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Conscious Control of Inattention in Task-Switching

To what extent are the processes of preserving/changing a task volitional? In certain conditions not making an error may become a goal in itself. An erroneous action must find itself in the contents of consciousness, which may lead to interruptions in performing the original task. This hypothesis is tested in our study. Sixty people (ages eighteen to twenty-seven, students and people with a higher education) took part in the experiments. The test subjects were assigned to three groups. The task was to mentally alternate operations of addition and subtraction of pairs of single-digit numbers (from 1 to 9), presented sequentially, one after another. Tentatively, we can single out the levels of automatic (executive) and conscious control. Conscious control operates the way a "manager taking a walk" does; it may be focused on both the external situation and internal operations.

Many professional tasks consist of sequences of operations of the same type (e.g., knitting or playing a musical instrument), where the order in which they are performed, as a rule, is not repeated and requires conscious planning and control. The essence of the control boils down to maintaining an optimum balance between two opposite tendencies: the tendency not to switch and the tendency to switch the current task. To what extent are the processes of preserving/changing the task volitional? In everyday life we often resort to planning our behavior by arranging very familiar actions in a sequence according

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to some algorithm (e.g., cooking according to a recipe, etc.). The use of such instructions and self-instructions, however, does not always produce the desired result. Sometimes we make absurd errors by performing one automatic action instead of another, or we go completely astray like the centipede in the famous joke. These errors show how limited our capabilities are in controlling our own behavior (for an overview, see Reason, 1990). We surmise that in certain conditions not making an error may become a goal in itself, which will also be controlled. In this connection, however, an erroneous action must find itself in the contents of consciousness, which may lead to interruptions in performing the original task. This hypothesis is tested in our study.

One of the best-known action control models is that of Norman and Shallice (1986), which separated willed and automatic control. Automatic control triggers and monitors schemas of habitual actions that are stored in memory. The need for willed (conscious) control arises in the absence of information, or when there is a sudden change in the situation, or when there are several equivalent options for behavior (i.e., when necessary, making a decision in a situation of uncertainty, when the body either has no prepared program of behavior or the available automatic behaviors come into conflict). It is common knowledge that we can consciously perform only one thing at a time. The conscious performance of two tasks simultaneously is impossible; the actor will be forced to constantly switch from one task to the other. However, the task-switching speed is also limited. Many works also use the collective concept of executive control, which may be defined as the result of the high-level process used in establishing a goal and choosing a strategy when performing a task, and programming bottom-level processes for the strategies used and for monitoring the execution (Logan, 2003; Monsell, 1996).

The simultaneous execution of multiple tasks or sequential, rapid switching from one task to another is required in many types of activity. The problem of shifting from one automatic operation to another has been reflected in a whole host of studies done under the experimental procedure of "task-switching." The point of this experimental procedure is that test subjects must constantly change the nature of the actions being performed with regard to sequentially presented stimuli. For example, if the stimuli are digits, then the switching could be between addition and subtraction; if they are words, between reading and identifying the color of letters. The value of such research is that they directly test the balance between the tendencies not to switch and to switch a goal, which is critically important for control mechanisms (Velichkovskii, 2006). Although the first studies in this field were done in the first third of the past century (Jersild, 1927), intensive study of task-switching processes began in the 1990s (Allport, Styles, and Hsieh, 1994; Rogers and Monsell, 1995) and is being actively carried on by leading cognitive psychologists.

The main effect that has been recorded in tasks of this type and has yet to be given a clear explanation is the significant increase in the time to accomplish a single task feature under switching conditions (i.e., switch trial) compared with the time to accomplish similar task features under repetition conditions (i.e., non-switch trial). This phenomenon has been called "switch cost."

What are the components of switch cost? What mechanisms are activated in this process and is there some central location that is responsible for them? In other words, to what extent do task-switching processes depend on the external situation and to what extent on the internal goals of the subject himself? The data from the experiments do not allow for an unequivocal answer to these and other questions. Explaining the effect of switch cost is a subject of spirited debates. Some writers say there is inertia from the preceding task set, which causes negative priming if the task is switched and positive priming of it is repeated (Allport, Styles, and Hsieh, 1994). Other writers link switch cost to the operation of specific executive processes that provide preparation and transition to the following task (Rogers and Monsell, 1995). We will explore the results of these and other studies in more detail.

In one experiment Jersild (1927) gave participants columns of two-digit stimulus numbers. While proceeding down the columns, the participants performed the same arithmetic assignment (e.g., they would add six and orally state the result) in accordance with each stimulus in the column, or they chose between two different assignments (e.g., adding six to the first stimulus number and reporting the sum orally, subtracting three from the second stimulus number and reporting the result orally, adding six to the third stimulus number and reporting the sum, etc.).

The difficulty of the arithmetical operations varied. Either it was relatively low (e.g., adding six and subtracting three) or high (e.g., adding seventeen and subtracting thirteen). The average time for performing the operation in task-alternating and repetition trials was computed. More difficult operations required more average time. Task-switching also increased the average time of execution. It turned out that these two effects interacted: the difference between the reaction time for task alternation and repetition was more for simple assignments than for difficult ones. According to the logic of the additive factor method (Sternberg, 1969), this interaction assumes that the difficulty of the operation and task-switching influence at least one processing stage in common.

By way of developing Jersild's research, a new study by Spector and Biederman (1976) was conducted with various versions of the task-switching procedure. It revealed that the amount of switch cost depends on visible cues about what task is to be performed next. This association assumes that there is a control process through which such cues can be used along with other information to identify and prepare for impending tasks. In one experiment Spector and Biederman gave participants columns of two-digit stimulus numbers. For each column the participants added three to each stimulus number and orally reported the result, subtracted three from each stimulus number and reported the difference, or alternated adding and subtracting three. No visible cues were provided that would have indicated what the next operation to be performed was; instead, the necessary operations had to be retrieved from memory. Under these conditions the alternation of tasks took much more time than the repetition of tasks, as Jersild (1927) had found.

In another experiment Spector and Biederman modified their procedure, offering visible cues (e.g., "+3" or "–3") to the stimuli, which indicated what arithmetical operations had to be performed. The alternation of tasks, as before, took more time, but the switch cost was noticeably lower than in the absence of cues to the next operation.

A study by Rogers and Monsell (1995) also showed that knowledge of what tasks would have to be performed substantially reduced switch cost, since an orientation was formed in advance toward accomplishing a certain task set. However, since the shift time even in these cases was not reduced to zero, the hypothesis was proposed that switch cost included amounts expended on forming an orientation and on some other, additional processes.

Based on their results, Rogers and Monsell (1995) proposed a task-switching model with two different types of executive control: endogenous and exogenous. According to this model, endogenous control takes place in a flexible, up-and-down manner, executing preliminary operations for impending tasks during predictable interstimulus intervals. These operations reduce the switch-time cost, but they leave the system partly unprepared. Exogenous control, which completes the preparations for the next task, is triggered by the stimulus of the next task. Allport, Styles, and Hsieh (1994) investigated how the combination of the stimulus and response (the S-R mapping) influences switch cost in alternating tasks. They hypothesized that switch cost consists not so much of the mechanisms of choosing a necessary program as of inhibition of the one already in effect. This hypothesis is based on two assumptions: (a) Performance of the preceding task requires a kind of set to be imposed on the task feature, making the S-R mapping more important, and may suppress other competing responses, and (b) the S-R mapping of the primary task remains partially active even after long interstimulus intervals, potentially influencing the choice of response to subsequent task features.

According to Allport, Styles, and Hsieh (1994), this proactive interference is higher when the stimuli and responses for the primary task and following one are similar and when the primary task uses a less dominant S-R mapping than the following task.

The greater the correlation between stimuli in alternating tasks, the greater the switch cost, since it becomes necessary to activate precisely the set that was suppressed by the previous action. These assumptions are partly confirmed by experiments. When test subjects were alternately presented digits and words, and the digits had to be added together while the words had to be read, there was no switch cost (Koch and Allport, 2006). In other studies, test subjects were asked to alternate between three types of tasks (we will call them A, B, and C, respectively). It was found that the switch cost was higher for the transition from B to A in an ABA sequence than for a transition from B to C in an ABC sequence. This indirectly confirms that the transition from A to B entails an inhibition of A and it is more difficult to subsequently return to task A than shift to the absolutely new task C (Arbuthnott and Frank, 2000). A similar effect was detected in Stroop's classic task. Researchers (Dalrymple, Alford, and Budayr, 1966 in Milliken and Joordens, 1996) noticed the following phenomenon: if in the previous stimulus the word denoting color was identical to the color of the following stimulus, the time needed to read that following stimulus was significantly longer. Therefore, we may conclude that active inhibition of alternative interpretations of a stimulus indeed takes place, and it occurs automatically.

In Allport's experiments (Allport, Styles, and Hsieh, 1994), however, results were obtained that contradicted the task-set inertia hypothesis. The participants in these experiments alternated between tasks of a standard and reverse Stroop test (naming the color of a font and reading words, respectively) (for a decription of the classic Stroop test, see Stroop, 1935). According to the task-set inertia hypothesis, participants were supposed to suppress the name of the color and impose the set of the word-reading task during the reverse Stroop test in the alternating blocks of tasks. This control, in turn, was supposed to bring about a significant cost of switching back to the standard Stroop test, which used color-naming rather than word-reading. Contrary to this prediction, however, the average switch-time cost for the standard Stroop test essentially proved to be zero.

Can automatic inhibition disappear, and if so, when does this occur? We hypothesize that when a task is under conscious control the unattended task is not simply suppressed; in certain conditions it even receives an additional advantage compared with the main task.

A similar effect has been described in studies of tasks involving a visual search of differences between two areas of a space as the "inhibition of return" effect. The crux of it is that immediately after the eye visits some point in space, the probability of returning to the same point proves to be very low. However, as soon as the test subject begins to suspect (i.e., consciously perceive) the difference he is searching for, the "inhibition of return" disappears, so that the eyes repeatedly and sequentially fix on the same critical areas! (based on Velichkovskii, 2006).

The results of the above experiments lead to the conclusion that switch cost is maximized if the stimuli themselves do not contain any cues for what operation must be performed, and the order in which the tasks are performed is determined only by explicit instructions given beforehand, which automatically triggers conscious control of compliance with them. In our view, this is the situation in which a task is performed under conscious control. If the task has external cues or the stimuli themselves make it possible to predict a necessary operation (e.g., if the sequence of stimuli is repeated), then conscious control is not needed in the task and can proceed to other tasks. In this instance switch cost will decrease, possibly even to zero (Koch and Allport, 2006).

What is time spent on during conscious control? We believe it is spent on checking operations. The number of control points at which checking is done will be determined by the purpose of the task in question (which in fact is predefined by the experimenter's instructions or by self-instructions). The simpler the task, the greater the number of control points and the greater the difference between its automatic and controlled execution. The simpler the task to be executed, the higher the probability that conscious control will slide onto irrelevant tasks. In a situation of two alternating, equivalent tasks the highest probability is that control of the current task will shift to control of inattention to the alternative task. This effect is well known in perceptual research and is based on the involuntary reversal of alternative meanings in the perception of ambiguous images, for example, "faces–vase."

Thus, the difficulty of the main task may influence both the number of control points and the sliding of control onto the unattended task. The simpler the main task, the more likely it is that control will shift to the supplementary (auxiliary), unattended task.

According to the theory of V.M. Allakhverdov (1993, 2000), the processes of inattention form the basis for the emergence of psychic interference, since the very attempt to control inattention results in a breach of instructions and in errors. The difficulties with performing such tasks are based, among other things, on how often a person verifies the fulfillment of an unattended task. Then increasing the difficulty of the main task may be viewed as a way to reduce interference, since more attention will be paid in this case to performing the main task.

The inattention-control hypothesis is tentatively confirmed by Allport's results that were obtained in alternating the tasks of a standard and reverse Stroop test. That procedure used two nonequivalent tasks: word-reading and font color-naming. The word-reading task is more difficult than the color-naming, but at the same time it is more habitual. The test subject must perform one task, but to do so he must ignore (not perform) the second one. When Stroop's direct task is being performed, the unattended task is latently formulated; when it alternates with the reverse task it is overtly formulated. There was a switch cost only for a shift to word-reading, but not for a shift to color-naming, because color-naming is always complicated by the process of inattention.

We emphasize that it is the relative difficulty of the main and unattended tasks that is important. On the whole, the more difficult the main task, the lower the probability of a shift to control of inattention. In Jersild's above-mentioned experiments, when alternating tasks were made more difficult the switch cost decreased, because the jump to the unattended task became more complicated.

In Stroop's task, the main task is simpler than the unattended one, so the jump to inattention becomes a frequent occurrence specifically during the direct Stroop test but not during the reverse one. Accordingly, when the conditions of task repetition and alternation are compared, there is a switch cost only for a shift to the reverse task (i.e., from the simple one to the difficult one).

The hypotheses of the study

We hypothesize that task-switching in the absence of external cues is under conscious control. This conscious control is focused on internal operations, since the choice of the following operation is based only on the choice of the preceding one (one or more). Since the operations are highly automatic, the probability that conscious control will slide onto irrelevant tasks increases. In a situation of two alternating, equivalent tasks the highest probability is that control of the current task will shift to control of inattention to the alternative task. This shift may bring about not only an increase in reaction time but also interference-type errors (disruption of the order of alternating tasks).

Increasing the difficulty of the main task may be viewed as a way to reduce interference, since more attention will be paid in this case to performing the main task. One of the ways of increasing the difficulty of the task is to introduce a hierarchy into the sequence of tasks (grouping). The possibility of grouping tasks should also reduce interference and result in decreased switch cost because conscious control in this case will be concentrated on the alternation of groups of tasks rather than single tasks, which will result in a decrease in the number of control operations.

To test these hypotheses, the following study was conducted.

Experiment

Test subjects

Sixty people (ages eighteen to twenty-seven, students and people with a higher education) took part in the experiments. The test subjects were assigned to three groups on a random basis.

Procedure

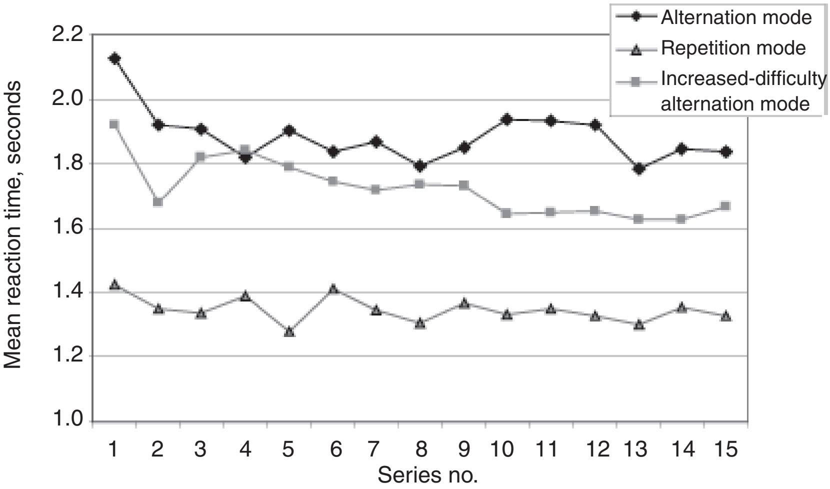
To test the proposed hypotheses, a special methodology was devised. The test subjects' main task was to mentally alternate operations of addition and subtraction of pairs of single-digit numbers (from 1 to 9), sequentially presented one after another. In all, sixteen possible pairs were used (pairs that yielded zero, negative, or double-digit answers were excluded). Each pair of numbers was presented on a computer screen without the appropriate sign, so the subject had to keep track in his mind—that is, under conscious control—of the sequence of operations. The subject would enter his answer in the computer, after which the next pair would appear. If the subject made a mistake, the appropriate error message would appear on the screen. The subject would have to return to the initial sequence.

The task was to be performed as rapidly as possible. The experiment consisted of the continuous presentation of 240 pairs of numbers, one after the other, and took approximately ten minutes. As was already stated, a total of sixteen possible pairs were used. These sixteen pairs made up series that followed each other. All of the pairs were presented an equal number of times, specifically fifteen. The sequence of stimuli in the series was quasi-random.

Therefore, the task lacked any external cues that facilitated the choice of the current operation; neither the stimuli themselves nor the answers communicated any indirect information that eased the choice of an operation. The interval between the test subject's response and the presentation of the following pair of stimuli was zero, so the test subject's reaction time in the task consisted of both the switch cost and the task performance time.

Three groups of test subjects (twenty people each) participated in the experiment. The only difference between the groups was the sequence of the tasks that the instructions prescribed. The test subjects in the first group either only added or only subtracted the numerical pairs that were presented

Figure 1. **Change in Reaction Time as a Function of the Number of Exercises** (series no.)



(task repetition mode). The test subjects in the second group performed both operations in turn (simple task-alternating mode). The third group alternated series of two consecutive addition operations with three consecutive subtraction operations (increased-difficulty alternating mode).

Results of the experiment and discussion

The switch-cost effect (analysis of mean reaction time)

The analysis of reaction time excluded from the calculations trials with erroneous responses and those that directly followed them. Also excluded from the analysis were outliers that exceeded the mean reaction time in a series by more than twofold (which we designated as "lapses"). Errors and lapses indicated that the test subject had strayed from the correct sequence of operations and was spending extra time on retrieving it from his memory. The number of errors and lapses was analyzed separately.

Each test subject performed 240 trials, which during the calculations were broken down into series of sixteen trials apiece, and the mean time in each series was analyzed. Then the average results were analyzed by groups of test subjects, and these data are presented in Figure 1. As was expected, the shortest mean reaction time was observed in the first group, which performed

Table 1

Proportion of Erroneous Responses During Performance of Addition and Subtraction Operations in Alternation Mode (%)

	Erroneous responses as proportion of total		
	Arithmetical errors	Substitution errors	Lapses as proportion of total responses
Repetition mode	2	0	1
Alternating mode (simple and increased difficulty)	1	6	3

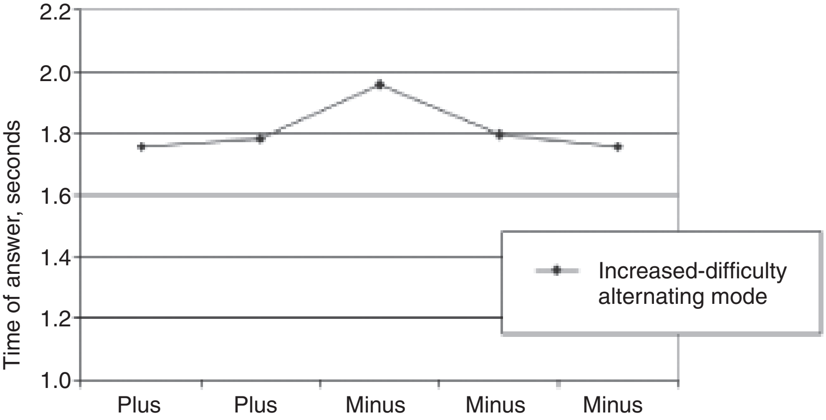
the tasks in repetition mode (the difference was statistically significant). We hypothesized that the increase in reaction time in the switch mode was caused by the emergence of an interference effect in the task-switching process, stemming from conscious control of alternation of the operation. The results of the experiment support the hypothesis. The results of the second and third groups were the most surprising. It was determined that task performance in increased-difficulty alternating mode is more efficient than the performance of similar tasks in simple alternating mode. Mean reaction time in the third group was shorter than in the second one (the difference was statistically significant) (see Figure 1).

The interference effect of control operations (error analysis)

The number of errors and lapses (sharp increase in reaction time) made by test subjects in the alternating mode is greater than in the repetition mode (see Table 1). We should note the difference in the nature of the errors made. When performing addition or subtraction operations in the repetition mode, test subjects made only arithmetical errors (about 2 percent), while in the alternating mode they mostly made substitution errors, that is, they added instead of subtracting and vice versa (about 6 percent), and the number of arithmetical errors dropped (about 1 percent; the difference is statistically significant).

Thus, the average number of errors in the second and third groups was significantly greater than in the first one, yet their very nature was different. Most of the errors in task-switching conditions stem from interference: test subjects perform the wrong operation, adding instead of subtracting or sub-

Figure 2. **Variation of Performance Time for an Arithmetical Operation According to Its Position in the Series**



tracting instead of adding, yet the number of arithmetical errors (incorrect calculations) in the second and third groups is significantly lower than in the first one! In our view, this effect is related to the task itself that the subject is controlling. In the first group control consisted of checking calculations, while in the second and third groups it consisted of checking the correctness of the alternation.

The position effect

We compared how the performance time for an arithmetical operation (addition or subtraction) varied according to its position in the series. In the increased-difficulty alternating mode there were five such positions: the first addition, the second addition, the first subtraction, the second subtraction, and the third subtraction (see Figure 2).

It was determined that the performance speed for a single task in increased-difficulty alternating mode varies according to its position in the series: performance time for the first task in a series of three consecutive subtractions is significantly greater than performance time for the second and third task.

The results of our experiment show that the test subjects had most of their difficulties when shifting from addition to subtraction. What is surprising is that the shift from subtraction to addition was as rapid as the remaining operations (see Figure 2). One might assume that the time difference is related to the fact that the test subjects were better at adding than at subtracting. In the

Table 2

Comparison of Switching Speed from Addition to Subtraction and Vice Versa in Simple and Increased-Difficulty Alternating Mode

Group of test subjects	Proportion of test subjects (in %) who switch more easily: From addition to subtraction	Proportion of test subjects (in %) who switch more easily: From subtraction to addition	Significance of difference according to Mann-Whitney U-test
Increased-difficulty alternating mode	14	86	Difference between groups is significant at $p < 0.01$
Simple alternating mode	45	55	

control group, however, the test subjects broke down into two roughly equal segments: 45 percent of the test subjects were faster at subtraction, while 55 percent were faster at addition (see Table 2). The difference between the mean times for addition and subtraction ranged from –0.4 to +0.3 seconds. Meanwhile, in the experimental group only 14 percent of the test subjects were faster at subtraction and 85 percent were faster at addition (see Table 2). We compared the mean times for addition and subtraction only in the task-switching situation (i.e., for shifts from minus to plus and from plus to minus), and the difference between the mean times for addition and subtraction ranged from –0.2 to +0.7 seconds.

Since the difference between groups was related specifically to the length of the series of alternating operations, it was control of the alternation of the series that caused the time delays. Evidently the performance time for the first task in a series was influenced by the length of the entire series. Therefore, in our experiment the reaction time for the first subtraction in the series of three subtractions proved to be significantly greater, while the reaction time for the first addition in the series of two additions did not. We should note that this result contradicts the above-mentioned Allport hypothesis regarding inhibition of the previous task set, according to which a switch cost should have been observed both for the shift from addition to subtraction and for the shift back.

Results of the postexperimental interview

As a survey showed, most of the people who participated in the study attempted to devise some strategy that would help them not to become confused in choosing a sign. The most frequent strategy proved to be mental repetition of the plus (+) and minus (–) signs (since the instructions forbade talking aloud). Such repetition does not add any new information to the available instructions, which could have facilitated the choice of the necessary sign. This phenomenon matches the well-known technique that is used for learning by heart, that is, repetition of the stimulus material, and apparently is of a related nature. As Allakhverdov (1993) has previously noted, repetition of stimulus material in learning by heart is nothing other than an intuitive attempt by the test subject to select a distractor task that would be congruent to the main task of memorization. Since the main task in our case is alternation between addition and subtraction, repetition in the mind of pluses and minuses helps to fill the consciousness with performance of a supplemental congruent task and thereby reduce the probability that control will slide off.

The effects of verbalization and task-naming by test subjects in a task-switching situation have been noted before. The experiments of Thomas Goschke (2000) showed that this verbalization in itself can make a significant contribution to switch cost. He varied the interval between the subject's response and the presentation of the next stimulus. When the interval was long enough for the subject to be able to name the next task, switch cost decreased severalfold. If, however, the subjects had to utter distractor words unrelated to the tasks, switch cost remained high, regardless of the length of the interval between tasks.

Summary discussion

To sum up, processes at various levels are triggered in task-switching. Tentatively, we can single out the levels of automatic (executive) and conscious control. This division is similar in part to the definition of two types of control by Rogers and Monsell (1995), namely, endogenous and exogenous control. Automatic control, to a large degree, turns out to be a known situation; switching processes will be directed by automatic control if the situation itself provides a basis for anticipating subsequent events (and hence the necessary responses). When a situation does not provide such information, task-switching is based on conscious control, which depends on the test subject's understanding of the content of the task to be performed and, as a rule, is directed by the experimenter's instructions.

Automatic control operates like a "switchman" who blocks alternative tracks of stimulus interpretation throughout the time the task is performed. Such control has an aftereffect, noted by Allport and other researchers. The probability of a response to a specific stimulus is redistributed, which generates a speedier response when the task is repeated and some slowdown when the task is switched. It also may result in implicit learning, for example, if the entire sequence of stimuli is repeated multiple times (Moroshkina, 2003).

Conscious control operates the way a "manager taking a walk" does; it may be focused on both the external situation and internal operations. In task-switching without external cues, conscious control assumes an internal focus. This leads to the point where the current operation, which is being checked, makes its way into the content of consciousness, but an alternative interpretation of the stimuli is also checked, that is, control of inattention takes place. This in turn leads to errors and lapses. A shift to control of inattention occurs if the unattended task is a habitual, automatic one. In particular, repeating one of two messages that are presented dichotically is more difficult when a very familiar, meaningful task is presented through the irrelevant channel (Velichkovskii, 2006).

It is therefore advisable, when performing a sequence of automatic operations, to switch conscious control to an external focus (such effects have been described by researchers in motor learning; see, e.g., Maxwell et al., 2001). If such a switch is impossible, the difficulty of the main task must be increased; then the probability of a shift to control of the unattended task will decrease. One of the ways of increasing difficulty is to consolidate the tasks in a series and switch conscious control to supervision of the series of tasks.

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