-normal visual acuity. Group 1 (immediate recognition) consisted of 7 participants (5 females); Group 2 (recognition with delay of one day) – 11 participants (6 females).

Procedure and design

For the purpose of the experiment, we used toy cars no larger than 7 cm each. These toy cars were presented in a row of 14 items (Figure 4.3). Each trial consisted of a different set of 14 toy cars. Subjects were presented with 84 different toy cars throughout the experiment.

In the first part of the experiment, subjects were presented with a "retention set #1", which consisted of 14 toy cars for 15 sec. After a pause, a recognition set consisting of 14 just presented and 14 new toy cars was shown. The recognition task was limited to 25 sec. This procedure was repeated three times, each time with the same set presented for memorization.

Then a new "retention set #2", also consisting of 14 toy cars, was presented for 15 sec. Its recognition was either delayed for one day (Group 2), or followed immediately the first part of the experiment (Group 1). This recognition procedure comprised the second part of the experiment. The recognition set (28 toy cars) for the second part of the experiment, aside from cars from "retention set #2", also contained the items from "retention set #1". These items were either recognized correctly or not recognized by an individual participant during all three trials in the first part of the experiment. On average, subjects were able to correctly recognize about three items.

Altogether 84 model toys cars were used, 2 sets of 14 items used for retention and 4 sets of 14 items used for recognition. New items that were presented for

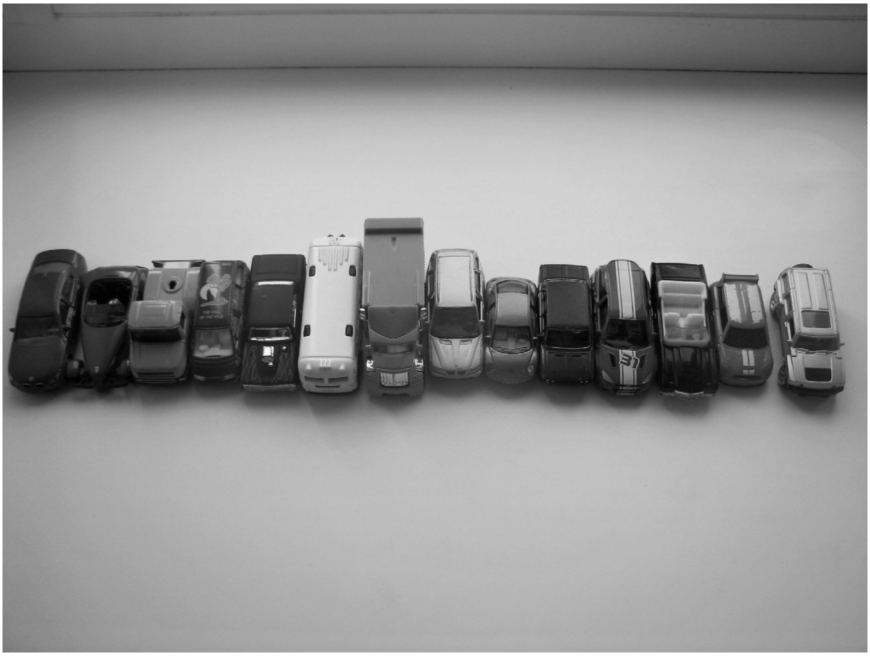

FIGURE 4.3 An example of a set of the toy cars used in the experiment of M. Filippova.

recognition were not presented anywhere else. We hypothesized that the first part of the experiment could create a possibility for repeated mistakes to occur. After that we would be able to test the robustness of recurring mistakes in another task. Immediate presentation of the other task ("retention set #2"), in our opinion, could not override the memory tag "not to be retrieved" for the recurring mistakes that appeared in "retention set #1". On the other hand a delay for a day could have affected the memory traces and loosened the connections between certain stimuli and responses. If recurring mistakes were dependent on a current memory for stimulus–response association then we might find former recurring mistakes as false alarm mistakes in a different task.

Results

At first, we tested whether any of the toy cars in the subsets was salient enough to be recognized better or worse than any other item. We did not find any differences between the recognized and unrecognized set of items in terms of their stimuli specificity ($\chi^2(13) = 12.214$, $p = .510$). Thus, the stimuli set happened to be more or less homogenous and recognition effects could be attributed to some reason other than the saliency of the items.

Then, we compared frequencies of recurring and non-recurring responses. If the item wasn't recognized in three consecutive trials it was considered to be a

TABLE 4.5 Probability of different response types in first part of experiment (N = 18).

All types of mistakes	*Recurring mistakes*	*Non-recurring mistakes*
0.22	0.15	0.07

recurring mistake. Otherwise recognition in at least one trial made a response a non-recurring mistake. This procedure is slightly different from the one that was offered by V. M. Allakhverdov and described above. It was chosen to guarantee that the subject had some consistency in her/his responses.

Altogether the number of recurring (34) and non-recurring (16) mistakes was 22% of all possible recognitions on the last trial (14 items to recognize per 18 subjects). Table 4.5 represents the frequency of different types of response measured as a proportion of these answers to the overall amount of items to be recognized (252).

The number of recurring mistakes was significantly different from that of non-recurring mistakes ($\chi^2(1) = 6.480$, $p < .05$).

The previously described procedure included only one possible response (correct or incorrect) per trial. In the current experiment, the number of participants' answers in each recognition test was not restricted and varied from 7 to 15. When given such a possibility, subjects can chose a strategy to "recognize" as many or as few items as possible. When the subject chooses a large number of responses, such responses have a higher chance of having all correct responses than the choice of a small number of responses. In other words, if I chose 14 out of 28 toy cars, the chance that I picked up correct items is 0.5. If I chose 7 out of 28 toy cars, the chance that I picked up the correct items is 0.4.

The generalized linear mixed model was used (see summary statistics table, Table 4.6) to examine the predictors of the number of responses together with the previous history of erroneous recognitions. The history of previous erroneous recognitions was calculated as a cumulative sum of the number of mistakes made before the current trial. We assumed that the more recurring mistakes a subject made before, the higher is the probability of making such a mistake again. A dependent variable was a response in the current trial which could be either correct recognition ("0") or incorrect recognition ("1").

As can be seen from Table 4.6 the erroneous recognition in the current trial is dependent on the history of previous erroneous recognitions although the number of responses can become a confound.

The second part of the experiment consisted of one recognition trial of "retention set #2". Items that the subject worked with during the first part (previously recognized or not recognized) became fillers for the second part. Thus participants didn't have to report on them and once recognized the stimuli were considered to be false alarm mistakes (Table 4.7). If recurring mistakes are kept in the memory then they will pop up in the mind during the second part of the experiment in the form of false alarm mistakes.

TABLE 4.6 Generalized linear mixed model summary for the experiment of M. Filippova.

	Erroneous response		
	Odds Ratio	*CI*	*p*
Fixed Parts			
(Intercept)	0.25	0.00 – 17.55	.525
Previous recurring errors	11776.31	283.14 – 489796.19	<.001
Number of responses	0.73	0.45 – 1.16	.181
Previous recurring errors: Number of responses	0.57	0.41 – 0.79	<.001
Random Parts			
$\tau_{00.\ \text{Subject}}$		1.063	
$\tau_{00.\ \text{Stimulus}}$		0.000	
N_{Subject}		17	
N_{Stimulus}		7	
ICC_{Subject}		0.244	
ICC_{Stimulus}		0.000	
Observations		325	
Tjur's D		.690	
AIC		179.652	
Deviance		143.255	

Mean accuracy for recognition in Group 1 where the second part was presented immediately after the first one was 54%. Most responses were correct rejections and not false alarms. Subjects still remembered items from the previous "retention set #1" and tried not to retrieve them.

Mean accuracy for recognition in Group 2 where the second part was delayed for 24 hours was 37%. Previously unrecognized items were chosen with a similar frequency as previously recognized ($\chi^2(1) = .578$, $p = .81$) and numerically more often than previously not presented items ($\chi^2(1) = 2.8$, $p = .09$).

TABLE 4.7 Possible responses for the stimuli in the second part of the experiment based on the first part of the experiment.

	Responses in the first part of the experiment	*Responses in the second part of the experiment*
Item is presented in the first part of the experiment	miss	false alarm correct rejection
	hit	false alarm correct rejection
Item is presented in the second part of the experiment		miss hit

TABLE 4.8 Probability of recognition in the second part of the experiment based on the history of responses in the first part of the experiment.

First part of Experiment	*Recurring misses*	*Recurring hits*	*Item is not presented in the first part*
Second part of experiment	*False alarm mistakes*		*Misses*
	0.39	0.42	0.19

With a time delay (Group 2) items from "retention set #1" became more salient and were retrieved in the second part as if they were the actual stimuli (Table 4.8).

Discussion

This experiment was aimed at illustrating robustness of recurring mistakes with time. The difference between the first and the second part of the experiment showed that a 24-hour delay is enough to break the association between the stimuli and a hypothetical tag "not to be retrieved". According to V. M. Allakhverdov's approach the stimulus stays activated in the memory even when this tag disappears. That is why items that were not correctly recognized in the first part of the experiment started to appear in the second part of the experiment in a form of false alarm mistakes. It's important to notice that the false alarm rate for the items that were previously correctly and incorrectly recognized was similar. This evidence supports an idea of equal memory storage for correct responses and recurring mistakes.

Another type of context change was investigated in the study of A. Odainic. His experiment was aimed at testing the robustness of recurring mistakes with a change of task context.

Matrices experiment

Participants

Sixty observers (38 females, 16–30 years old, age mdn = 19) at Saint Petersburg State University voluntarily participated in the experiment. They were not paid for participation. All reported normal or corrected-to-normal visual acuity. Participants were randomly allocated to one of two conditions (see design).

Procedure and design

Observers memorized a series of matrices. Each element of the matrix consisted of a single digit number and a capital letter of the Roman alphabet (for example "8Q"). The following letters – B, C, D, F, G, H, J, K, L, M, N, P, Q, R, S, T, V, W, Y, Z – and digits – from 1 to 9 – were used. There were five trials; each consisted of the presentation of two matrices. Each matrix consisted of 16 elements (four by four size). All elements were generated through an automatic randomization procedure. Four elements out of 16 were repeated, so that each subject on each trial observed a matrix with 12 new and 4 old elements. The trial began with a matrix presentation for 20 sec. The task was to memorize all the elements and to recognize those that were shown again on the second matrix, which was presented immediately after the 20-sec presentation of the first matrix. No time limit was established for the recognition task, which participants carried out by clicking on the items they thought were repetitions. No feedback was provided. The procedure was repeated three times with short time intervals between repetitions. The entire experiment consisted of two conditions randomized between subjects. In the "different place" condition, repeated elements kept their identity, but not the location where they were presented (Figure 4.4).

In the "same place" condition, repeated elements were presented at the same locations they had been shown before. Thus, we checked for the influence of the factor of location in the recognition of the repeated elements. The manipulation aimed to test whether memory for recurring errors contains information about location together with information about identity. We expected that recurring errors would show up in the "same place" condition more frequently than in the "different place" condition. Response in the current trial, i.e. the number of recognized items, could vary from 1 to 16 (there were 16 elements in a matrix). A participant could prefer different strategies of answer: she could decide to trust her memory, be more confident about her response and try to name as many items as possible, or she could decide to distrust her memory and name only the items that

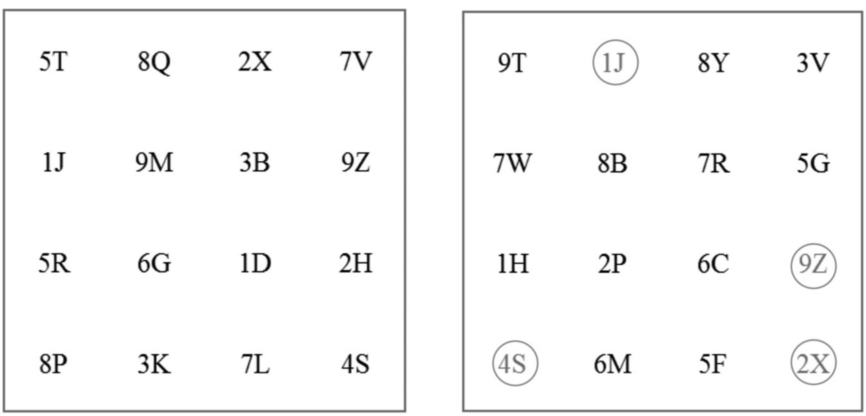

FIGURE 4.4 Design of one trial in the "different location" condition. On the left panel there is a set of elements to remember. The set is presented for 20 sec. On the right panel there is a recognition set. Elements that were repeated from the previous set are highlighted. Repeated elements keep their identity but not their place. In the "same location" condition repeated elements keep their place as well as their identity.

she was sure about. Such reduced response strategy could influence the calculation of recurring mistakes. For example, out of 16 elements presented in every trial, a participant could choose to name only two in every recognition trial. In this case there is a 50% chance level that two elements out of four will be missed and will be treated as a recurring mistake.

Results

We used the same approach to the analysis of mistakes as in the previous experiment.

The generalized linear mixed model was used (see summary Table 4.9) to examine the predictors of number of responses together with the previous history of erroneous recognitions. The history of previous erroneous recognitions was calculated as a cumulative sum of the number of mistakes made before the current trial. We assumed that the more recurring mistakes a subject made before, the higher is the probability of making such a mistake again. A dependent variable was

TABLE 4.9 Generalized linear mixed model summary for the experiment of A. Odainic.

	Erroneous response in the current trial			
	Estimate	*CI*	*SE*	*p*
Fixed Parts				
(Intercept)	2.54	1.35 – 3.72	0.61	.040
Previous recurring errors	5.55	3.99 – 7.11	0.80	<.001
Number of responses	−1.45	−1.83 – −1.08	0.19	<.001
Location	0.22	0.01 – 0.43	0.11	.042
Previous recurring errors: Number of responses	0.21	−1.73 – 2.15	0.99	.834
Previous recurring errors: Location	1.25	0.24 – 2.27	0.52	.016
Number of responses: Location	0.64	0.16 – 1.12	0.24	.009
Previous recurring errors:Number of responses:Location	2.26	−0.28 – 4.80	1.30	.082
Random Parts				
σ^2		0.428		
$\tau_{00,\ Subject}$		0.025		
$\tau_{00,\ Stimulus}$		0.097		
$\tau_{00,\ Repetition}$		0.990		
$N_{Subject}$		26		
$N_{Stimulus}$		4		
$N_{Repetition}$		3		
$ICC_{Subject}$		0.016		
$ICC_{Stimulus}$		0.063		
$ICC_{Repetition}$		0.643		
Observations		345		
R^2 / Ω_0^2		.599 / .599		
AIC		743.371		

a response in the current trial i.e. the amount of repeated elements misses (ranging from 0 to 4).

As can be seen from the results the erroneous response is dependent on the history of previous erroneous recognitions, number of responses and location of the elements, and, partially, on their interactions. Placing elements onto the same positions over the course of trials results in more mistakes in comparison with placing elements on randomized positions ("Random places group"–"Same places group" contrast estimate = – 0.3 (0.15), df = 76.36, t-ratio = –.207, p = 0.04)

Discussion of experiments of A. Odainic and M. Filippova

Both experiments presented above tested the idea of the relevant robustness of the recurring mistakes effect. We hypothesized that a recurring mistake is more likely to happen in presence of the same context, i.e. when the binding between identity of the item and its location is kept the same throughout trials. If the location changes, then the recurring mistake loses its location-identity binding and, possibly, also loses the stimulus–response association in memory.

Both experiments showed that the previous history of recurring errors, i.e. the cumulative sum of the omissions per item, influences the current response. This happened only when the place of the element was not changed throughout the trials (in the experiment of A. Odainic) and when there was a time delay between the retention and recognition procedures (in the experiment of M. Filippova). When the place of the element is changing from trial to trial a factor of previous erroneous responses doesn't influence the current response. We can conclude that binding of location and identity plays an important role in the recurring mistakes effect. If context doesn't change then we are more likely to find recurring mistakes in the sequence of trials.

In both experiments we also see the influence of the subject's number of responses, which goes along with our predictions. The strategy to report a smaller number of elements increases the occurrence of repeated mistakes. Such strategy works because both experiments used free recognition procedure instead of forced-choice recognition. Free recognition allows us to vary the amount of items recognized in particular trial and may depend not only on a subject's memory but also on a subject's choice to respond to more/less items. If these experiments had used a forced-choice procedure, we could have expected no influence of a "number of responses" factor.

Conclusions

Summary of the "negative choice aftereffect" findings

Several experiments described above show that mistakes tend to be repeated. This effect was dubbed the "negative choice aftereffect". It was shown that recurring mistakes may happen in response to the same stimulus when this stimulus is presented several times. Recurring mistakes occur in different cognitive tasks involving either retrieval or recognition processes. This type of error leaves traces in memory that include information not only about the identity of the item that was associated with the erroneous response but also information about the location of and the previous response to this item. Recurring mistakes are different from the set of single mistakes: they elicit shorter reaction times than single errors. There seems to be no post-error adjustment after recurring errors. In addition, recurring errors correlate with higher confidence ratings in comparison with single errors. These results taken together with the ones obtained in implicit learning studies (Reber, 1989; Dienes and Scott, 2005) describe a stable "erroneous" (from the experimenter's point of view) association of response and stimulus that is stored in memory for quite some time. Integrating over the results of the experiments discussed above, those of the experiments by Allakhverdov (1993), and those of the experiments of Dienes and Scott (2005) and Reber (1989), we can list some conditions in which recurring mistakes are more likely to be found:

- The stimulus set must be homogenous, that is, stimuli should have similar features, although they also should be easily named and identified.
- There should be no feedback on accuracy of performance in the task.
- Efficiency of the performance should vary from 50% to 80% of correct responses.
- The location of the item in the presentation set should be constant.
- The item should be repeated several times in a row to elicit a possible recurring mistake response.
- The memory test should not be delayed. If the delay is substantial (for example, more than 24 hours) then recurring mistakes lose the strength of stimulus–response association in the memory and very likely will pop up in the mind.
- Subjects should make an effort to perform well on the task.

"Negative choice aftereffect" in other studies

As we stated it in the beginning of the chapter, recurring errors result from explicit or, more probably, from implicit learning of irrelevant or distracting information. Other examples of "erroneous" association of response and stimulus can be found in a variety of experiments (VanRullen and Koch, 2003; Warriner and Humphreys, 2008; D'Angelo and Humphreys, 2015; Hajcak and Simons, 2008; Neill, 2007).

For example, VanRullen and Koch (2003) presented several different tasks in the study of competition and selection in visual processing. They used free recognition, forced-choice recognition and priming picture-word matching tasks to test how many items a subject can remember after being briefly presented with a natural scene that contained these items. They showed that items not reported during the free recognition task and subsequently missed in the forced-choice recognition task showed a significant negative priming effect, that is, elicited longer responses and were more associated with errors than novel items. The authors concluded that "the negative priming effect suggests that these objects were in fact represented in the visual system, but that this representation was eventually suppressed"

(VanRullen and Koch, 2003, p.80). We suggest that the effect VanRullen and Koch (2003) observed is related to recurring errors. There is a succession of tasks that use the same stimuli; there are items that are missed in both the first (free recognition) and second tasks (forced-choice recognition); these twice-missed items then elicit more errors in the picture-word naming task. All these features match our description of recurring mistakes.

In a study of the tip-of-the-tongue (TOT) state, Humphreys and colleagues (Warriner and Humphreys, 2008; D'Angelo and Humphreys, 2015) found that making an error once increases the chances that it will be repeated. They presented definitions of words that participants then had to name. If participants were unable to remember the word but felt that it was likely to be remembered (i.e., participants experienced a TOT state), they read the same definition once again but after a time delay. The delay was either 10 or 30 sec. In the latter case, (when the delay was longer) subjects showed difficulty in recalling the same words again the second time when the procedure was repeated. Authors concluded that speakers tend to repeat TOT states for individual words. This case, although very different from that described in VanRullen and Koch (2003), also exhibits some similarities with the "negative choice aftereffect". When we described the hypothetical mechanism of recurring mistakes, we assumed that a correct response for the task would be remembered together with the representation of the task, but with a tag "not to be retrieved". This tag prevents the correct response from being used when we carry out the same task after we made an initial mistake. The TOT state is a good example of how such a "not to be retrieved" tag could be experienced subjectively.

The described experiments share one feature: the items that elicit a recurring mistake response are shown to be processed differently from the novel items that do not have an erroneous association between the stimulus and response.

Hypothetical mechanisms of recurring mistakes

Humphreys and colleagues (Warriner and Humphreys, 2008), in their research on repeated TOT states, suggest that implicit learning of the incorrect activation pattern (particularly the co-activation of a word's lemma and phonology) is a cause for repeated errors. Implicit learning of a TOT state happens when the participant tries to produce the word. Unresolved TOT states (the correct answer was not found and the word remained forgotten) are stored in memory together with the incorrect link to the phonology of the word. This extra information increases the likelihood of the TOT state repetition (Warriner and Humphreys, 2008, p. 540). Similarly to the previous explanation, Allakhverdov (2000) suggests that if we continuously do not retrieve the very same words as before, we still remember them but with extra information – a "not to be retrieved" tag. This tag keeps the words in memory although preventing us from reporting them until the context of the task is changed and predictions about the stimulus pattern and response are changed as well. Neill and Valdes (1992) used similar terms when they described the mechanism of the negative priming effect. In their opinion, task performance is mediated by the retrieval of past instances of the current stimuli. If the retrieved episode indicates that the current stimulus was recently ignored, responding is impaired which is called "inappropriate transfer". Analyses of this effect support the idea that a stimulus and response are associated within a given task/context and their association might alter the performance (Neill, 2007).

Here, we followed the Alpha model perspective on stimulus–response association, assuming that a response to a given stimulus pattern increases the probability that the same response will occur on the recurrence of the same stimulus pattern. According to the Alpha model, simple associative learning might happen after a first few iterations of a stimulus–response co-occurrence and continue throughout an experiment. Does it then mean that all possible responses for all stimuli are stored? The hypothesis of "negative choice aftereffect" leans towards this assumption. Supportive evidence comes from the neural network field. It was shown that a Bidirectional Associative Memory model (based on a Hebbian learning rule) with a Quick Learning algorithm can reproduce a human pattern of recurring mistakes when a participant learns and then repeats a hand movement trajectory (Lyahovetskiy et. al., 2013). According to its authors, the Quick Learning algorithm greatly reduces learning epochs, guarantees the recall of all training pairs and increases memory capacity (Hattori, Hagiwara and Nakagawa, 1994). Interestingly, McClelland emphasizes that Hebbian learning mechanisms that were utilized in Quick Learning for the Bidirectional Associative Memory algorithm tend to strengthen the pattern of neural responses that are highly correlated with each other. In his opinion, the Hebbian approach may even strengthen response when it is incorrect or when there is no feedback given (McClelland, 2006). Thus, a model that assumes a storage of all stimulus–response associations also assumes a possibility of recurring errors.

If the Alpha model implies that our memory stores correct and incorrect responses together, then it should also imply some separation of these responses. Ideas of "incorrect activation pattern" (Warriner and Humphreys, 2008), "negative choice aftereffect" (Allakhverdov, 1993, 2000) and "inappropriate transfer" (Neill and Valdes, 1992) all try to explain how incorrect responses could be distinguished from correct and from incorrect but non-repeating responses. Recurring mistakes are different from the non-recurring errors in the way they are stored in memory. The extra information (the tag "not to be retrieved") that is linked to correct answers makes it clearly distinguishable from other types of responses and prevents it from being used in the task.

Does this mean that the representations that are not retrieved are suppressed as VanRullen and Koch (2003) suggested? "Negative choice aftereffect" and recurring mistakes may happen because the correct response is not only stored in memory with a tag "not to be retrieved" but also is actively suppressed from further processing. To confirm that the suppression mechanism is active, we need to infer the consequences of such suppression. Usually, the suppressed elements elicit longer reaction times than non-suppressed elements. In line with this, in VanRullen and Koch's (2003) study the items that elicited more errors in the priming picture-word matching task also elicited longer reaction times, i.e. a negative priming effect. On the contrary, the results of Allakhverdov's group experiments described above did not show any negative priming effect. Thus, we cannot confirm the suppression hypothesis of recurring mistakes.

The recurring mistakes effect can be shown in a variety of tasks. It implies that the cognitive system stores excessive information about the stimulus–response association. This stimulus–response association can be implicitly learnt as an undesirable pattern of response (Yates, 1959) but still will be stored in memory. We began this chapter with an example of a repeated misspelling ("spychology" instead of "psychology"). Based on our current knowledge, we can conclude that it will be quite hard to get rid of this mistake. Firstly, the mistake recurrence will be supported by the increased probability that on the recurrence of the same stimulus pattern, the same response will occur. Secondly, this stimulus–response association will be stored in memory until the context of the task is not changed. Is it possible to get rid of the recurring mistake? In terms of Allakhverdov's approach, one should try to change the context of the task or the task itself. Dunlap (1942) offered instead to make it so that the information we were unaware of is brought to awareness. This approach involves a technique known as "negative practice". According to this method, one should try to repeat an error explicitly several times to correct it (Dunlap, 1942). Likewise, McClelland suggested increasing the contrast and exaggerating the differences between otherwise undistinguishable stimuli that previously elicited recurring mistakes (McClelland, 2006). Sure enough, this method helps to get rid of spelling and pronunciation errors. However, it is not known whether it works for the recurring mistakes that occur in other situations.

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Notes

1 We would like to thank our colleague Y. Ledovaya for this example of a negative choice mistake.
2 It's important to notice that we assume that each stimulus in a set is more or less independent of any other and does not form a semantically connected string.
3 These results were obtained in 1974. Unfortunately, raw data files were not stored until 2017. We put here numbers in accordance with results published as a Doctoral dissertation (see Allakhverdov, 1993).

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