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COGNITIVE FUNCTIONS IN THE DIGITAL ENVIRONMENT: WORKING MEMORY AND ATTENTION UNDER REAL AND DIGITAL CONDITIONS

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COGNITIVE FUNCTIONS IN THE DIGITAL ENVIRONMENT: WORKING MEMORY AND ATTENTION UNDER REAL AND DIGITAL CONDITIONS[3]

The digital environment surrounds us everywhere and influences our cognitive system. However, there is a lack of theoretical models in the human-digital domain, and there are few studies aimed at finding the precise mechanisms of how the digital environment influences cognitive functions, namely attention and working memory. The present work is aimed at a consideration of the theoretical approaches and empirical studies related to the marked domain. Two experiments on working memory and attention were carried out. In the present paper, we have compared the attention and working memory processes under real and digital conditions within the comprehensible task like usage of the organizer (Experiment 1). As a result, we clarified the presence of differences in attention and WM within these two environments of performance. After that, the focus was shifted on digital properties: Experiment 2 focuses on such digital properties as saturation and were aimed at clarifying the attention process (shifting and sustainability of attention) under digital conditions. So if the digital system has feedback, the rates of attention sustainability will be higher than in the absence of feedback. Thus, within the result of the second experiment, it can be supposed that the digital environment might be considered as a system of cues improving the performance of complex tasks.

JEL Classification: Z

Key terms: a digital system, a cognitive system, attention sustainability, attention shifting, working memory, the complexity of the digital system

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Introduction

Our present-day life is unthinkable without digital tools such as computers, smartphones, and tablets, etc. This raises questions about the impact of this close interaction on cognitive functions and, as a result, on comprehensive theoretical and experimental studies. However, not much is known about the properties of the digital environment in terms of processing human information. Several theoretical approaches endeavor to develop a system of understanding about human-digital interaction (Falikman M, 2021) as well as some empirical studies that show different kinds of changes taking place in the working memory, attention sustainability and shifting under digital conditions (Wilmer, H. H., Sherman, L. E., & Chein, J. M., 2017). Nevertheless, there is a gap between the theoretical and empirical understanding of the specific digital influence on attention and working memory.

Literature Review

Several approaches can be identified that work in one way or another with the above-mentioned constructions and try to understand the interaction between them - distributed cognition, extended cognition, the science of artificial, human-computer interaction (HCI), artefact ecology, and digital ecology (Falikman M, 2021). It is worth noting that all the approaches highlighted here are very closely interrelated. These approaches have in common to blur the boundaries of the cognitive system and include surrounding tools, among them digital gadgets, into an individual's activity. However, the extent of including and format of it is different. For instance, in the approach of distributed cognition, the instrument is a cognitive artefact, which changes the course of the activity itself and redistributes, in particular, cognitive resources. However, the cognitive artefacts are just means of scaffolding. Whereas the digital tools as cognitive artefacts are more complex, and, following the science of artificial, HCI and digital ecology, they can evolve under interaction with humans, but it is still a distinct means to reach the goal of human activity. Another example is an activity-centered design (ACD), which is included in a HCI approach and distributed cognition theory and based on the theory of activity of A.N. Leontiev (Williams, 2009). ACD approach focuses on human activities in the digital environment in general and on ways to optimize these activities. The main contribution of ACD is that this approach raises the question about what tasks or activities must be enabled by the digital system (Williams, 2009). At the same time, in the extended cognition approach, the tool-like digital device becomes a part of a new system – a coupled system, one where cognitive and artificial parts work together and the artificial is an integral part of the cognitive system. Here the digital system is not the tool, it is a unique part of our reality, providing access to plenty of new functions and possessing some level of autonomy and complexity. Thus, mentioned theoretical approaches try to outline and characterize the human-digital interaction, but without any certain constructs, which can be operationalized for empirical tests. However, ideas that come from them suggest that human interaction with the digital environment has the potential to alter the course of cognitive processes. The opened question is in the specific digital properties responsible for that changes. Some scholars pinpoint the key features in the digital system such as editability, interactivity, re-programmability and distributedness (Kallinikos et al, 2013). Nevertheless, these properties reflect just the digital entity and are not linked with the cognitive functions directly.

Turning to the consideration of empirical studies, it should be noticed that researches might be divided into comparison studies (comparison of cognitive functions under real and digital conditions) and the digital environment studies themselves (variation of some parameters in digital tools). In the context of comparing cognition in real and digital contexts, there are far fewer studies to date than those that focus solely on cognitive function in digital contexts. The most revealing is the study of short-term memory under conditions of recall and recognition (Snow et al., 2014), where significant differences were shown between groups of memorization real objects, their photographs, and their black and white (drawn) version on the screen. The subjects demonstrated significant differences both in terms of accuracy and in terms of errors, which allowed the authors to conclude the best memorization of real objects in comparison with other conditions. The advantages of memory for real objects can be associated with additional binocular signals about depth and distance. The same results occurred in the investigation of infants' perception of real objects and pictures of those objects in 7- to 9-month-old groups (Gerhard et al., 2016). In addition, there is neuroimaging evidence that confirmed behavioral experiments of perception and memorization in both conditions (Snow, 2011).

As far as known, there are several studies aimed at showing the impact of digital devices on attention sustainability and shifting. For example, in the study of Ophir (2009), participants were separated into two groups by their subject reports according to the ordinary number of digital content items consumed simultaneously: heavy media multitaskers and light media multitaskers. Then researchers examined participants' attention and working memory by several different methods. As a result, the heavy media multitaskers performed worse in all tasks especially as those tasks became more complicated. Ophir interprets the obtained results in terms of the heavy multitaskers' low ability to focus attention, and frequent attention shifting on irrelevant information, which points to a low filtrating capability (Ophir et al.,2009). The study demonstrates the importance of the everyday use of digital systems in the context of changing cognitive functions. However, this study shows only a long-term influence by digital multitasking habits on general attention capacity.

Giving special emphasis to the direct impact of digital systems on attention, the research of Stothart (2015) elucidates light on the sustainability of attention in the presence of digital media. In this study, participants had to press a bottom each time they saw a number from 1 to 9, except for 3 (Sustained attention to response task – SART). During the performance, participants might get text messages on a personal phone, calls, or nothing (control group). Notably, participants did not interact with the cell phone, and if they did, the authors excluded them from the analysis. The obtained results show the decreasing of attention sustainability, and researchers describe results as promotion task-irrelevant thoughts by notification (Stothart et al., 2015). In general, the results demonstrate a sensitivity of attention to the digital exogenous interruption, but it does not show the direct influence produced by the digital task space.

Another interesting example is a study of working memory, closely related to the attention construct, which also shows changes when the gadget is near. This research was conducted by Ward (2017), and the authors used the Automated Operation Span task, when participants have to retain some sort of information, then calculate an equation, and then realize what they had retained. In addition, they used a Go/No-Go task, resembled on SART, to exam the attention sustainability. As a grouping factor, they used the extent of gadget presence: on a desk, in a pocket, in another room. Notably, all phones were turned on silent without vibration. According to Ward's experiments, even when participants maintain attention sustainability, the mere presence of these devices reduces working memory capacity (Ward et al, 2017). This example illustrates how a person can rely on a gadget, thereby reducing cognitive ability. Nevertheless, the question of what in the digital environment immediately affects us remains open.

Finally, another promising line of research is the impact of content richness (saturation) on attention. In Levy's study (2016) participants were divided into five separate groups by type of disruption to be received: text banners or graphic banners, popped out browser windows, text SMS or picture MMS, and a control group. During the experiment, they had to play a competitive Internet-based game, while messages were being received. As a result, the group with graphic banners and picture MMS disruption had the longest recovery time of all the groups. Thus, Levy demonstrates that content saturation will have an impact on the duration of the return to the task(Levy et al, 2016). This study emphasizes the crucial aspect of further research direction – the richness/saturation of digital systems. However, in Levy's study richness was not a part of task space (in that case, a game), but just an external destructor.

Taken together, the empirical studies demonstrate diverse and sometimes conflicting evidence about the direction and details of influence by the digital system on cognitive capability (Firth et al., 2019). Also, there is a lack of comparative studies that are aimed at the investigation of working memory and attention under distinguished conditions: real and digital. Another issue is uncertainty in understanding what has to be variated in a digital system during humans' interaction with gadgets – what are the digital properties that should be variated? For that, certain features of the digital system have to be built up, and then a valid test has to be used to examine the attention in different digital conditions.

Research question and main assumptions

Based on the previous part of the paper, it can be concluded that there is currently no unified theoretical understanding of the interaction between the digital environment and the cognitive system. Identifying specific properties of the digital environment with their refraction through the cognitive system seems to be a difficult task. The empirical studies show differences in the cognitive process performance dependent upon the condition of such performance. Also, various studies dedicated to cognition in the digital environment demonstrate a diversity of digital influence. However, these studies provide just local examples of impact without reference to the existent approach or any specific system of digital properties. As mentioned earlier, there are some attempts to emphasize the set of digital properties (Kallinikos et al., 2013), where the property of interactivity can be considered relevant as a construct linked with cognitive functions. Moreover, some empirical studies (Ophir et al.,2009, Levy et al., 2016) highlight the constructs like richness, multitasking, and destructing of the digital environment. Taking it together and adding the ACD idea of the auxiliary potential of the digital environment, we can propose the following digital properties.

We suggest that the complexity of a digital system through the cognitive system can be expressed through the properties of saturation and degrees of freedom. These parameters are highly variable in their operationalization, implying further adjustments as empirical data and theoretical representations. By the saturation of the digital environment, we will understand the property of the digital environment to contain a large number of interactive elements of different characters: feedback from the interface element, notifications, banners, and information not related to the task at hand. We assume that the saturation might primarily affect the attention – disrupt, reallocate, overload the attention. Thus, the environment's saturation should be understood as a system of guidance that directs our attention or can disturb it. The critical point is that information organization can be incorporated into the notion of saturation as one aspect of the guidance system.

Another construct we identify is the degree of freedom, which can be defined as the property of the digital environment to contain capabilities (affordances, the space or system of affordances) that change the way of activities, i.e., change the search, processing, storage, and application of. In this case, we assume that the degrees of freedom of the digital system can influence the strategies of the cognitive system, such as information retrieval, memory, reasoning. In the present paper, we have just focused on saturation construct and comparison of cognitive functions under real and digital conditions. Thus, the elaboration of suggested constructs (saturation and degrees of freedom) is a goal for further research.

In the present research, we have attempted to compare the attention and working memory (WM) processes under real and digital conditions within the comprehensible task like calendar usage (Experiment 1). Experiment 2 focuses on such digital properties as saturation and aims to clarify the attention process (shifting and sustainability of attention) under digital conditions.

Empirical section of the present study

Experiment 1

The first experiment was aimed at comparative analysis of working memory (WM) and attention under real and digital conditions. The first stage was a pilot, after which corrections for the main study were made.

The central hypothesis in this stage was differences in working memory performance and attentional performance (shifting and sustainability) in real and digital environments. The real environment was implemented in a paper organizer, and the digital one was a computer organizer (the description below). We generally compared speed (total time spent by the subject on trial), the number of correct/incorrect filled slots and the total amount of processed slots in the working memory task, correct detected slots, and falls alarm in the attention task.

Description of the conditions

Participants were randomly assigned to one of the groups – digital or real condition. Participants in digital condition performed tasks on the computer, and real condition did the same tasks on paper. Both conditions had the same appearance - a Google calendar interface (Fig.1). In the digital condition the participants performed the task on the real Google calendar website, while in the real condition the participants dealt with the printed version of the Google calendar pages. The digital condition was made on ASUS ZenBook UX305 computer, screen resolution - 13, 3 (3200×1800). The real condition was made on paper, size – A4 (210×297 mm). The experiment was recorded using the Bandicam program for the computer version and the Go-pro hero camera for the paper version. Later, the records were used to compare the time with the stopwatch data, which directly recorded the time during the experiment.

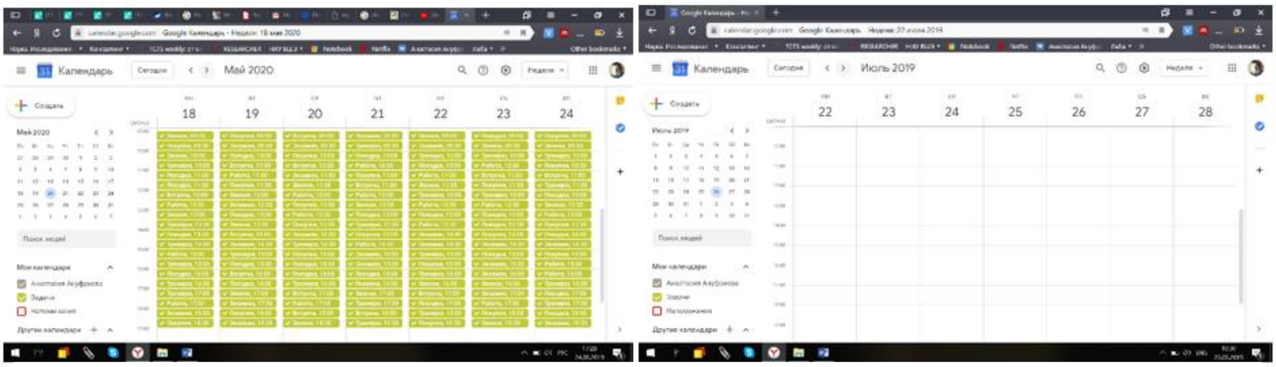

Figure 1. The appearance of the task space (Experiment 1)

Description of the pilot stage

In the pilot stage, 22 participants took part in the experiment. In the pilot frame, the exploratory comparative analysis was carried out to establish a baseline of differences between parameters of WM and attention under real and digital conditions. The methods described below were the same with one difference: the duration for each trial in every method was 2 minutes. As a result, subjects from the real group managed all tasks faster than subjects from the computer group, which can be explained in terms of motor activity. In the context of the visuospatial sketchpad task, the most intricate result was a proportion of processed slots and accuracy in time: the real group was faster than the digital group, the real group filled more slots within-trial and made fewer mistakes in comparison with the digital group. Roughly speaking, in 1 minute real group do 10 units of task and make 2 mistakes, whereas digital group do 5 unites and same 2 mistakes. Therefore, there was not a trade-off between accuracy and speed of performance. Furthermore, there was only one task that showed significant differences by all parameters – the Modified Burdon test. In these tasks, the real group made fewer mistakes (falls alarms), found more slots correctly (correct detected slots), and was faster compared to the digital group.

After all, we have designed an experiment where we diminish the time of task execution (1 minute for all methods), increasing the total number of participants to 65, add Bourdon test in a classic form (presented on paper before the main part) for test the hypothesis of equality by sustainability between groups.

Sample

The empirical part of the study was implemented on the basis of Department of psychology, National Research University Higher School of Economics. 65 volunteers aged from 18 to 28 years (M=21.5, 37 female) with normal or corrected to normal visual acuity, without neurological disorders, were invited to participate for course credit. All participants provided written informed consent. We did not seek approval by an institutional review board for the experiments because it is not required for a study of the type reported in this manuscript.

Procedure and methods

First, each subject took a survey in Google forms in order to determine the experience of using the organizer and the preferred environment for work: computer and paper. The subjects were assigned to one of two groups: A - digital and B – paper based on the data obtained. Thus, there are 4 subgroups by the experience of using the organizer: 0 – no experience, 1-digital organizer,2-paper organizer,3-usage of both types.

Therefore, the next proportion was obtained:

In A group – 8 people in "0" subgroup, 11 in "1", 8 in "2" and 8 in "3" (Total 35 people).

In B group – 7 in "0",7 in "1", 8 in "2" and 8 in "3" (Total 30 people).

The subjects were told that they were expected to pass an experiment with 4 tasks. All tasks were presented in a random order. For each task, an instruction was prepared on the screen/paper and the experimenter made further verbal clarifications by the subject's request. Four tasks were elaborated for testing, and their description is given below.

The WM tasks

Phonological loop task

Subjects were presented several phrases auditory (the recording) for 5 seconds. Two conditions were used: "day of the week – type of activity" and "day of the week – type of activity – time". The task was to fill in the task space of the organizer according to the content of the audio recording. The time was limited to 1 minute. The task lasts about 10 minutes and contains 8 probes (4 for each condition).

Visuospatial sketchpad task

Subjects were shown an organizer for 5 seconds with the slots filled in (varying the number of slots on the spread to be memorized). They were then presented with a to-do list (the to-do list was available from the beginning of the trial). Their task was to write out as many to-dos's from the list as possible in 1 minute, so the to-do would not overlap with the slots they had already seen in the organizer before. The task lasts about 5 minutes and consists of 4 probes (2,3,4 and 5 slots on screen for memorization).

The attention tasks

Modified Bourdon test

Subjects were presented three words for memorization by 5 seconds. After that, subjects had to find and cross out all the words presented earlier in the organizer (find and cross out correct slots surrounded by distractors. The time was limited to 1 minute. The task lasts about 6 minutes and contains 6 probes.

Shifting task

Subjects were presented the combinations of the day of the week and the type of cases for 5 seconds. In each trial, the subjects had to cross out one type of stimulus on certain days and another on other days. In each trial, pairs of target stimuli are replaced. The task was to search for combinations on the spread and cross them out; in addition, the subject had to change the target (the combination) he was searching for by command of the experimenter every 15 seconds. The total time for this task was 1 minute. The task lasts about 6 minutes and contains 6 probes.

In addition, all of the subjects passed the N-back to control equality of working memory capacity between groups and passed the classical Bourbon test with Russian letters on paper as a method to control equality of attention sustainability between groups.

Data analysis

Comparison of groups A and B based on the results of the n-back task showed no significant differences between the groups ($W = 56.5, p = 0.61$). The classical Bourbon test as a method to control equality of attention sustainability between groups showed no significant differences between the groups ($W = 53.5, p = 0.54$). In addition, analysis of covariances showed that "subject's experience" does not impact on obtaining results (all $p > 0.05$).

The phonological loop task showed the following results: in the condition of presenting audio recordings "day of the week – type of activity", no significant differences were found between the groups by all parameters (volume, mistakes, corrected written out words) under all conditions (for all $p > 0.05$). However, in the conditions of presentation "day of the week – type of activity – time", significant differences were found only in the accuracy (as the corrected written out words) in prob with 5 stimuli ($W = 341.5, p < .01$)

The visuospatial sketchpad task showed significant differences in parameters of the number of written words and their correctness (see Table 1). There are no significant differences in other parameters like intersections and mistakes (for all conditions $p > 0.05$)

The number of stimuli	The differences in the number of written words	The differences in the correctness
3	$W = 227.5, p < .000$	$W = 176, p < .000$
4	$W = 154.5, p < .000$	$W = 108, p < .000$
5	$W = 138, p < .000$	$W = 140.5, p < .000$

Table 1. Comparison of real and digital group in the visuospatial sketchpad task. The results of the Mann–Whitney U-test.

The results of the attention shifting task showed significant differences between groups only in time of execution ($p < .02$) and no significant difference in any other parameters like mistakes (crossing the wrong task, crossing in the wrong day), the amount of non-found slots and the number of correctly detected slots (for all $p > 0.05$).

The only task that showed significant differences in all comparison parameters was the Modified Bourdon test. There are significant differences in the number of crossed slots, mistakes as crossing wrong slots, the amount of non-found slots, and correctly detected slots under all conditions (for all $p < 0.001$)

Discussion of Experiment 1

This study aimed to test the hypothesis about the influence of environmental type (real and digital) on the parameters of working memory and attention. To test this hypothesis, we developed a series of previously tested tasks in the pilot study.

Before considering the obtained data, the limitations of the study should be clarified. The study's main limitation is the lack of control over the way tasks are performed between groups. By this we mean that the groups were equalized by all the parameters of the execution of the tasks, except the way the tasks were performed - the real group wrote by hand and the digital group answered by mouse (touchpad) keyboard. We clearly understand that the purity of the comparison requires using the tablet as a digital medium where the actions are executed by the stylus (handwriting). We intent to eliminate this limitation in future studies. The next constraint is that when the tasks on the computer were performed, the browser page (the space to do the tasks) was loaded for an average of 10 seconds, making it possible to repeat the material. The impact of this constraint can be reflected in the accuracy of the tasks, but the results do not show a clear impact of this constraint. Despite this, the restriction requires the development of forms of control.

This study shows that we can discover differences in some parameters of working memory and attention, which partially supports the main hypothesis. The motor constraint described above can directly affect the speed of the tasks, which is confirmed by the tests: the real group performs much faster than the digital group. However, the ratio of realized units of tasks to the accuracy of execution is remarkable for the Modified Bourdon test and the visual sketchpad task. The real group in both these tasks was more accurate, faster, and made fewer mistakes.

Concerning attention shifting task and phonological loop tasks, the pattern of differences is ambiguous. In the attention shifting task, we can see that the differences occur randomly. We attribute this to the less attention-shifting sensitivity compared to the sustainability property, that is, shifting attention from one target category of stimulus to another one in real and digital environments does not demonstrate a direct environmental impact. However, this may add the impact of the task difficulty. That fact can be indicated by the result of the phonological loop task - significant differences appear only in the maximum loading condition (condition 5 audio recordings, each consisting of 3 elements).

Concerning the results of the Bourdon test (sustainability of attention), we suppose that idea of attention as the central executive component of working memory system (Engle, 2018) can explain the results in another part of our present study, for example, the result of Visuospatial sketchpad task. In addition, sustainability might be sensitive to overload produced by the "richness" of environment properties (Roda, 2011, Lee et al., 2015). Such properties can include the stability of perception of elements, the number of possible actions and consequences, and the possibility of performing auxiliary actions. The digital environment can be classified as less stable, more saturated, and not conducive to performing auxiliary actions. The using this type of environment, the subject has to increase selective attention to keep relevant and suppress irrelevant information. Therefore, we consider attention as a focus of our future study.

Experiment 2

Based on the review of theoretical approaches in the field of human-digital interaction, the construct of "digital saturation" was identified, which is hypothesized to affect visual attention performance (see "Research question and main assumptions" passage). In this construct, the general hypothesis was formulated that measures of sustainability and shifting attention would differ significantly between simplified (unsaturated) and complex (saturated) digital environments. Based on cognitive loading theory, it can be hypothesized that sustainability and shifting will be higher (more accurate) in an unsaturated environment. An alternative hypothesis, based on an activity-centered design approach, is that a saturated environment contains cues about affordances that guide attention. This hypothesis predicts that sustainability and shifting performance will be higher in a saturated digital environment.

This study proposed to vary the degree of digital "complexity" expressed in the saturation - the property of a digital environment to contain many interactive elements of various kinds. The digital saturation is operationalized in this paper as the system's response (feedback) to the subject's action - a change in the color or state of an interface element when it is hovered or clicked on with the mouse. In the context of this part of the study 2 experiments with intergroup plans were conducted. The first experiment (Experiment #2.1) aimed to investigate attention sustainability in 2 digital environments: simplified/unsaturated and complex/saturated. The second experiment (Experiment #2.2) aimed to study the shifting of attention in the same digital conditions.

The complex/saturated condition was operationalized as a website with all the interactive elements developed for the study. Thus the specific real site was used in the experiment (see Fig.2). In the saturated condition, subjects worked on a website where all elements gave a hover/click response, the top and bottom panels were interactive (part of the browser). The simplified environment condition was a screenshot of a computer screen without interactive elements (implemented in Psychopy).In the simplified condition, subjects worked in full-screen mode, so they only saw the screen, where the top and bottom panels were part of the screen, so there was no change when hovering over any interface element. Only when they clicked on a word in the blue slot did a crossed-out line appear. The modified Bourdon test was used to measure attention (correct detection and false alarm). The modified part of the test is the form of its presentation: the typical calendar design was recreated (the Google calendar was a reference), the search words resembled the form of a to-do note in a diary. The subjects from both groups saw almost the same task space with the only difference – feedback of a system. In addition, a critical remark is that in the complex/saturated condition, the browser and the bottom control panel belonged to the personal device since the experiment was conducted online.

Thus, the modified Bourdon test was presented either in Psychopy (via the Pavlovia online service), where most elements are not interactive, and only stimulus slots responded by crossing out the stimulus when clicking on a word (simplified/unsaturated digital environment condition), or the test was performed on a website, where all elements are interactive, i.e., performance is as close to natural use of the website as possible (complex/saturated digital environment condition).

After completing the experiment, all subjects were asked to indicate how many tabs were open at the time of the experiment (for the simplified condition, subjects were guided by the number of browser tabs on the screen), did they were distracted by the cellphone, notifications, how difficult they found the task on a 5-point scale, whether they used a mouse or touchpad, whether are they used to diaries, if so, which one (paper, electronic, both) they prefer. This information was then used for a covariance analysis.

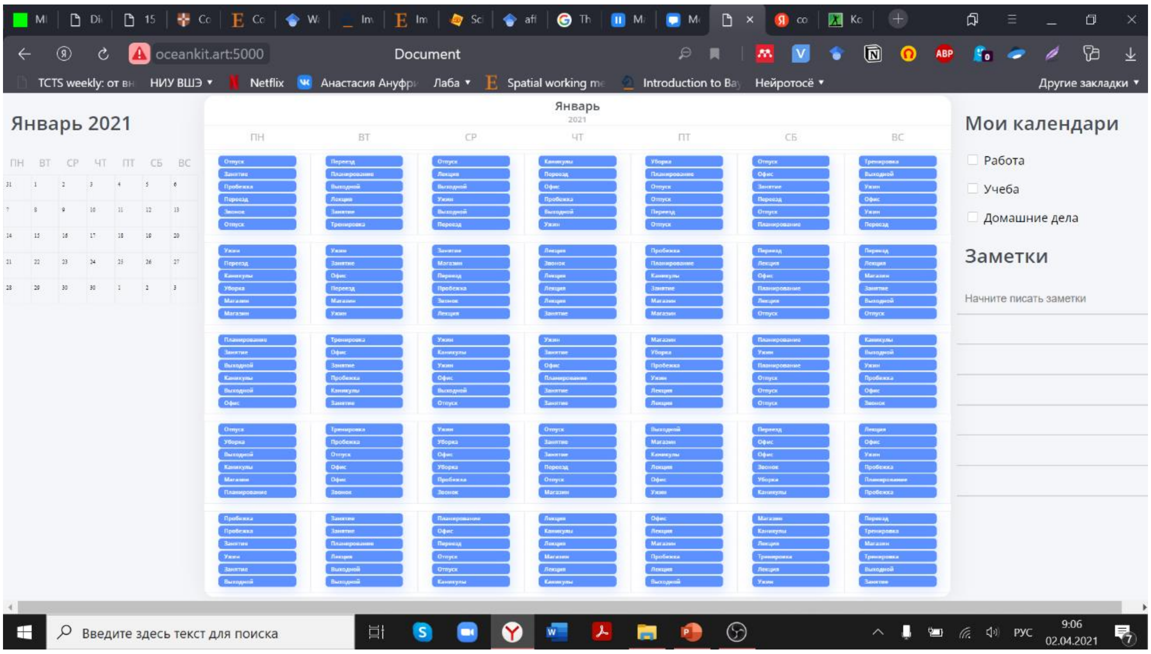

Figure 2. The appearance of the task space (Experiment 2.1 and 2.2)

Experiment 2.1.

The general hypothesis of experiment #2.1 was that the parameters of sustained attention would differ significantly in the unsaturated and saturated digital environments. Under the assumption of high attention load (Cognitive load theory), accuracy scores (number of correctly detected slots and false alarm) in the modified Bourdon test were expected to be higher in the unsaturated condition (version without interactive items), and the time taken to complete the task would be lower in this condition than in the complex condition (interactive site). An alternative hypothesis based on the activity-centered design approach suggests that accuracy rates will be higher under the saturated condition, and the time for performance would be lower.

Preliminary two subgroups of the saturated condition group were compared to test the hypothesis about the effect of experimenter control on task outcome. The first subgroup consisted of 15 people who underwent the experiment in the Laboratory for the Cognitive Psychology of Digital Interface Users in the presence of an experimenter, using standard laboratory computers. The second subgroup consisted of 15 people who were sent a link to go through the experiment; they went through the experiment on personal computers without the experimenter's control. The comparison of the two subgroups resulted in no significant difference in either the number of correctly found words or the number of distractors ($W = 410.5$, $p = .56$, $r2 = .00$) . This fact allowed further data to be collected in a remote format through the link.

Sample

The empirical part of the study was conducted based on the Psychology Department of the Higher School of Economics. Students with normal or corrected vision without neurological disorders were recruited (42 participants). Participation in the experiment was rewarded with a bonus point in academic disciplines. All participants provided written informed consent. An additional 30 people were recruited using the Yandex.Toloka, where participation was rewarded with a fee of 60 rubles (about 70 cents) for a 30-minute experiment. Participants from Yandex.Toloka was selected using special filters (age from 18-30, native language Russian, citizenship Russia). The exclusion criterion for them was the time and quality of the task: if the subject completed the task in less than 25 minutes, their data were excluded; if the subject made only three clicks in each trial, their data were not accepted. At the stage of data processing, 4 persons were excluded because they did not follow the instructions; thus, the final sample was 68 subjects aged from 18 to 30 years old (M=23.4, 30 men; 34 - complex, 34 - simplified condition). We did not seek approval by an institutional review board for the experiments because it is not required to study the type reported in this manuscript.

Procedure

During the experiment, participants in both groups memorized three words shown to them for 5 seconds. After that, they searched for all the slots that contained the target words for 1 minute. The total number of stimuli in each sample was 210 (grid of 30 rows and 7 columns). The number of target stimuli per sample varied: 10/25/45 percent of all stimuli, 10 trials for each condition, hence a total of 30 trials. Data were collected by sharing a website link or link to the Pavlovia service.

Results

The data were analyzed using the software R v. 1.2.1335. Accuracy (number of correctly detected words - targets) and error rates (number of false alarms - distractors), as well as the task completion rate (the number of total stimuli found divided by the time of the sample), were analyzed. Mann-Whitney test and two-factor mixed ANOVA were used as statistical tests to test the hypothesis of differences between the groups.

The normality of the distribution was tested using the Shapiro-Wilk test; the distribution was significantly different from normal ($p < .003$). From data analysis, significant differences were found between the groups with saturated and unsaturated ($W = 4361.5, p < .04, r^2 = .02$). A two-factor mixed ANOVA was performed to compare the groups, with the group as the between-group factor and sample type as the within-group factor. According to the Mauchly test, sphericity of the data was impaired ($p \leq .022$), as a consequence of which Geisser-Greenhouse corrections were made (data from further tests are given with corrections), the Lievene test confirms homogeneity of variance between groups ($p \geq .152$). A significant effect of group ($F(1, 66) > 6.31$, $p < .011$, $\eta p^2 = .072$) and trial type ($F(2, 132) > 694.83$, $p < .000$, $\eta p^2 = .70$) was found; a significant interaction between factors was found ($F(2, 132) > 4.61$, $p < .023$, $\eta p^2 = .013$).

Further comparisons were made between groups by trial type (10/25/45 percent target stimulus). Comparisons using analysis of variance yielded significant differences between the groups for all trial types (see Table 2)

Trial type by percentage of target stimuli	The result of analysis
10% target stimuli	$F(1, 67) > 5.32, p < .02, \eta p^2 = .08$
25% of target stimuli	$F (1, 67) > 5.41, p < .02, \eta p^2 = .08$
45% target stimuli	$F (1, 67) > 6.15, p < .02, \eta p^2 = .09$

Figure 3. Results of A two-factor mixed ANOVA analysis by trial type in Experiment 2.1

An analysis of the differences between groups in the number of 'false alarm' errors (pressing a non-target slot) showed no significant difference between the experimental groups ($W = 4877.5, p < .44, , r^2 = .00$).

A two-factor mixed ANOVA was performed to compare the groups on the number of 'false alarms', where group was the within-group factor and sample type was the between-group factor. According to Mauchly's test, sphericity of the data was intact ($p \geq .26$), according to Leaven's test, variance was homogeneous ($p \geq .51$) There was a significant effect of the sample type factor ($F (2, 132) > 4.431, p < .01, \eta p^2 = .03$), but not the group factor ($F(1, 66) > .021, p > .89, \eta p^2 = .00$). No significant interaction was found between factors ($F(2, 132) > .93, p < .44, \eta p^2 = .00$).

Analysis of the total number of clicks showed that under the saturated condition averaged 26,2 clicks per 60 seconds were made and under the unsaturated condition 22,1 clicks per 60 seconds, the differences being statistically significant (*W = 409551, p < .00, , r^2 = .02*), indicating a higher rate of execution in the saturated condition

Additionally, a covariance analysis was performed where the covariates were the responses to the post-experiment survey. Results of the analysis of covariance showed no statistically significant effect of the following factors: number of tabs, experience of using a planner, preferred type of planner, subjective feeling of difficulty and distraction ($p \geq 0.5$). Post-experimental survey analysis yielded the following distributions of responses about the number of open tabs: in the simplified condition, 5,4 tabs were opened on average, and 7, 4 in the complex condition; statistical differences were not significant (*W = 459.5, p > .13*). Subjective task difficulty was rated by subjects in the unsaturated condition as 3,5 out of 5 on average and 3,1 out of 5 in the saturated condition; differences were not statistically significant (*W = 687.5, p > .17*). When asked about the fact of distraction during the experiment, the following answers were obtained: for the group in the unsaturated condition: 27 out of 34 responded that they were not distracted, in the saturated one - 30 out of 34. In the question about the experience of using organizers in the group with the unsaturated condition, 16 out of 34 subjects had experience of using organizers, 7 of which preferred using paper, 7 electronic and 2 used both types. In the saturated condition group, 13 out of 34 had experience of using dailies, 5 preferred paper, 5 electronic and 3 used both types. Using a computer mouse or touchpad also had no significant effect on task performance (*W = 449.6, p > .23,r^2 = .02*).

Discussion of the results of Experiment 2.1.

The results show that the higher rates of attention sustainability were in the saturated environment than in the unsaturated environment; also, the rate of execution was higher, but without loss of accuracy (the number of false alarms was the same as under unsaturated condition). Thus, the results are consistent with the activity centered design approach, which assumed that attention sustainability rates would be higher in a saturated digital environment due the interface's cues.

Based on the results, it can be assumed that the feedback helps to keep the attention on the activated element or region of the interface. In such a case, the feedback may act as a kind of cue, the presence of which allows the actual focus of attention to be actualized, thereby leading to higher rates of accuracy and tempo of task performance. According to some studies, low sustainability rates can be observed in digital environments with impaired usability principles (Wang et al., 2014). The present study was performed without violations of basic usability principles and with the preservation of all calendar/organizer type sites interface. This fact suggests that saturation influences of different sources were excluded and, consequently, the findings are the result of the experimental conditions.

The original assumption was that an unsaturated environment (due to its lack of responsive elements (color and state changes in interaction) considered distractors) would "help" conserve attention resources. However, the idea of considering the system response as a cue is consistent with the activity-centered design approach (Norman et al., 2005), where the system response directs attention to objects that contain affordances and relevant information. In this way, a saturated digital environment, through a feedback system that prompts the presence of affordance and actualizes the focus of attention, ensure that attention resources are saved, resulting in higher attention task performance.

Experiment 2.2

This experiment compared attention shifting in a digital environment. Attention shifting was defined as a change in the search target by an auditory signal(resembled cellphone sound). The general hypothesis of Experiment #2.2 was that attention shifting performance would be significantly different in unsaturated and saturated digital environments. In the context of Cognitive load theory it is hypothesized that in the saturated digital environment, accuracy scores (number of correctly detected words) in the modified Bourdon test were expected to be higher in the simplified condition, and also the time taken to complete the task would be less in this condition than in the complex condition. An alternative hypothesis based on the activity centered design approach suggests the opposite results.

Sample

The empirical part of the study was conducted based on the Psychology Department of the Higher School of Economics. Students with normal or corrected vision without neurological disorders (30 participants) were recruited. Completion of the experiment was rewarded with a bonus point in disciplines. All participants provided written informed consent. An additional 43 people were recruited using the Yandex. Toloka, where participation was rewarded with a fee of 60 rubles for a 30-minute experiment. Participants from Yandex.Toloka was selected using special filters (age from 18-30, native language Russian, citizenship Russia). The exclusion criterion for them was the time and quality of the task: if the subject completed the task in less than 25 minutes, their data were excluded; if the subject made only three clicks in each trial, their data were not accepted. At the stage of data processing 3 persons were excluded for non-compliance with the instruction, the final sample was 70 subjects aged from 18 to 30 years old (M=23.4, 30 men; 36 -

complex condition, 34 - simplified condition). We did not seek approval by an institutional review board for the experiments because it is not required for a study of the type reported in this manuscript.

Procedure

During the experiment, participants memorized three words demonstrated for 5 seconds. They then searched for all slots that contained the target words for 1 minute. While searching, participants had to change the target by a sound that sounded every 15 seconds for one minute (the sound was a 2-second beep similar to a telephone ring). For example, if the words "training, call, meeting" were given, subjects would first search for "training", then "call", "meeting", and then "training" again. The total number of stimuli in each sample was 210 (grid of 30 rows and 7 columns). The number of target stimuli per sample varied: 10/25/45 percent of all stimuli, 10 trials for each condition, hence a total of 30 trials. Data were collected by sharing a website link or link to the Pavlovia service.

Results

Data analysis were performed using R v. 1.2.1335. The accuracy (number of correctly detected words - targets) and false alarm (number of incorrectly detected words - distractors), as well as the task completion rate (number of total stimuli found divided by sample time) were analyzed. Mann-Whitney test and two-factor mixed ANOVA were used as statistical tests to test the hypothesis of differences between the groups.

The normality of the distributions was tested using the Shapiro-Wilk test ($p < .04$). There are no significant differences between the groups under saturated and unsaturated conditions were found in the accuracy parameter ($W = 5046, p > .57, r^2 = .00$). A mixed two-factor ANOVA was performed to compare the groups, where group was the within-group factor and trial's type was the between-group factor. According to Leaven's test, variance was homogeneous ($p \geq .49$), the sphericity of the data was impaired ($p \leq .001$), hence the Geisser-Greenhouse corrections were made. Only trial type ($F(2, 134) > 503.67, p < .00, \eta p^2 = .64$) was found to have a significant effect, no group effect ($F(1, 67) > .96, p > .33, \eta p^2 = .01$) and interaction between factors ($F(2, 134) > 1.61, p > .22, \eta p^2 = .00$). Comparisons were also made between groups by trial type (10/25/45 percent target stimulus). Comparisons using ANOVA showed no significant differences between groups by trial types (see Table 3).

Trial type by percentage of target stimuli	The result of analysis
10% target stimuli	$F(1, 67) > 0.46, p < .49, \eta p^2 = .00$
25% of target stimuli	$F (1, 67) > 0.46, p < .49, \eta p^2 = .00$
45% target stimuli	$F (1, 67) > 6.39, p < .24, \eta p^2 = .02$

Figure 4. Results of analysis by trial type in Experiment 2.2

An analysis of the differences between groups for the number of false alarm type errors (pressing a non-target word) showed no significant difference between the experimental groups ($W = 4618, p > .09, r^2 = .01$). A two-factor ANOVA was also performed to compare the groups, where group was the within-group factor and type was the between-group factor. There were no differences in variance between groups ($p \geq .33$), and sphericity of the data, according to the Mauchly test, was not impaired ($p \leq .93$). There was no significant effect of group and trial type factors ($F > 2.13, p < .14, \eta p^2 = .01, F > 0.21, p < .81, \eta p^2 = .00$). There was also no interaction between factors ($F > 1.61, p > 0.22, \eta p^2 = .01$)

Analysis of the total number of clicks showed that the under saturated condition averaged 19, 7 clicks was performed whereas under the unsaturated condition 18,3 clicks per 60 seconds. However, no significant difference was found ($W = 5045.5, p > 0.52, r^2 = .00$).

Additionally, a covariance analysis was performed, where the covariates were responses to the post-experiment survey. Results of the analysis of covariance showed no statistically significant effect of the factors: number of tabs, experience of using the planner, preferred type of planner, subjective sense of difficulty, and fact of distraction ($p \geq 0.5$). Post-survey analysis yielded the following distributions of responses on the number of open tabs: in the simplified condition, 5, 7 tabs were open on average, and 6, 4 in the complex condition; no differences were found ($W = 567.5, p > .23$). Subjective task difficulty was rated by subjects in the simplified condition as 4, 1 out of 5 on average and 4, 7 out of 5 in the complex condition; no difference was found ($W = 645.5, p > .31$). When asked about the fact of distraction during the experiment, the following answers were obtained: for the group in the simplified condition: 26 out of 34 responded that they were not distracted, in the complex condition, 29 out of 36. When asked about the experience of using a diary in the simplified condition group, 14 out of 34 subjects had experience of using a diary, 6 of which preferred to use paper diaries, 5 electronic and 3 used both types. In the complex condition group, 16 out of 36 had experience of using dailies, 6 preferred paper dailies, 7 electronic dailies and 3 used both types. Using a touchpad or computer mouse had no effect on task performance (Using a computer mouse or touchpad also had no significant effect on task performance ($W = 556.4, p > .21$).

Discussion of the results of Experiment 2.2

In the attention shifting experiment, no significant differences were found in the accuracy and false alarms, and no differences were found in the rate of task performance. Thus, the obtained results are not consistent with the theoretical hypothesis posted above.

The results may be due to the fact that shifting attention task did not require a drastic change in the search area (e.g., a previously unused part of the interface, another tab, another gadget) or performing another different task. Instead, participants just had to change the target word, which they had seen before the trial. For example, Kern (2010) showed that the effectiveness of cues increases as the distance between shifting points increases used various types of cues in digital environments to minimize attention shifting errors precisely in the context of changing screen tabs (Kern et al., 2010). In our study, in contrast, the distance was significantly less due to the reliance on an earlier study (Gorbunova & Anufrieva, 2020).

Another possible explanation is that the task instruction fostered a search strategy, where participants consistently focused on one out of three targets for 15 seconds of trial. This strategy facilitates task performance because it requires focusing on only one target and holding the other two. Perhaps this strategy is worth less resources of attention in comparison with situation of searching three targets simultaneously as it was in the sustainability task. Thus, each time the subject switched by the audio signal, so the target changed, which may be a restructuring of the activity as it requires updating the conditions, in particular what are distractors and what are target stimuli. As a result of this restructuring of the activity, the task could be effectively accomplished without the cues of the digital environment. At least, the efficiency of the performance under saturated condition was as under unsaturated condition.

Discussion of Experiment 2.1 and 2.2

The aim of Experiment 2 was to test the hypothesis that attention parameters would differ significantly between unsaturated and saturated digital conditions in sustainability and shifting attention tasks. Based on cognitive load theory, it was hypothesized that attention sustainability and shifting parameters would be higher in the unsaturated condition, because this condition contains fewer distractions that can deplete attention resources. An alternative hypothesis, based on activity centered design, that a saturated environment contains cues about the affordances that direct attention, suggested the opposite - an advantage of a saturated environment over an unsaturated one.

The results of Experiment 2.1 showed significantly higher rates of attention sustainability in the saturated environment. The data obtained indicate the advantage of a saturated digital environment over an unsaturated one, which is consistent with activity centered design assumptions. The results obtained in this experiment may be related to the fact that the response of the digital system acts as a kind of cue, facilitating concentration and showing the presence of affordances. In the case of Experiment 2. 2, the hypothesis was formulated based on the assumption that in a saturated digital environment, the feedback would act as a distractor, interfere with effective shifting by the need to suppress colour and state changes when interacting with an item. However, since shifting was not frequent and did not involve a drastic change of task or space, the performance of the task in the two digital conditions was not statistically different. In this case, the restructuring of the activity and the overall task strategy enabled the task to be handled equally effectively despite the differences in the digital conditions.

Referring to Ophir (2009), both tasks in this paper fostered multitasking and constant switching by target words. However, in the case of the sustainability task, such switching was more frequent, and in the case of the attention shifting task itself, the time intervals between switching were less frequent. Thus, in the case of the sustainability task, multitasking was high-intensity, and in the case of the shifting task, multitasking was lighter. In the case of high-intensity work in a digital environment, additional information filtering is needed to complete the task. Therefore, the feedback of the digital environment can act as a cue to facilitate filtering. Also, the advantage of the saturated condition over the unsaturated one is supported by the theoretical statements of human-centered design, which emphasize the role of activity goals, the possibility of their restructuring, and the connection with the affordances. Cueing in the form of the system’s feedback emphasizes the relevant information and helps organize activities according to the goals in a high-intensity task environment. Thus, the assumption of the saturated digital system as an attention-overloading environment can be reconsidered in the context of the saturation construct operationalized in this paper. Instead, we should view the saturated digital environment as a system of cues that improve the performance of complex tasks (heavy -multitasking tasks).

Conclusion

The present study aimed to review the human-digital interaction in the context of changes in cognitive processes under digital conditions. The consideration of theoretical approaches revealed no unified point of view on the main features that distinguished digital environment from real one or any other specific mechanism of human-digital interaction. It can be noted that there is a general tendency to break down the boundaries of the cognitive system and incorporate the tools that humans use to achieve their purpose. However, the critical question and the difference in the approaches outlined will be the degree of independence: whether the tool becomes only a means to a specific end or becomes an integral part of the cognitive system. Based on empirical studies, it can be said that there are an improvement in attention and memory performance in non-digital environments, which raises the question about the exact environment properties and further refinement of the effects. However, considering the studies that consider attention and working memory only under digital conditions, we should avoid evaluative judgments about the direction of changes. The cognitive system changes some aspects of its performance when interacting with the digital environment, and sometimes simply in its presence, which does not imply a negative or positive effect, but only highlights the restructuring of system performance when interacting with another environment.

The experimental part of the present study showed that the parameters of visual working memory and attention sustainability are significantly different in the real and digital environment in the use of the organizer. However, there are some limitations of comparing these two conditions, and the main one is a motor component of executing tasks. The main point from this subpart of research is that cognitive functions can be sensitive to overload produced by "saturation" of environment. The digital environment can be classified as less stable, more saturated, and not conducive to performing auxiliary actions. To perform operations using this type of environment, the subject has to increase selective attention to keep relevant and suppress irrelevant information. Therefore, we considered attention to focus on our next study, where we compared it under differently saturated digital conditions. In turn, this experiment revealed that the parameters of attention sustainability are higher in the saturated digital environment, which seems to call into question the earlier assumption of cognitive overload through an over-saturated digital environment. Instead, we should view the saturated digital environment as a system of cues that improve the performance of complex tasks.

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