The Effect of Visual Distractors in Peripheral Vision on User Performance in Large Display Wall Systems

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ABSTRACT
Supported by their large size and high resolution, display walls suit well for different collaboration types. However, in order to foster instead of impede collaboration processes, interaction techniques need to be carefully designed, taking into regard the possibilities and limitations of the display size, and their effects on human perception and performance. In this paper we investigate the impact of visual distractors (which, for instance, might be caused by other collaborators' input) in peripheral vision on short-term memory and attention. The distractors occur frequently when multiple users collaborate in large wall display systems and may draw attention away from the main task, as such potentially affecting performance and cognitive load. Yet, the effect of these distractors is hardly understood. Gaining a better understanding thus may provide valuable input for designing more effective user interfaces. In this article, we report on two interrelated studies that investigated the effect of distractors. Depending on when the distractor is inserted in the task performance sequence, as well as the location of the distractor, user performance can be disturbed: we will show that distractors may not affect short term memory, but do have an effect on attention. We will closely look into the effects, and identify future directions to design more effective interfaces.

ACM Classification Keywords
H.1.2 User/Machine Systems: Human Factors; H.5.3 Group and Organization Interfaces: Computer-supported cooperative work; H.5.3 Group and Organization Interfaces: Evaluation/Methodology; H.5.2 User Interfaces: User-centered design

Author Keywords
Large, high-resolution displays; short-term memory; peripheral vision, collaboration

ISS'16, November 06-09, 2016, Niagara Falls, ON, Canada.

DOI: http://dx.doi.org/10.1145/2992154.2992165

INTRODUCTION
Large display environments such as high-resolution tiled-display walls are highly suitable for different types of collaborative work, including remote and partially distributed, but in particular also co-located collaboration. Systems often implement a whiteboard metaphor with novel interaction techniques and devices to resemble collaboration principles that have been known to be effective over decades.

Enabling multi-user collaboration in such systems, however, will raise the necessity for rendering visual feedback for each user independently. Due to the inherent characteristics of large wall displays, it will often occur that co-user's visual feedback will appear in the peripheral visual area of the other user: users are frequently aware of most parts of the visual display other than their active working area as it often falls within the human visual field. In this paper, we regard the peripheral vision as the visual field area outside central vision defined by the macula, from 17 degrees field of view extending outwards to the border of the visual field. Feedback for other users will be perceived and processed by the user's brain, as peripheral vision is sensitive to motion and visual changes [14, 18, 25, 30]. There is no drawback if collaborators are working tightly coupled. In fact, it has been shown that such workspace awareness is apt to facilitate groups' task performance [4].

Collaborative processes, however, consist not only of tightly-coupled shared activity. Various studies have investigated user behavior during collaborative work in single display environments, partly looking into the specific underlying processes and stages [5, 8, 13, 23, 27]. These studies have shown that collaboration processes consist of multiple work phases: loosely-coupled (individual) work, and tightly-coupled (shared) work.

While loosely-coupled work exhibits multiple tasks in parallel (for instance, datasets are often split to support users to process only a part of the data, a typical approach to process input data more effectively), tightly-coupled work targets effective combination of gained knowledge into a solution. Such collaboration processes where users alternate between tightly-coupled and loosely-coupled work are called mixed-focus. Mixed-focus collaboration is typical for different collaborative tasks, e.g. sensemaking, construction, design, planning. During the parallel work stage, however, interaction of co-located users might result in recurrent system generated visual feedback that does not carry any relevant information for the user's current task, or work coordination. Thus, this visual feedback becomes task-irrelevant distractor. This is the category of distractors our studies look into.

Collaborative frameworks often only consider tightly-coupled interaction, while ignoring of phases of individual work is seen as a trade-off in favor of workspace awareness. Moreover, computer-supported cooperative work (CSCW) researchers often consider only the focus / working area of the user as critical. For instance, users can cause interference when invading a co-user's working area [31]. The peripheral area, on the other hand, was considered as safe. There is, however, no empirical evidence that confirms this assumption. For instance, previous work in the psychology domain has provided indications that distractors can negatively affect human performance and efficiency [21, 28]. Also, Gutwin et al. [4] argued that increased workspace awareness will likely decrease effectiveness of individual users. Such tendency might be ascribed to distractors' impact as well. We believe that better understanding of how system generated visual events affects users will allow for better performing collaborative interfaces.

In context of tasks that heavily depend on memory capabilities, there are two ways distractors may impact efficiency, either through attention capturing [10] (start of memorization process is delayed, because attention was driven away) or through memorization impairment (memorization process is interrupted) [19, 32]. In the latter case a distractor interferes with the process of storing information in short term memory, affecting immediate recall of the information.

The design of user interfaces for collaborative environments used at large display walls has to consider human perceptual abilities as a critical factor in order to ensure effective collaboration. As such, distractors should be taken into regard, in case a truly negative effect can be shown. In this paper, we base our research on insights gained in [11] that implies short-term memory is prone to interruptions, and in [3, 16] that showed that task-irrelevant feedback could not be ignored and decreased task efficiency. Yet, these studies only provide initial indications on how to design interfaces, and were mostly focused on smaller display types. We extend the understanding provided by this and other related studies by providing following **contributions**

- Through two user studies, we explore the effect of distractors in peripheral vision for the user working on a large display wall. Doing so, we specifically focus on visual distractors caused by visual system feedback, not on other distractors caused by collaborators themselves, such as motions. Such visual distractors are typical for loosely-coupled work stages in mixed-focus collaboration scenarios.
- We assess the effects of the distractors on short-term memory and attention, and show that distractors can have an effect depending on when the event occurs. However, and surprisingly, in comparison to non-stimuli conditions, we could not find a significant effect of distractors on performance (Levenshtein distance, see section *Results*). However, overall cue-insertion time (the moment the distractor becomes visible to the user) does have some effect when solely looking at the conditions including distractors. As a result, we extend the understanding of the effects of visual events in peripheral vision on user performance, looking specifically into factors associated with display area, learning curve, distractor awareness and workload.
- Based on the outcomes, we identify fruitful directions of future research through a set of research questions.

RELATED WORK

In this section, we explore related work that has considered the effect of visual distractors on user performance.

Interferences in display environments. Zanella and Greenberg [31] defined interference as "*the act of one person hindering, obstructing, or impeding another's view or actions on a single shared display*". Pinelle et al. [20] listed interference issues that can occur in single-display environments, and proposed mechanisms for counteraction. Also, Izadi et. al [9] identified some "overlap"-situations where one user's interactions interfered with another's. Hornecke et al. [7] determined that touch input leads to more interferences than mouse input. Tse et al. [26] conducted a comprehensive study to investigate if interferences are common in practice. He identified that participants often avoid interferences by spatially separating their actions. Still, he argued that interaction techniques have to be designed with interferences in mind in order to mitigate the latter.

Multiple attempts targeted the mitigation of interferences: new strategies and techniques were proposed and evaluated [17, 20, 31]. Yet, researchers have considered only interferences that have a direct impact on user's performance (e.g. a user cannot execute an action because a co-user's interface component occludes his working area). Moreover, a general assumption has been prevailed - without any empirical evidence - that interferences can only occur in the user's focus / working area. In this paper, we will look at interferences that occur in peripheral visual area. Based on indications in related work, we assume they might have an indirect impact on user's performance, such as causing attention, memory, or mental workload issues.

Effects of task-irrelevant and task-relevant stimuli. In this paper, we differ between task-relevant and task-irrelevant distractors. Bundesen defined task-relevant distractors as stimuli that are similar to the target along the defining characteristics of the target [1]. By contrast, task-irrelevant distractors carry no information with regard to the task. Both task-relevant and task-irrelevant distractors may be of two conditions: congruent and incongruent. Congruent distractors activate the same response as the target for the trial, while incongruent distractors activate incorrect response. For instance, imagine a scenario where two symbols - one on the left side of the display, and one on the right side - are presented to the user. One symbol is a predefined trigger symbol the user was instructed to look for. Depending on the position of the trigger symbol (left or right) the user has to push the left or the right button. In addition, each time the symbols are shown one side of the display becomes highlighted, thus drawing attention of the user. If the highlight distractor draws attention of the user to the display side where the trigger symbol is, then the distractor is congruent. Otherwise it is incongruent.

Forster et al. [3] conducted a number of experiments on a 15" screen and showed that task-irrelevant stimuli can distract the user. As a result, decrease of effectiveness could be observed. Task-relevant peripheral stimuli can also decrease task performance. Chewar et al. [2] investigated secondary task display attributes (e.g. position, color) aiming to lessen interference of peripheral task-relevant stimuli with the primary task. The conducted experiments showed that users' primary task performance decreased due to peripheral stimuli. In contrast, Mori et al. [16] showed the effect of windows in the peripheral visual field on user task performance. They found that peripheral windows impair user's efficiency the stronger the closer peripheral windows are to foveal vision. It was also shown that dynamic stimuli have more negative impact in comparison to static stimuli.

The above described experiments were conducted on common desktop displays. Thus they investigated effects in very near peripheral vision area only. Moreover, the experiments did not consider high load tasks that make heavy use of humans' memory (in particular short-term memory) and attention resources.

Interferences with indirect impact. We differ between interferences with direct impact and interferences with indirect impact. Interferences with direct impact make task execution impossible. For instances, a pop-up window that occludes a text, or a loud noise that prevents the user to make a report are interferences with direct impact. The user is not able to work on the task until the interference is resolved. By contrast, interferences with indirect Impact rather slow down the user during task completion. For instance, a semi-transparent pop-up window will allow the user to read the text, or a high frequency, faint noise will allow the user to make a report, mental load of the task will be much higher due to interferences though. Interferences with indirect impact might have immediate or delayed effect. For instance, interruption of memorization process, or drawing of user's attention represents an immediate effect. In contrast, overloading of user's awareness through irrelevant visual events represents a delayed effect that accumulates over time, and which might, for instance, lead to fatigue, and subsequent to performance decrease. Both, short-term memory and attention are important factors for analytical work (e.g. compare objects, find relationships, find an object based on information just gained from another object), and multiple studies have shown that both can be affected by distractors [3, 10, 11].

In conclusion, while some studies indicate a negative effect of visual distractors on human performance in interactive systems, the effects of distractors in the peripheral visual field during task performance are not fully understood. It is here our studies tie in, extending previous work, to better understand potential effects of distractors on task performance in large display walls.

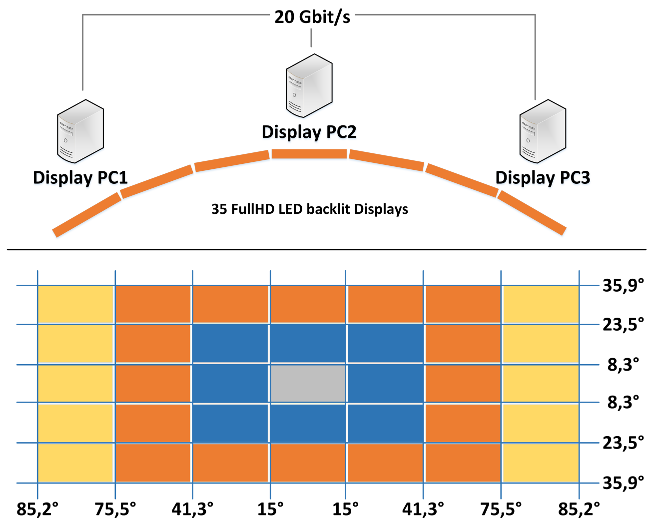

Figure 1. Large wall display: (top) View from the top - the display shapes a slight curve; (bottom) View from the front with angle range for each screen. Angles are given with regards to the user's head position defined in meters as (0, 0, 2) with the origin in the middle of the middle screen (grey), and Z-Axis orthogonal to it and showing away from the display. The color zones depict the three areas used for analysis with their associated degrees: blue (near peripheral visual field, area 1), orange (middle peripheral visual field, area 2) and yellow (far peripheral visual field, area 3).

EXPERIMENTS

In order to address the gap in understanding on the effect of visual distractors, we performed two interrelated user experiments. In these experiments, we explored the effect of visual task-irrelevant events such as caused by visual feedback to co-workers in peripheral vision during accomplishment of high-load tasks. Doing so, we specifically targeted display area location effects, learning issues, distractor awareness and workload issues to address the various dimensions distractors can affect user performance. We chose high-load tasks to explore the effect of distractors in cognitively demanding applications, an area in which large wall displays are often deployed. We performed the experiments by contrasting **short-term memory** and **attention**-driven distractors, two directions that have been focused on in previous work. The underlying assumption is, that information stored in short-term memory might get lost while being distracted, resulting in decreased effectiveness by complex tasks, which require memorization of intermediate results. On the other hand, since the humans' peripheral vision system is movement oriented [14], dynamic visual events have an increased potential to

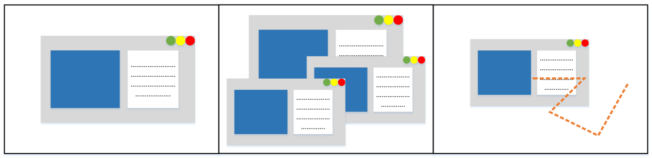

Figure 2. Stimuli: (left) pop-up window, (middle) multiple pop-up window, (right) pop-up and move window

Figure 3. Schematic depiction of a background image as shown at a single display

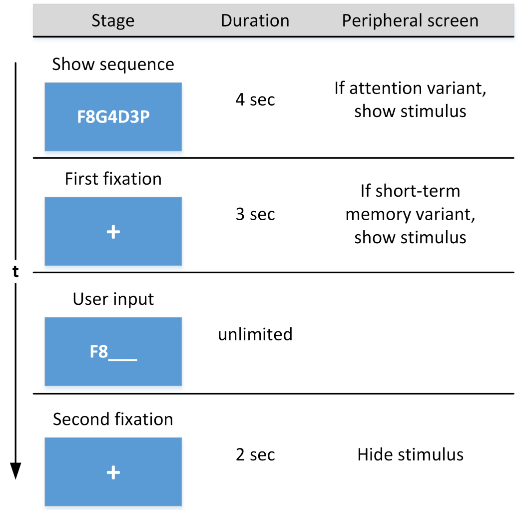

Figure 4. Trial loop, with insertion of distractors in the first fixation (short-term memory experiment 1) or during the show of the sequence (attention experiment 2)

attract user attention at an unconscious level, thus become distractors that can affect performance.

Apparatus

The experiments were performed at a large curved tiled display wall comprising 35 LCD displays (Figure 1), ordered through a seven (column) by five (row) grid. Each of the columns has a relative angle difference of 10 degrees along the Y-axis to adjacent columns, as such creating a slight curvature. Each LCD display has a bezel of less than three millimeters, minimizing the visual rim effect. The LCD displays are 46" panels with a 1080p resolution, resulting in a total of 72 megapixels.

Participants sat in front of the display at a distance of 2 meters. The height of the stool was adjusted in such a way that participant's eyes were at the same level as the center display. The distance was chosen to cover most of the user's peripheral vision with the display, approximately 170 degrees horizontal and 72 degrees vertical (Figure 1). In front of the participant a console with a keyboard was placed, used for typing in the results of the memory task.

Procedure and design

Both experiments were conducted as a within-subject study, employing a 3 x 4 factorial design, consisting of the factorial combination of four different event types (pop-up, multiple pop-up, move and no stimulus, Figure 2) that would appear in one of the 34 displays ordered in one of the three different areas (Figure 1). Of course, it should be clearly noted that "no stimulus" was not associated with any display area, and as such was analysed accordingly. Each window contained an image field and a text field. During the experiment each stimulus was shown exactly one time on each peripheral screen.

The 34 locations were associated with each single screen that makes up the tiled display wall, with the exception of the center screen, which was used for the memory task itself. Screens were clustered in three areas, to analyze the effect of cues in the near, middle and far peripheral visual field (Figure 1). The areas were defined through angular distances with some tolerance due to apparatus geometry. As a result, 136 samples per participant were recorded. The order of trials was fully randomized. All screens showed 1 of 15 static background images (see Figure 3), representing a newsfeed. The background images were different, though very similar in structure and usage of color and text, containing a number of news notes as text with a corresponding image. Design of background images and used stimuli was akin on purpose in order to lower contrast between them.

The difference between the two experiments was the point of time at which a specific distractor was inserted. As described in Figure 4, each trial spans 4 stages. First, a character sequence was shown to the user in the middle of the focal screen for 4 seconds. The main task was comprised of remembering this particular sequence, and recalling it from memory afterwards. Next, the sequence was hidden and a fixation point in form of small cross appeared for 3 seconds. Directly afterwards the screen contents blanked and the participant had to recall and enter the sequence using the provided keyboard. During the input, the participant was able to observe the sequence she is entering on the center screen, and correct if needed. No time limits were set for that stage, however, users were requested to start input directly after the screen blanked, to avoid differences in memory decay. The input stage was finalized by the participant by pressing the Enter key and followed by a second fixation point stage, which lasted for 2 seconds, after which a new trial began. Users were requested to focus on the center screen or the keyboard during the full experiment, specifically avoiding the direct focus of attention at the distractors.

In case of the first experiment (labeled **short-term memory** or STM), a distractor was shown during the first fixation point stage. This means that the participant had 4 seconds to remember a sequence. After it becomes hidden, the system tries to clear the content of short-term memory using a distractor. In case of the second experiment, called the **attention** experiment, a stimulus was shown during the stage of sequence showing. This means that the system tried to distract the participant while she was trying to remember a sequence, thus drawing their attention away and reducing the time for the task. Regardless of the experiment variant, shown stimuli remained static on the screen after animation until the second fixation point stage and were erased at the beginning of it.

Each sequence had a length of 7 tokens with the pattern *LDLDLDL*, where L stands for letter token, and D stands for digit token. All letters were upper case. For the sake of clarity, we omitted the digits 0, 1, 5 and characters O, L and S during the process of sequence generation. We also rejected the digit 7 and the letters W and Y since their words have more than one syllable.

The participants were instructed not to look at other screens apart from the focus screen in the center of the display wall. Each participant could practice the memorization task up to 20 trials and ask questions beforehand. No stimuli were shown during the practice stage.

At the beginning of the experiment, each participant filled in a survey that contained questions regarding age, gender, eyesight, color blindness, LHRDs experience, and computer games experience. The question about LHRDs experience was a single choice question with the following options: have never seen before; have seen a couple of times; have worked with them. The question about computer game experience was a Likert scale question from 1 (novice) to 7 (professional). During the experiment users were asked 2 questions after each block of 34 trials:

1. How mentally demanding was the last series of the trials?

2. How well could you concentrate during the last series of the trials?

The participants had to answer the questions using a 7-point Likert scale from 1 to 7, with seven being very high or very good, using the provided track pad. At the end of the experiment, each participant had to fill in a standard NASA TLX [6] survey, and a questionnaire regarding stimuli awareness and the application static background. The question about stimuli awareness was a Likert scale question with three Likert items (one for each stimulus type). Each Likert item had a 7-point scale from 1 (low level of awareness) and 7 (high level of awareness). In addition, an oral interview was made. Through these questions, we addressed issues related to mental demand, stimuli, background (level of distraction), and their strategy of remembering the sequences. Furthermore, users were observed, looking specifically at indications of concentration and distraction.

The rational behind the experiment is as follows. First, we choose a single user controlled experiment as we wanted to investigate the effect of particular stimuli in particular areas of a large display. Such an investigation with multiple users would be barely possible, as the presence of additional users would result into uncontrollable variables: co-users might make sounds or motions in peripheral area that affect the user, thus distorting the results. As such, we only focus on visual distractors casued by system feedback, instead of also focusing on other visual distractors that can be caused by for example users. Second, we chose high-load tasks to explore the effect of distractors in cognitively demanding applications, an area in which large wall displays are often deployed. The task seems to be very specific, however, remembering and recalling of small information chunks underlies multiple general tasks such as comparing, searching or determining relationships. Third, we decided to use a highly visual with information saturated background for two reasons: to reduce contrast between stimuli and background, and to emulate an information rich environment, which is typical for large display applications. Fourth, we are aware of the fact that curved displays have a higher potential to increase visual distraction in comparison to flat displays. In our study, however, we made use of a large display to cover as much of the human FOV as possible, for which the used curved display was an excellent option. Though likely covering a smaller FOV, similar negative effects are to be expected at flat wall displays, as the results particularly showed that distractors in the near peripheral field had the highest negative impact.

Participants and demographics

Experiment 1 was performed with 8 participants (2 females) aged between 22 and 33 years ($M = 27.00, SD = 4.10$), with normal or corrected-to-normal vision. The participants had rather a high level of computer games experience ($M = 5.00, SD = 1.41$) and most participants had seen large, high-resolution displays a couple of times before or worked with them (7 participants 87.5%). Similarly, experiment 2 comprised 8 participants (1 female) aged between 22 and 40 years ($M = 27.75, SD = 5.52$), with normal or corrected-to-normal vision. The participants also had rather a high level of computer games experience ($M = 4.50, SD = 2.00$) and most participants had seen large, high-resolution displays a couple of times before or have worked with them (6 participants 75%). All participants had an academic background (students or research associates). The participants were paid for taking part in the experiment. Each participant took part only in one experiment (either short-term memory or attention).

RESULTS

Data of 816 trials per experiment (102 trials per participant, totalling 1632 trials) was analyzed using two-way repeated measures ANOVA for each experiment separately with within-factors display area (near peripheral, mid peripheral, far peripheral) and stimulus type (pop-up window, multiple pop-up window, pop-up and move window). As noted before, ”no stimulus” was not associated with a display area, and as such corresponding trials were not included in this ANOVA. Levenshtein distance [12] was used to calculate the difference between two sequences, being the correct sequence and the sequence provided by the user. As explanation, for sequences A and B Levenshtein distance is defined as $LD(A,B) = min(a(i) + b(i) + c(i))$. Here B is obtained from A by the minimal number of $a(i)$ replacements, $b(i)$ insertions and $c(i)$ deletions of characters. For example, the Levenshtein

	STM		ATT	
Condition	Mean	SD	Mean	SD
Stimuli				
Display Area 1	0,88	1,19	1,33	1,59
Display Area 2	0,83	1,26	1,15	1,47
Display Area 3	0,87	1,34	1,09	1,40
No Stimuli	0,82	1,21	1,16	1,35

Table 1. Stimuli vs. No-Stimuli condition for Levenshtein distance)

distance between ”ocean” and ”means” is 3, since the following three edits change one into the other, and there is no way to do it with fewer than three edits: Deleting ”o”, replacing ”c” by ”m” and inserting ”s”. Finally, as we noted, displays were clustered in areas (Figure 1) to analyze the effect of distractors in specific areas of the peripheral vision, ranging from near (1) to the far (3) peripheral field. While the display areas contain different amount of displays, the number of trials per area was high enough to warrant no negative effects. Mean values for each participant for each display area were finally included in the analysis. The population mean values for each display area can be estimated through the sample mean values. The mean value is more precise if it is based on many trials. As a great number of trials was used for each display area to calculate the mean values, differences in the number of trials should not affect the results as we can assume representative values for each display area. The Šidák correction was used to counteract the problem of multiple comparisons. Within the following we compare the results of both short-term memory and attention experiments, identifying the differences of the cue effects.

General performance. Analysing the general performance as based on Levenschtein distance, we found a surprising result: there was only a marginal difference between the no-stimili conditions, and the stimuli conditions in the attention and STM groups (see Table 1). As we will note in the discussion, this result is not in line with previous findings, and needs further research. However, we did find a significant difference between the attention and STM group, when performing a between-subjects analysis over ANOVA: the attention group produced significantly more errors than the STM group ($F(1,1630) = 21.58, p < .001$).

Display area. There was no main effect of display area or stimulus type (pop-up, multiple pop-up, pop-up and move) on recall time, number of correct tokens from position 0 till the first error and Levenshtein distance in both experiments. Display area, but not stimulus type showed marginal influence on the number of correct tokens at proper position ($F(2,14) = 3.606, p = .055, \eta_p^2 = .34$) only in the attention experiment. With respect to the different areas in peripheral vision, for this experiment, post-hoc pairwise comparisons show a greater number of correct tokens at proper position for display area 3 ($M = 5.21, SD = .2.22$) than 1 ($M = 4.84, SD = 2.40$) than, $p < .001$ (Šidák corrected). These results indicate that distractors in far peripheral vision did affect performance less than distractors in near peripheral vision. Interestingly enough, the stimulus ”pop-up and move window” had almost the same effect in areas 1 and 3 in both experiments. However, in the display area 2 the effect was lesser in attention experiment, and stronger in the short-term memory experiment. Overall, and also in reflection to the errors produced by non-stimuli conditions, the effect of display area can be disregarded.

Learning. To gain better insights in learning effects, trial data from 136 trials was categorized in 4 equal time periods of 34 trials. To compare both experiments, we performed repeated measures ANOVA for each experiment with the within factor time period, which showed a significant effect on Levenshtein Distance in the STM group, $F(3,21) = 12.11, p < .001, \eta_p^2 = .634$. Mean Levenshtein Distance decreased from $M = 1.24(SD = 0.88)$ for the first 34 trails to $M = 0.59(SD = 0.56)$ for the last time period (see Figure 5). Post-hoc pairwise comparisons of time periods (Šidák adjusted) showed a significant difference of Levenshtein Distance between period 1 and 3 ($M = 0.64, SD = 0.67$), $p = .024$ and period 1 and 4, $p = .033$. As can be seen clearly in Figure 5, performance increased over time, showing a strong learning effect. Additionally, a comparison of learning curves has yielded that the overall distraction level was higher in the attention experiment. This is in line with the results of ANOVA between-subjects analysis.

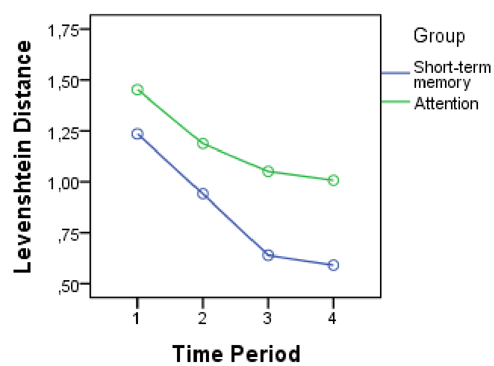

Figure 5. Mean Levensthein Distance over time

Awareness. A repeated measures ANOVA was conducted for both experiments to assess the effect of stimulus type on the level of awareness rating. Stimulus type affected awareness ratings only in the attention group ($F(2,14) = 4.688, p = .028, \eta_p^2 = .401$) as awareness seemed to differ between windows: Moving windows showed rather high awareness ($M = 5.63, SD = 1.30$) followed by multiple windows ($M = 3.63, SD = 2.2$) and single windows ($M = 3.38, SD = 2.33$). However adjusted post-hoc comparisons were not significant here. In the STM group the awareness of stimuli seemed to be similar for different distractor types.

Workload. Overall workload as depicted by NASA TLX (all subscales) was located in the center on a 21-point scale ($M = 11.56, SD = 3.26$). Mental demand, temporal demand and effort showed above-average mean values and thus seemed to be more relevant to the task than the other subscales (see Table 2). Standard deviations of all subscales are remarkable and vary from 4.07 (Mental Demand) to 5.29 (Frustration).

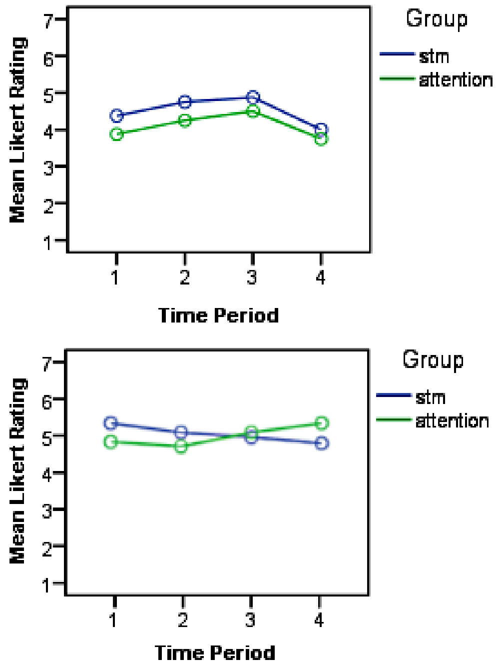

Figure 6. Mean Likert rating for frustration (top) and mental demand (bottom) for different time periods

The NASA TLX ratings show that the memory task was quite demanding, and as such can be rated as moderately high-load.

Repeated measures ANOVA showed no significant influence of time period on mental demand or mental frustration in both groups (see Figure 6). Mean mental demand was constantly high over time ranging from 4.83 to 5.83 in the STM group and from 4.75 to 5.38 in the attention group with standard deviations between 0.75 and 1.55. Mean mental frustration showed similar values ranging from 4 to 4.83 in the STM group and from 3.75 to 4.5 in the attention group with standard deviations from 1.17 to 1.94.

In oral interviews participants were asked about different aspects of the experiment. Most participants found the experiment mentally demanding: 75% of participants in attention group and 87.5% in the STM group said that the experiment was either "demanding from the start" or "became demanding throughout the experiment". Only few participants were distracted by the static background, as 37.5% and 25% of participants in attention and STM group respectively gave positive answer. On the other hand, all participants agreed the dynamic distractors did indeed distract them. The answers to the question which area of distraction was most distracting were fully in line with their performance: 100% of participants of the attention group indicated the near peripheral area, while in the short-term memory group 75% of the participants indicated the near peripheral area, 12.5% indicated all three areas, and 12.5% said that "stimuli were not distracting". Finally, participants were asked if they recognized disappearance of the stimuli during the second fixation phase and if it was distracting. In the attention group 75% of participants as well as 62.5% of participants in the STM group did not recognize the disappearance. The remaining participants stated that they recognized, it was not distracting though.

	Min	Max	Mean	SD
Mental Demand	5	20	15.0	4.07
Physical Demand	1	17	7.19	5.95
Temporal Demand	1	19	12.63	4.88
Performance	4	16	9.63	4,05
Effort	3	20	15.00	4.43
Frustration	2	19	9.94	5.29
Overall Workload	4.33	16.83	11.56	3.26

Table 2. Descriptive statistics for NASA-TLX subscales

DISCUSSION

As a result of the study, we showed that distractors similar to those in mixed-focus collaborative scenarios could affect performance negatively. Even though no further person was in view, the distractor design was chosen as such that similar effects can be expected in true multi-user scenarios. Still, the optical flow produced by a nearby user while interacting can also potentially cause further distraction, which is an interesting issue to follow up in further research. These distractions could be counteracted by tunneling effects, an issue we discuss here after, but also this warrants further research.

While we assumed that task-irrelevant distractors would affect short-term memory and attention, we could determine some effects of stimuli on user performance during experiments, mostly related to the area in peripheral vision the distractor would appear.

Short-term memory. The mental load of our task was high: by design, character sequences were constructed in a way that makes it harder to apply chunking as memory aid, while also the number of elements the participant had to keep in mind was rather high [15]. The level of task load was supported by the feedback acquired through questioning during (see Figure 5) and directly after (see Table 2) the experiment, as users noted (moderately) high cognitive demands. Another indication of high mental demand was gained through observation, as participants exhibited clear lip movement throughout the experiment. The results of short-term memory group revealed that the stimuli effect remained more or less constant regardless in what area in peripheral vision it was. As such, we conclude that the provided stimuli did not impair short-term memory.

Attention. In contrast to the short-term memory experiment, the results we obtained in the attention experiment only endorsed our anticipation of a negative effect when comparing to the STM group, but not to the conditions excluding a distractors.

The gained results are surprising: with respect to previously performed studies, we could not show that task-irrelevant stimuli did always affect performance in our moderately high-load tasks, as shown by Forster et al [3], even though a higher task load was confirmed. However, it should be noted that Forster et al noted that especially low-load tasks were affected. Interestingly, the oral interviews showed that stimuli in near periphery distracted most, while in far periphery were barely perceived consciously, which would be in line with results achieved by [16] - yet, performance results did not confirm the latter. Let us look more closely at how these results can be explained, by looking at both the cue (distractor) and task design.

Distractor design. It is possible that perception and effect of far-off stimuli could be amplified through increased contrast between stimuli and background. With respect to stimulus type, the stimulus pop-up and move window distracted most as expected, as it exhibits the highest level of visual change. Interestingly enough, it is followed not by the stimulus multiple pop-up windows, but by single pop-up window. However, the effect of the distractors was not significant enough, as we showed while comparing our results to the no stimuli conditions. The question remains if other types of distractors (e.g. more salient distractors) will produce different results. While literature only provides limited indications, the peripheral visual field is more receptive to, for example, to blue colours [18]. Furthermore, issues such as transparency, and the size of cues can also have a larger effect, as at least large size cues would produce more optical flow in the peripheral visual field to which it is receptive.

Task design. One possible explanation for our results is that high cognitive load has been shown to produce attention tunneling, in which a human is less receptive to events outside the central visual area: mental workload is known to reduce the area of one's visual field (perceptual tunneling [24, 29]), but little is known about its effects on the shape of the visual field. Initial studies seem to indicate the expected limitation of the visual field and a potential shape distortion [22]. Hence, due to the high-cognitive load, attention may have been tunneled, as such that distractors could have a lower impact than if a low cognitive load task would have been deployed. If tunneling would have occurred, distractors in area 2 and 3 would have less effect than distractors in area 1, which is in line with Mori's experiment [16] and which users noted orally. However, as we showed, performance was not affected significantly by display area. Hence, it would be appropriate to perform the same experiment, however, with a lower cognitive load task to be able to confirm this assumption.

CONCLUSION

To foster effective collaboration in large wall display systems, apt graphical user interfaces need to be designed in a way that afford concentration on the primary task, especially in cognitively demanding applications. Visual feedback caused by the actions of a collaborative user can draw attention from the main task, as visual distractors can trigger attention towards other areas of the screen. In this article, we reported on two interrelated experiments to improve the understanding of the effects of dynamic visual task-irrelevant stimuli in far, mid, and near peripheral vision areas on users' efficiency at very high-load memorization tasks. The experiments showed that in some conditions such stimuli might impair users' performance and as such can place requirements on the design of the graphical user interface. For example, the partitioning of private and public spaces on large wall displays could be affected, as in particular attention effects could be shown for the near peripheral visual field. We have also shown that insertion time of visual stimuli may have a significant impact on users' performance. Since there is no way to control time of visual feedback emergence, we can try to mitigate interference through visual attributes' manipulation of stimuli.

Results also show that this experiment is a first step towards fully understanding the effects: it is clear further research has to be performed with an aim to minimize negative impact. In our future work, we intend to investigate the analysis of effects of stimulus attributes, e.g. color, transparency or size, on users' performance, and the study of various dynamic screen partitioning methods. Knowing the impact intensity of different attributes, we can experiment with their values to detect if impairment factor can be reduced, e.g. to make a pointer of co-user semi-transparent if it nears the near area of user's peripheral vision.

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