Proactive and Reactive Strategies in Interruption Handling

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Abstract

Two interruption handling strategies were distinguished based on experimental data. Reactive strategy implies an immediate switch from the main task after the onset of interruption. Proactive strategy relies on investing additional processing in the creation of a stable, interference-resistant representation of the main task. It is shown that in the though proactive strategy is associated with longer transition from the main to the additional task, it can also lead to quicker additional task execution and main task resumption. It is concluded that proactive strategy can be more effective in the long run. Selection of an appropriate interruption handling strategy is determined by the perceived cognitive complexity of the interruption episode.

Keywords: interruptions; strategy; representation; interference; working memory; resumption.

Introduction

Interruptions are inescapable in modern life. This obvious truth makes the study of interruption effects especially important. Indeed, interruptions are assumed to exert pronounced influence on human performance as well as on affective experience (Zijlstra, Roe, Leonova, & Krediet, 1999; Kapitsa & Blinnikova, 2003). The consensus is that this influence is largely negative, although the experimental evidence is somewhat ambivalent (Burmistrov & Leonova, 2003). In studies of office workers, interruptions were shown to slow the performance down, raise the number of errors, produce fatigue and lead to negative affect (Bailey, Konstan, & Carlis, 2000). In human factors literature, interruptions are made responsible for incidents with severe consequences (Dismukes, Young, & Sumwalt, 1998). Consequently, discovering the mechanisms by which humans manage to handle interruptions more or less effectively is of considerable theoretical and practical value.

One important question in this respect is to what extent the subject is actively involved in the transition between the main (interrupted) and the additional (interrupting) tasks. Does this transition proceed in an automatic manner, triggered by the interruption, or is it actively controlled by the subjects? It will be shown in the present study that possibly both accounts are true as two distinct *modes* (or *strategies*) of transition between main and additional tasks can be distinguished based on experimental data. The *reactive* strategy consists in an immediate switch to the additional task, seemingly without any active preparation. This is a quick way to handle an interruption which can be counter-productive in the long run. For the *proactive* strategy it is assumed that, before the transition occurs, time and resources are invested in some form of preparatory cognitive-behavioral activity, which, for example, can be aimed at making the mental representation of the main task less susceptible to interruption-induced interference. Thus, the proactive strategy can be more effective overall, even if it takes more time and effort initially.

How is an appropriate interruption handling strategy selected? One possible answer is that this is governed by the perceived cognitive complexity of an interruption episode. The more complex an interruption episode is, the more actively the subject will control the interruption handling process. Here, an ecologically valid study of interruption effects is reported, in which subjects were provoked to use either the proactive or the reactive interruption handling strategy by manipulating the level of cognitive complexity of the main task. By manipulating the complexity of the additional tasks, it was also possible to test whether each strategy has a predicted effect on performance during interruption handling.

According to the above description of different interruption handling strategies, several testable predictions about the effects of manipulating the complexities of the interrupted and the interrupting tasks can be derived:

(H1) It can be assumed that subjects used the proactive strategy while switching from complex main tasks (high workload) and the reactive strategy while switching from simple main tasks (low workload). As the proactive strategy takes more time to implement, the time to switch from the interrupted to the interrupting task should be greater in the conditions with complex main tasks.

(H2) Also, due to having a more efficient main task representation, the proactive strategy may lead to a more efficient processing of the additional task itself.

(H3) As the proactive strategy leads to a more effective storage of main task representation, in the condition with complex main tasks we may expect their quicker resumption.

(H4) It can be expected that in the most taxing experimental condition (complex main task paired with complex additional task) interruption handling will be at least as effective as in other – arguably more simple - conditions. This is because in this case the very effective proactive strategy should neutralize possible negative effects on performance.

(H5) In cases with complex main tasks, there should exist an inverse relationship between the time to “enter” the interruption and the time to “exit” the interruption. It is characteristic of the proactive strategy that additional time investment in the interruption preparation phase pays off through easier resumption of the main task after the interruption is over. On the contrary, in cases where the

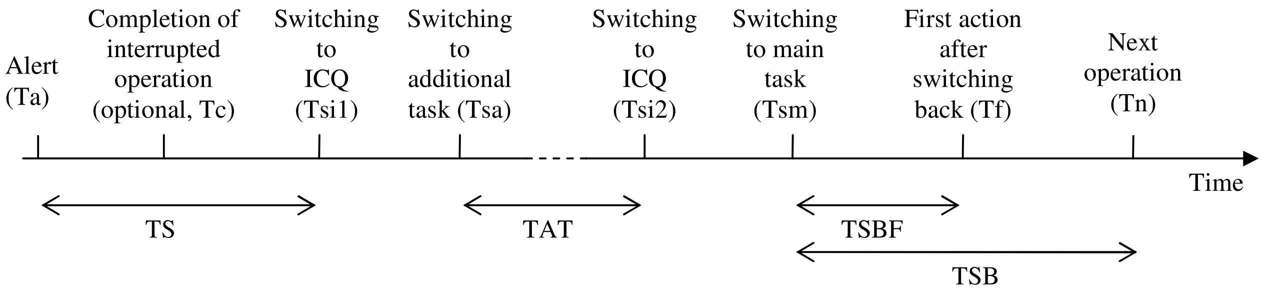

Figure 1: Time course of an interruption episode.

reactive strategy will be selected more often (simple main tasks), there should be no such relationship because there is no causal link between the amounts of processing before and after the interruption.

(H6) For the reactive strategy it is expected that the time needed to resume the main task after the interruption is over will be positively associated with the duration of the additional task. In the absence of an interference-resistant representation of the main task, longer additional tasks have more chances to disrupt working memory main task representations, thus forcing the subject to build it anew. In the case of the proactive strategy the duration of the additional task does not influence the length of main task resumption, presumably because a stable, interference-resistant representation of the main task context was formed and stored securely *before* the execution of the additional task has begun.

(H7) In the present study, the collection of behavioral indices was backed up by recordings of eye-movement activity. It was expected that in the case of the proactive strategy there will be a correspondence between spatial characteristics of eye movements in the preparation and the resumption phase of interruption handling. This would reflect the fact that one manifestation of the proactive strategy is the extraction of visual cues before the transition to the additional task, which are later re-used in re-creating the context of the main task after the interruption is over.

Method

Subjects

42 third year students of psychology from several Moscow universities took part in the study (40 female). Age ranged from 17 to 32 years with mean age equal to 19.8 years. All participants got comparable amounts of computer training during their studies. Part of the subjects got partial course credit in exchange for participation.

Tasks

The main task consisted in editing a 30-page long scientific psychological text according to editor's remarks inserted into it. The editing was done with the use of MS Word software. Each remark consisted of an opening and a closing tag embracing the text part to be edited. The opening tag specified the type of the editing operation to be performed as well as some additional information. There were two types of editing operations: cognitively simple and cognitively complex. Simple editing operation consisted in changing the font of the text embraced between the tags (either to bold, or to underscored, or to italic), which required highlighting the relevant text part and pressing the corresponding button on the MS Word toolbar. Complex editing operation consisted in relocating a text paragraph through "cut-and-paste" procedure (the target location was specified in the opening tag). It was assumed that relocating text parts involved more cognitive workload because it strains the working memory to a much greater extent than changing the font does. The simple editing operations were distributed uniformly through the text with approximately 3 operations for one page. There were eight complex editing operations, distributed uniformly through the text.

The additional tasks consisted in answering questions about air tickets with the help of a specialized website (http://www.pososhok.ru). There were two types of possible questions: cognitively more simple and cognitively more complex. The simple problems involved the decision whether there existed a flight complying with pre-specified characteristics, which would be cheaper than some threshold (for example, "Is there a flight from Moscow to Amsterdam on 27th July 2009 which is cheaper than 400 USD?"). Cognitively complex problems involved the decision whether one of two possible flight routes between two cities is cheaper than another (for example, "Is it true that flying from Moscow to Amsterdam via Frankfurt on 27th July 2009 is cheaper than flying from Moscow to Amsterdam via Stockholm, same day?"). All questions were formulated in a way that allowed a "yes" or "no" answer. The simple questions required getting a list of flights complying with the specified criteria and comparing the price of the cheapest flight with a threshold. The complex questions required finding two pairs of flights (one pair for each of the alternative flight routes), mentally calculating the price totals for each pair and comparing the totals. Obviously, the complex additional task required much more processing than the simple additional task did. On the whole, the subjects perceived the experimental tasks as being representative of modern office activities.

Design

A 2x2 within-subject design was used, with factors "interrupted operation complexity" (OCOMPLEXITY) and "interruption complexity" (ICOMPLEXITY). There was one interruption episode for each combination of factor levels. The order of experimental conditions was counterbalanced across participants according to a Latin square. The interruptions were triggered manually when the subject reached specific locations in the edited document. In the document, the locations were distributed uniformly.

Procedure

The subject worked in a separate room. The screen output of the subjects' PC was made visible via a TV screen to the experimenter, who was seated in an adjacent control room. The experimenter's PC was connected to the subject's PC via an Ethernet network. ICQ 5.1 instant messaging software was installed on both computers, so that the experimenter could send interrupting messages specifying the additional task to be performed when the subject reached specific points during the execution of the main task. Subject's interactions with the computer were recorded into a video file with the help of Morae usability software. A second experimenter was present in the experimental room to monitor the eye-tracking hardware.

At the beginning of the study, the subject was instructed in the use of the text editing software, instant messaging software and air ticket search website. Afterwards, the eyetracking headset was put on, calibration procedure was executed and the subject started the execution of the main task. The subject was interrupted by the experimenter in the control room when he was in the middle of performing an editing operation. No specific instruction was given to the subjects whether they should switch to the interruption immediately. After having left the text editor and read the interruption message in the ICQ window, the subject switched to the Web browser and performed the additional task. After the subject solved the problem posed by the additional task, he switched back to the ICQ window, selected a smiley corresponding to "yes" or "no" answer from a list of smileys provided by the ICQ application, send it to the experimenter and switched back to the main task. All subject's interactions with the computer were designed in a way that only the computer mouse had to be used.

In the course of the experiment, the subject was additionally interrupted by the second experimenter to re-calibrate the eye-tracking hardware. The re-calibration interruptions never occurred during the execution of an editing operation or during a "regular" interruption. There were about 6-8 such re-calibration episodes pro subject which usually took no longer than 5-10 seconds. The execution of the experimental tasks took about 30-35 minutes.

Measures

The videos of subjects' interactions with computer were analyzed and timestamps for critical transition points during every interruption were extracted manually. The transition points of interest and their positions in the structure of the interruption are presented in Figure 1. The durations of critical time intervals, which were used as dependant measures, were computed on the basis of these timestamps. The durations computed are presented in Table 1 and graphically in Figure 1. From the eye movement data, mean saccadic amplitude immediately before the interruption (during the [Tsi1 – Tc] time interval) and immediately after the interruption (during the TSBF and TSB intervals) were calculated as a measure of spatial properties of eye movements. The total time of work on the experimental tasks was computed and used as a measure of computer proficiency.

Table 1: Time intervals within the course of an interruption used as dependent measures.

Duration	Description	Calculation
TS	Time to switch from the main task after the onset of interruption	Tsi1 - Ta
TAT	Time to perform the additional task	Tsi2 - Tsa
TSBF	Time to resume action after switching back to the main task	TSf - Tsm
TSB	Time till the beginning of the next editing operation after returning back to the main task	Tn - Tsm

Eye Movements Registration

An EyeLink I eye-tracking system with 250 Hz sampling rate was used. Eye movements for only the right eye were registered.

Results

Complexity Effects

To test the predictions H1 through H4, 2x2 repeated–measures ANCOVAs were performed on TS, TAT, TSBF and TSB with the total time of work controlled. Marginally significant main effects of OCOMPLEXITY were obtained for TS (F(1,41) = 3.2; $p = 0.081$), TAT (F(1,42) = 3.26; $p = 0.078$) and TSBF (F(1,41) = 3.95; $p = 0.054$). Simple main tasks led to shorter TS intervals than did complex main tasks. On the contrary, simple main tasks caused longer TAT and TSBF intervals. Significant main effects of ICOMPLEXITY were obtained for TSBF (F(1,41) = 6.31; $p < 0.02$) and TSB (F(1,41) = 10.0; $p < 0.01$). It took the subjects longer to resume activity after simple interruptions, but the next editing operation was performed later after complex interruptions. A significant OCOMPLEXITY × ICOMPLEXITY interaction was obtained for TSBF (F(1,40) = 6.1; $p < 0.02$). The time to resume activity in the main task after the interruption was maximal in the condition with simple main task and simple additional task (Figure 2).

Table 2. Spearman correlation coefficients between the durations of time intervals, blocked by experimental condition.

		Simple operation			Complex operation		
		TAT	TSBF	TSB	TAT	TSBF	TSB
Simple interruption	TS	0.04	0.05	0.43**	0.09	-0.29?	-0.49**
	TAT		0.35*	0.21		0.01	0.2
	TSBF			0.55**			0.16
Complex interruption	TS	-0.21	-0.17	0.09	0.15	-0.23	-0.44**
	TAT		0.13	0.3?		-0.11	0.03
	TSBF			0.4**			0.12

** - p < 0.01, * - p < 0.05, ? - p < 0.1

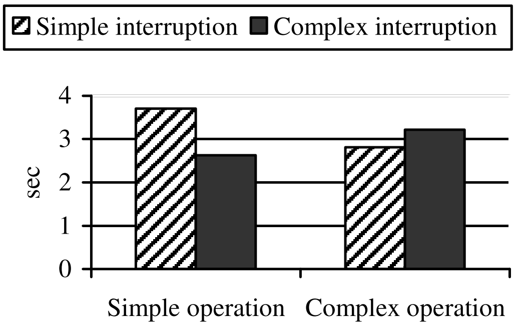

Figure 2: Time to resume activity after the interruption as a function of editing operation complexity and interruption complexity.

Correlational Analysis

An additional correlational analysis was run in order to assess the validity of predictions H5 and H6. TS, TAT, TSBF and TSB intervals were correlated using Spearman correlation coefficient, blocked by experimental condition. The results of the analysis are presented in Table 2. In the condition with simple main task and simple additional task, positive associations were found between TS and TSB, TAT and TSBF, and TSBF and TSB. In the condition with simple main task and complex additional task a positive relationship was found between TSBF and TSB, as well as a marginally positive relationship between TAT and TSB. For both conditions with complex interrupted operation, only TS and TSB were negatively related. Additionally, there was a marginally significant negative relationship between TS and TSBF in the condition with complex main task and simple additional task.

Eye Movements Analysis

In this analysis, prediction H7 was tested. Mean saccadic amplitude (a measure of spatial characteristics of eye-movement activity) during TS, TSBF and TSB time intervals were submitted to an ANCOVA with factors OCOMPLEXITY and ICOMPLEXITY while controlling for the total working time. No effects were found. Additionally, mean saccadic amplitudes during TS were correlated with mean saccadic amplitudes during TSBF and TSB, blocked by experimental condition (see Table 3). In the conditions with simple main task, there were no relationships between the spatial characteristics of saccades before and after the interruption. On the contrary, in the cases with complex main tasks, there was a marked correspondence between the spatial characteristics of eye movement activity before and after the interruption.

Table 3: Spearmen correlation coefficients between mean saccadic amplitude during TS, and TSBF and TSB, blocked by experimental condition.

	Simple operation		Complex operation	
	TS/TSBF	TS/TSB	TS/TSBF	TS/TSB
Simple interruption	0.26	0.0	0.51**	0.44**
Complex interruption	0.05	0.0	0.46**	0.51**

** - p < 0.01

Discussion

In the present study it is assumed that the proactive strategy of interruption handling implies the creation of a stable, interference-resistant representation of the main task prior to switching to the additional task, as well as securing that this representation can be effectively restored after the interruption is over (Oulasvirta & Saariluoma, 2006). The concept of the proactive strategy of interruption handling used here is especially motivated by the studies by Leonova (2003) and Velichkovsky, Blinnikova, & Kapitsa (2007). In the first study it was shown that with progressing complexity of interruptions automatic processing with the dominance of parallel processing mode is replaced by controlled processing with the dominance of sequential processing mode. In the second study, which employed a design that was similar to the one used here, it was shown that in the cognitively simple case of a simple interrupted operation the time needed to perform the additional task was much greater than in the case of other, cognitively much more taxing conditions. This finding motivates the conclusion that in such apparently very simple interruption episodes subjects immediately switch to the additional task without investing processing ressources in forming a compact main task representation and moving it to a secure store (reactive strategy). Therefore, both the main and the additional task are represented simultaneously in the working memory, where they interfere, reducing performance.

In the present study, the complexity of main task was the only factor determining perceived cognitive complexity of experimental interruptions. Thus, it was assumed here that by manipulating the complexity of the main task it was possible to provoke the use of a either the proactive or the reactive strategy. Empirical tests of the predictions H1-H3 showed that, indeed, the assumed use of the reactive strategy was associated with quicker transition to the interruption (main effect of OCOMPLEXITY on TS), but also with longer time on interruption (main effect of OCOMPLEXITY on TAT) and slower resumption times after the interruption was over (main effect of OCOMPLEXITY on TSBF). This pattern of results is indicative of the different interruption handling strategies.

The time to re-orient oneself in the previously interrupted main task (TSBF) can be taken as an index of stability of main task representation formed with the help of the proactive and the reactive strategy. Characteristically, no significant performance decrement was found in the cognitively most taxing experimental condition, which should led to less stability and more interference. This indicates that the proactive strategy can be associated with the use of a more stable main task representation. Paradoxically, the least effective re-orienting was found in the presumably easiest case of simple main task paired with simple interruption. This means that unless an interference-resistant representation of the main task is formed by the means of proactive strategy, possible unanticipated difficulties during the processing of the additional task can easily destroy the working memory representation of the main task used with the reactive strategy. The question arises why it is not the condition with simple main task and complex additional task which produces the largest negative effect, because complex interruptions arguably mean more working memory load and should damage the main task representation to a larger extent. It can be speculated that the subjects can use the time interval between reading the interruption requirements and actually beginning to work on the interruption for a partial implementation of the proactive strategy (safeguarding the main task representation).

The successful tests of predictions H5 and H6 largely support previous conclusions. It was indeed found that in cases, in which the use of a proactive strategy can be assumed, more intensive preparation leads to more effective resumption of the interrupted task after the interruption is over. On the other hand, the assumed use of the reactive strategy is characterized by the instability of the main task representation. This instability is reflected in the presence of a positive association between the duration of the interruption and the resumption time. A longer interruption means heavier working memory load, more decay and more possibilities for unexpected hindrances to occur. Taken together, these factors can damage or even destroy the main task representation provided (as is assumed by the notion of the reactive strategy) it is not held in a secure memory store.

It is also possible that subjects who use the proactive strategy actively extract and encode salient cues during the interruption preparation, which can be used to help to restore the main task context after the interruption is over (Altmann & Trafton, 2004). For visual cues this means that under the use of the proactive strategy the spatial distribution of eye movements immediately before and immediately after the interruption should be similar (that is, before the resumption of the main task begins the subject visually revisits the same locations he was attending to while leaving the main task, prediction H7). Indeed, such correspondence of eye-movement activity was found for the proactive strategy, and, equally important, it was absent for the reactive strategy. This differential result reproduces the pattern found previously and is exactly what is expected on the basis of differentiation between interruption handling strategies.

The results obtained in the present study extend some findings from the task switching paradigm (Monsell, 2003). There, it has often been shown that giving the subjects enough time to prepare for the execution of a new task substantially reduces the overhead associated with the switching (Rogers & Monsell, 1995). Usually, this result is taken as an evidence for the existence of endogenous control processes that govern the transition between different tasks. It can be assumed that in the case of the proactive strategy such higher-order control processes are employed voluntary to raise the overall efficiency of interruption handling.

Several methodological concerns should be noted. First, there were only 4 interruptions pro subject, which was dictated by the realistic nature of the experimental tasks. An attempt was made to compensate for the lowered internal validity of the study by using a relatively high number of subjects (more than 40). It remains to be seen whether the results obtained will be confirmed as more data is accumulated within the proposed paradigm. Second, the complexity of the main task could be confounded with practice effects (there were almost 100 simple editing operations as opposed to only 8 complex ones). However, such intensive practice generally should lead to better performance. The results suggest that, contrary to this expectation, simple main tasks were associated with reduced performance. Third, as mentioned in Procedure section, the subjects were additionally interrupted up to 8 times during the course of the experiment in order to re-calibrate the eye-tracker. While such interruptions could render the experimental interruptions less important, they involved absolutely no activity from the subjects and were considered by them as rest breaks. It can be argued that even if the re-calibration breaks influenced handling of interruptions, they did it in a uniform way, which is supported by the fact that predicted differences were found between the complex and simple interruption episodes despite their presence.

Conclusions

Although it is undisputable that interruptions can have detrimental effect on performance, it seems that applying the proactive strategy can help individuals to "survive interruptions" (Oulasvirta & Saariluoma, 2006). It was shown that the proactive strategy takes more time to switch from the main to the additional task, but is also associated with more effective processing of the additional task and main task resumption. The data suggest that the proactive strategy implies forming a stable, interference-resistant representation of the main task, which allows it to be very effective under cognitively demanding conditions.

On the contrary, the reactive strategy can be described by a quicker transition from the main to the additional task, but the additional task itself as well as the resumption of the main task would take longer in this case. There are indications that subjects using the reactive strategy rely on simultaneous representing both the main and the additional task in the working memory. Such setup, superficially very time-effective, is prone to interference and error, and can lead to performance decrements. Thus, the selection of interruption handling strategy seems to be guided by a simple tradeoff – either quick processing of interruptions with potential negative effects or more time-consuming processing with more predictable results.

The distinction between the proactive and the reactive strategies renders the process of interruption handling as being a complex and a highly adaptive one. It can involve mechanisms of executive control which secure stable performance under the demanding conditions of following several goals at once. The proactivity individuals show in handling interruption episodes reveals that potentially humans are able to withstand the detrimental effects of even most taxing interruptions, provided that they use an appropriate interruption handling strategy and are assisted through specialized technical means. Thus, studying interruption handling strategies can help in achieving the ultimate goal of interruptions being processed effectively and less effortfully.

Acknowledgments

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