Change Detection in Desktop Virtual Environments: An Eye-tracking Study

Abstract

It is common knowledge that attention is important for learning. We need to utilize attention in order to learn something efficiently and effectively. Similarly, we may also need to acquire familiarity with (i.e., learn) our surroundings in order to utilize our attention. In this study, learning is defined as a product of one's exposure to natural visual stimuli. Using a virtual model of a natural scene, we investigate both attention and its relationship to learning, according to this definition. Specifically, our focus is the effect of environment familiarity on gaze direction. Our findings reveal that the factor of familiarity with one's surroundings in virtual reality environments exerts a significant influence on peoples' ability to detect a variety of specific changes that occur within scenes under their observation.

Keywords: Spatial learning; Attention; Virtual reality; Eye movements; Scene memory.

1. Introduction

Our limited range of attention places tight constraints on human visual processing of natural, complex scenes. Certain image properties, such as contrast, edges and chromatic saliency, help to produce fixations when viewing images of scenes (Itti & Koch, 2001; Mannan, Ruddock & Wooding, 1997; Parkhurst & Neibur, 2003). Cognitive goals also lead to many visual fixations (Hayhoe, Shrivastava, Mruczek & Pelz, 2003; Hayhoe & Ballard, 2005; Land, Mennie & Rusted, 1999).

The image properties are applicable for normal, natural scenes. But, what if an unexpected change occurs in the environment? Is attention automatically attracted to a change in the scene? There are two answers to this question. First, some evidence indicates that people are very poor at detecting changes in scenes if the change is masked by a transient – this phenomenon is called "change blindness" (Rensink, O'Regan & Clark, 2003; Simons & Levin, 1997; Triesch, Sullivan, Hayhoe & Ballard, 2002). On the other hand, other evidences suggest that novel objects attract attention (Yantis, 1993; Yantis & Jonides, 1996). This is an interesting contradiction that we take as a starting point for this study. Since the nature of change blindness studies do not let their participants to learn the scenes, we hypothesized that perceiver's poor change detection performance may be improved by increasing their level of familiarity with the environment. If this is the case, the improvement may occur no matter what the change is.

In the literature, depending on the goals of the observer, several kinds of stimuli including:

- The abrupt appearance of a new object (Yantis & Janides, 1984),

- The sudden disappearance of an existing object (Theeuwes, 1991),
- Objects characterized by unique color and shape (Theeuwes, 1994), and
- Movement (Franconeri & Simons, 2003)

have been shown to capture attention. On the other hand, it is uncertain whether the same mechanisms that attract attention to new or unique objects in these simple stimulus arrays also operate under more naturalistic viewing conditions (Brockmole & Henderson, 2006).

Hollingworth and Henderson (2004) investigated two memory problems in scene perception. The first is the short-term retention and subsequent integration of scene information across saccadic eye movements. The second is the accumulation of scene information over longer periods of time during the visual exploration of a natural scene. This latter work focuses on the nature of the information retained from previously attended objects and on the role of long-term memory in scene perception. They found that despite evidence of change blindness, detailed visual information is reliably retained in memory from previously attended objects. Robust implicit effects of change indicate that explicit change detection does not provide an accurate measure of the detail of visual scene representation. In other words, they argued that elaborate representations of scenes are built up in long-term memory. If so, people may compare a currently viewed image with their learned representation of that scene in order to detect a change. This process might serve as a basis for attracting attention to changed regions of scenes. On the other hand, Wang and Brockmole (2003) stated that observers keep track of objects or places they are approaching (i.e., those they can see) and lose track of objects or places that they have passed (i.e., those they cannot see).

Furthermore, Brockmole and Henderson (2005a) examined whether long-term memory (LTM) can direct memory-guided prioritization of new objects in real world scenes. Their stimuli consisted of full-color photographs depicting thirty real-world scenes. Two photographs of each scene were taken, differing only in the presence or absence of a single object in the scene. The results show that observers can rely on their LTM to guide their attention through the scene and can identify changes, even when sufficient time is not afforded to generate a short-term memory (STM) representation capable of guiding attention to the new object (Brockmole & Henderson, 2005a). Thus, people should be more sensitive to changes in familiar environments than in unfamiliar ones.

In the present study, this issue was further investigated by the researchers. In particular, we examined whether the effect of scene familiarity could be generalized to natural environments. Does familiarity with scene content improve detection of scene changes in a 3D virtual reality environment? As described above, to investigate this question it is necessary to observe active visual behavior in a 3D environment, because the stimulus conditions and cognitive goals are very different from those associated with viewing 2D images, even when those images represent natural scenes (Droll, Hayhoe, Triesch & Sullivan, 2005; Hayhoe & Ballard, 2005; Triesch, Ballard, Hayhoe. & Sullivan, 2003). Since real natural environments are hard to control and 2D images are unsuitable, virtual 3D environments are commonly preferred for cognitive psychology research (Gillner & Mallot, 1998; Wilson, 1999; Heineken & Schulte, 2000; Melanson, Kelso & Bowman, 2002; Yoksawa, Wada & Mitsumatsu, 2005; Stankiewicz, Legge, Mansfield & Schlicht, 2006; Stankiewicz & Kalia, 2007). The use of this computer technology for research development helps researchers to control different circumstances that affect human perception. In a same manner, a 3D desktop virtual environment was devised in place of a real one, for being able to conduct the experiments of this study in a controllable natural environment. The participants walk along a footpath in the presence of a variety of stationary objects within this virtual environment. We examined whether the opportunity to become familiar with the environment influenced the direction of gaze, and in particular, whether participants preferentially fixate on scene changes once they have become familiar with the environment.

In order to understand the way that familiarity might improve the detection of changes, we also manipulated the kind of changes that were made. Previous work has revealed that attention may be captured by objects that vanish, as well as by those that appear (e.g., Theeuwes, 1991), although offsets (i.e., the disappearance of an existing object) might be less effective than onsets (i.e., the appearance of a new object) (e.g., Boot et al., 2005; Brockmole & Henderson, 2005). On the other hand, Mondy and Coltheart (2000) claimed that the identification of object deletion was more likely than the identification of object addition. As you can infer from these studies, the general idea was to compare the effects of appearance and disappearance of objects in a scene (Yantis & Janides, 1984; Theeuwes, 1991; Mondy & Coltheart, 2000; Wang & Brockmole, 2003; Boot et al., 2005; Brockmole & Henderson, 2005; Brockmole & Henderson, 2005a). In addition to these studies displacement of an object was also examined in isolation (Franconeri & Simons, 2003). On the other hand, in order to be able to compare reactions to the different changes in a broader context, all change types that can naturally occur should be considered. For this issue, two more change types, which were the displacement of objects and the replacement of existing objects with different ones, were included as additional change types to appearance and disappearance of objects. This type of comparison is new in the field and may provide important insights into the nature of the detection process. Furthermore, since we hypothesized that level of familiarity is the key point for change detection performance, considering more change types will let us to examine the process regardless of the change type.

Finally, we were interested in changes that did not involve a retinal transient. Since changes accompanied by a transient are typically easier to detect than those that are not (see, e.g., Brockmole & Henderson, 2005a), this represents the most challenging situation for the observer. And, as described above, in many of the situations in which an observer is required to focus his/her attention, a transient signal will not necessarily be present.

2. Method

2.1. Apparatus

Our experiments were conducted at the Human-Computer Interaction Research and Application Laboratory at the Middle East Technical University. This laboratory is a medium established to design, utilize, and evaluate interactive technologies, like websites and other computer software. The lab consists of an experimentation (test) room and a control room (see Figure 1). During the experiment, it was possible to obtain feedback by recording the facial expressions, hand movements (on the keyboard and mouse), and eye movements of the subjects. We were also able to monitor screen shots on the computers which displayed the virtual environment.

Figure 1. (a) Test Room and (b) Control Room of the Human-Computer Interaction Research and Application Laboratory

In this study, the answers for the previously mentioned research questions are obtained by comparing the eye fixation records of the participants. The fixation durations were used as a sign of their attention on a particular object or area. To record subjects' eye movement data, a Tobii 1750 Eye Tracker was used. The eye tracker is discretely integrated into a 17" TFT monitor without any visible or moving "tracking devices." Participants are allowed to move freely in front of the eye tracker. This non-intrusiveness ensures that the participants will behave naturally, thus providing the researchers with valid data. The setup also allows the researchers to perform long observations without unduly fatiguing the participants or reducing the quality of the data.

ClearView eye movement data analysis software was used for the analysis of the experimental data. This software provides a video of the screen contents, which is necessary for calculating the eye fixation durations of the participants.

2.2. The Participants

The participants were 128 undergraduate and graduate students affiliated with Middle East Technical University (METU) in Ankara, Turkey. Of the total, 85 were undergraduate students, and 43 participants were graduate students. Sixteen participants were allocated randomly into eight experimental groups. Among the participants, 75 were female. The average age was 23.42 years (sd = 3.599). The age range was from 18 to 35. The academic departments of the participants covered a range of 34 departments, and there were participants from each class level, from freshman students to Ph.D. candidates.

The computer usage habits of the participants differed widely, but most of them had been using computers for at least five years, and almost half of them had played computer games. All of the participants had normal or corrected-to-normal eyesight.

2.3. The Walking task

The experimental design for this study requires the participants to explore a desktop virtual reality environment which includes both stable and changing objects. The task of the participants was to learn the environment without bumping into the virtual pedestrians and the same purpose of the task was given to the participants in all experimental conditions.

For the environment, a segment of an imaginary town was created, using Active Worlds, a desktop 3D virtual reality software.[1] In the environment, the participants followed a rectangular

[1] For details of the software, visit http://www.activeworlds.com/.

path. From any side of this path (see Figure 2), they could not see the other three sides. This restriction is important, because the changes that were introduced in the setting had to be made without the awareness of the participants.

In this environment, in addition to the houses and trees, there were six objects, including:

- a park bench,
- a street lamp,
- a trashcan,
- a billboard,
- a fire hydrant, and
- a mailbox.

Here, all of the objects were stable except for the *trashcan*. This object was the changing object for each of the experimental groups, excluding those which encountered the new-object conditions (see the Procedure section for details).

Figure 2. Bird's-eye View of the Environment

In order to eliminate random fixations on the objects, a secondary task was created. The participants were asked to avoid potential collisions with other virtual pedestrians (see Figure 3).

Figure 3. A Snapshot from the Environment showing two of the four Pedestrians

2.4. The Procedure

Each participant was given time to become familiar with the environment while walking the same path eight times. These eight circuits of walking are counted as one trial. In addition, the experiments were conducted in a "one participant at a time" manner, so that none of the participants would be influenced by the others.

In this experimental setting, the directions of eye gazes were examined during the familiarization trials, and then again after changes were made in the environment. As explained above, one object (a trashcan) in the virtual environment is subjected to change. The changes applied to this object include:

- the appearance of a new object,
- the disappearance of an existing object,
- the displacement of an existing object, and
- the replacement of an existing object with a new object.

In the *new-object condition*, one object was added to the environment during viewing. In the *replaced-object condition*, one object was replaced with another object. The same object (a trashcan or a news-box) in each condition served as the appearing or the replacing object. In the *deleted-object condition*, one existing object was removed from the environment. In the *displaced-object condition*, one existing object was displaced in the environment (see **Error! Reference source not found.**). The same object (a trashcan or a news-box) in each condition served as the disappearing or the displaced object.

The changing objects were different for every other person in this experimental setting. In other words, while the trashcan was replaced with the news-box for half of the participants, the news-box was replaced with the trashcan for the other half of the participants. Moreover, while the news-box was the new (i.e., appearing) object and the trashcan was a stable object for the half of the participants, the news-box became a stable object and the trashcan appeared for the other half of the participants. This counterbalancing was applied in order to avoid potentially extraneous influences on the eye fixation durations, which might be caused by an unintended distracting property of these objects.

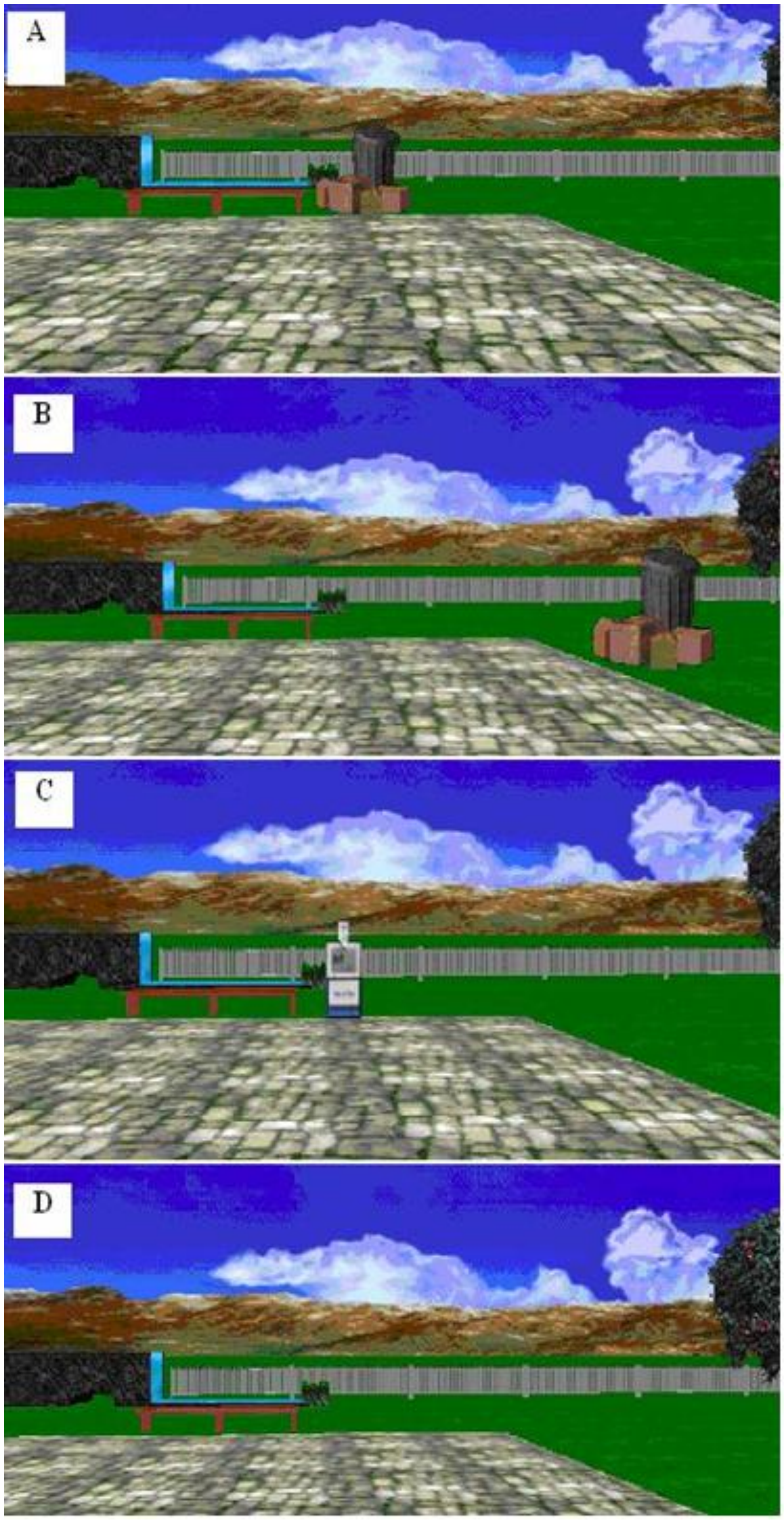

Figure 4. A. Object Appeared B. Object Displaced C. Object Replaced D. Object Disappeared

As the control condition, average eye fixation duration on stable objects was used for the *new-object*, *replaced-object* and *displaced-object* conditions. For the *deleted-object* condition, on the other hand, average eye fixation duration on the empty spot of the deleted object was used as the control condition. This allows us to measure the possibility to fixate on the empty spot without any effect of change. This value was obtained by analyzing the eye fixation durations on the specific empty spot before the appearance of the object in the *new-object* condition.

As explained earlier, the experiment was designed in a between-subjects format; eight groups were defined according to the participants' familiarity with the experimental environment and the type of change they would see. The groups were divided as explained in Figure 5 below.

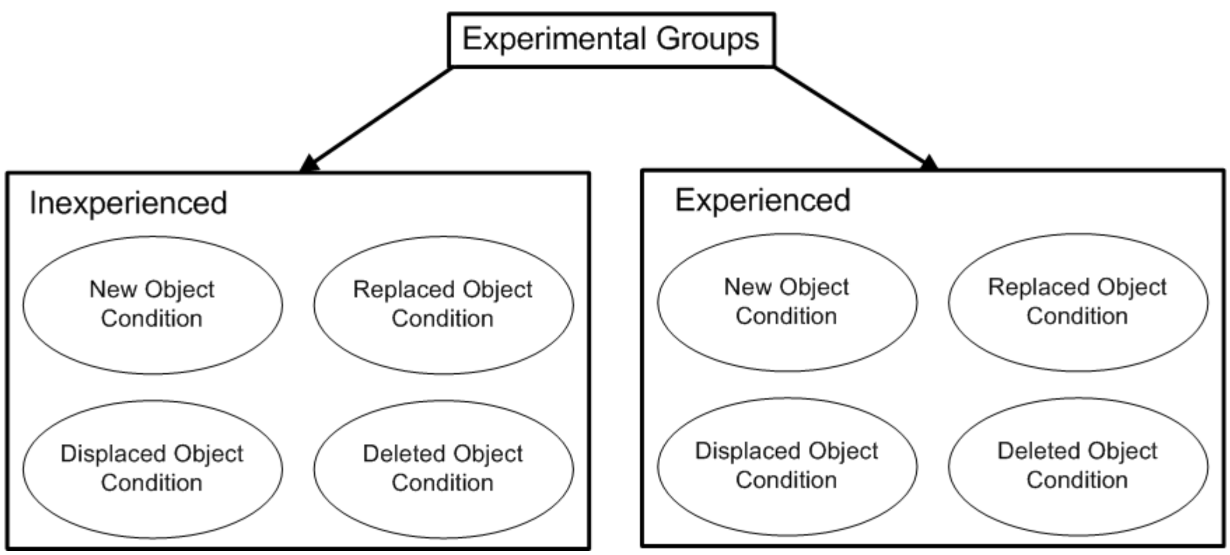

Figure 5. Experimental groups

Each group included 16 participants. The first four groups are labeled "Inexperienced" because they were able to see the changes after the first turn around the virtual monument (i.e., before they had become familiar with the environment). On the other hand, the second four groups were more familiar with the environment at the time of their changed-object test, because they took six turns around the virtual monument before the changes occurred. For this reason, they are labeled “Experienced.”

The durations of eye fixations on changing objects were recorded for the subsequent two turns, and further fixations were not recorded (i.e., the fixations of the Inexperienced groups were counted only for the 2nd and the 3rd turns, even though the changing object was visible for a longer time). The reason for ignoring further fixations for the Inexperienced participants was that the results could be compared more reliably this way, since the Experienced participants could observe the changes only for the last two (i.e., the 7th and the 8th) turns.

All of the participants were instructed to familiarize themselves with the environment while avoiding pedestrians. No explicit instructions concerning the actual changes were given to the participants.

The total duration of one session varied between 10 and 15 minutes according to the speed of computer usage of the participant. After each session of the experiment, the participant was asked to report the changes that they had seen while walking in the virtual environment. Their reports demonstrated their explicit knowledge about the changes.

2.5. Data Analyses

The point of the analyses was to calculate the average eye fixation time for a single object. The gaze durations were recorded by analyzing the video results of the experiments frame-by-frame. Fixations were defined as a constant location within a one degree radius for a period of 100 msec or more. We were interested in the total amount of time in which a participant fixated on a particular object. This might be composed of a single long fixation or several shorter fixations on the object. We will refer to this as gaze duration to avoid confusion with the duration of a single fixation.

The location of eye fixation was taken as an index of the locus of attention within the scene. The total duration of all fixations on stable objects was calculated, and also on all changing objects, separated by category of change. Gaze was also divided up into fixations on the background and on pedestrians. The total fixation duration was summed up for all of the stable objects, and also for all of the changing objects. Then, these values were divided by the number of turns around the monument, and the number of objects, to give the total time of fixation on a single object in one turn around the monument, averaged over the objects. For the *deleted-object* condition, fixation on the object's prior location was measured.

All the analyses were performed on the video files that were recorded during the experiments. These videos were then converted to a format that can be used with PCs. After this convertion, the images were imported to the Windows Movie Maker Application. The resulting video records were examined frame-by-frame to calculate the fixations. Then, the duration of each fixation was calculated in milliseconds. After these analyses, the durations of fixations were summed up to obtain the numbers that are necessary for the calculations explained above.

3. Results

3.1. Gaze durations on stable and changed objects

After examining the data, the average eye fixation duration on the changing object for the Inexperienced groups was found to be 709 msec, while that of the Experienced groups was 1922 msec. In addition, the average fixation duration for all of the stable objects for the Inexperienced groups was 848 msec, and that of the Experienced groups was 867 msec (for the detailed durations of all of the groups, see Figure 6).

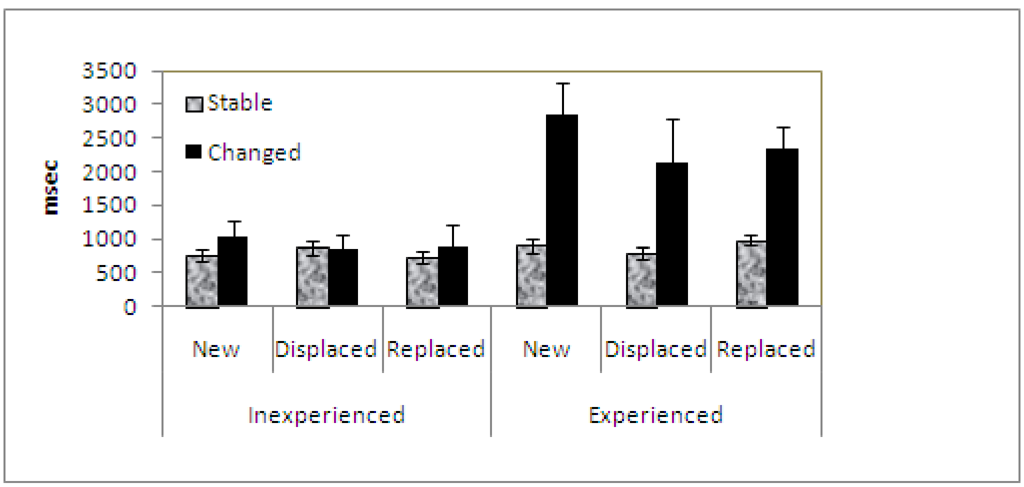

Figure 6. Mean gaze durations of the six change groups

Because the gaze durations for stable, new, displaced, and replaced objects were gazes on present objects and the gaze durations for the previous locations of removed objects were not gazes on present objects, these two parts of the data were analyzed separately. Gaze durations for the stable and changed objects were analyzed in an analysis of covariance (ANCOVA) in which presence of change (stable, changed), type of change (new, displaced, replaced), amount of experience (inexperienced, experienced), and gender of the participant were independent variables. Total time spent exploring the environment and the age of the participant were used as covariates. Thus, the ANCOVA had a 2 x 3 x 2 x 2 design, in which all independent variables except presence of change were between-participant variables.

Of the covariates, only total time spent examining the environment showed a significant relationship with the dependent variable (F (1, 82) = 29.60, $p < .001$). The reported means are adjusted according to the covariates (see Figure7).

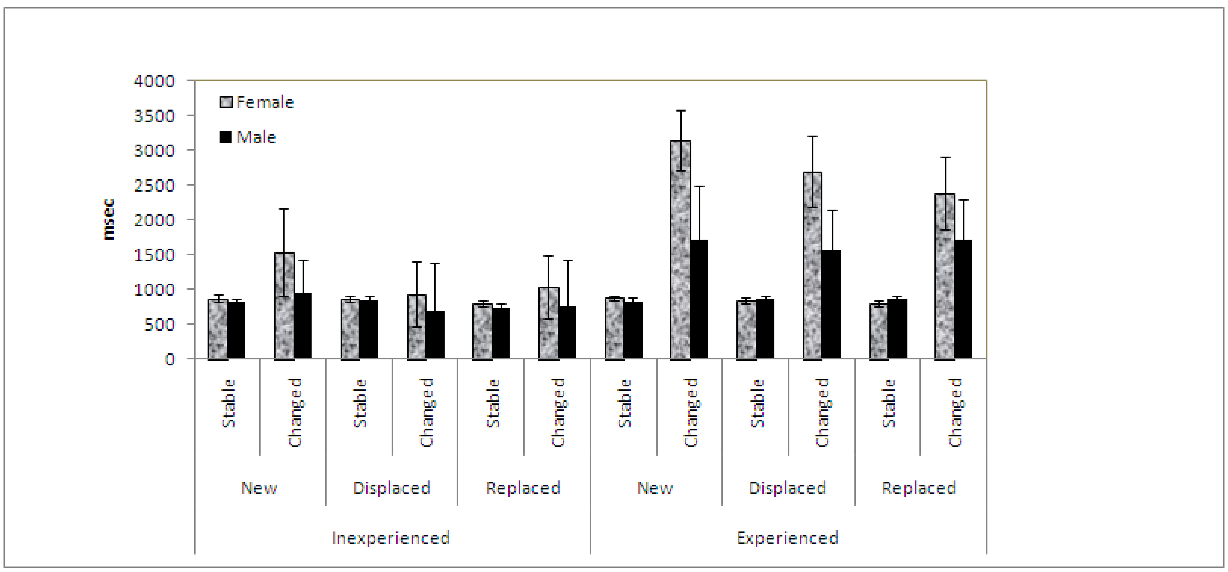

Figure 7. . Mean gaze durations of the six change groups on stable and changing objects according to their gender and level of familiarity

The main effect of the presence of change was not significant (F (1, 82) = 0.54, $p = .464$) but the main effect of familiarity was significant (F (1, 82) = 13.28, $p < .001$) and so was the effect of gender (*F* (1, 82) = 4.46, $p < .05$). However the effects of familiarity and gender are better understood in the light of their significant interactions with presence of change (*F* (1, 82) = 12.33, $p < .001$) for familiarity by change and (*F* (1, 82) = 4.20, $p < .05$) for gender by change. Separate analyses of the data for stable and changed objects showed that gaze durations differed between inexperienced and experienced participants (*F* (1, 82) = 12.88, $p < .001$) and between females and males (*F* (1, 82) = 4.36, $p < .05$) differed for changed objects only (see Figure 8 & 9 respectively). No other effect involving the independent variables reached significance.

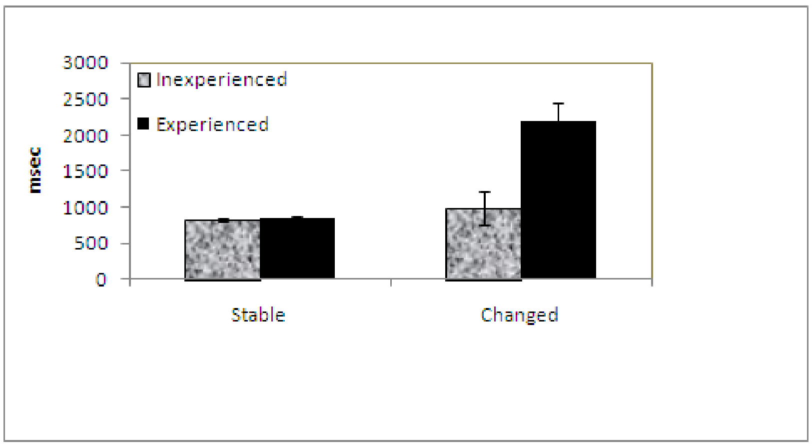

Figure 8. Mean gaze durations for stable and changed objects according to participants' level of familiarity

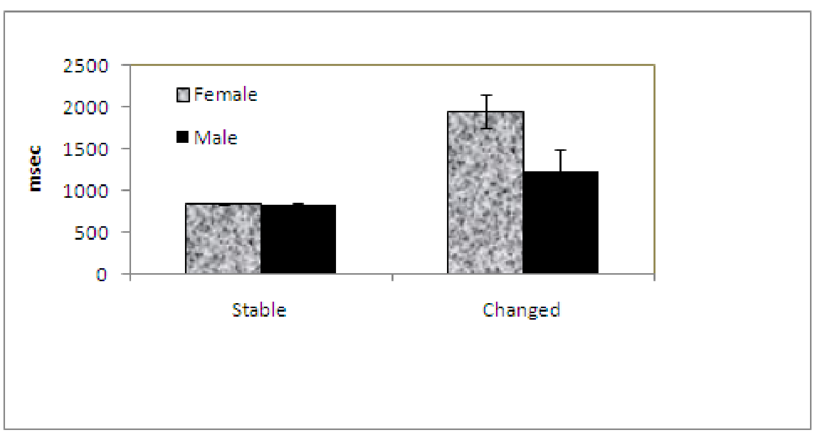

Figure 9. Mean gaze durations for stable and changed objects according to participants' gender

Participants who had experience with the environment looked substantially longer at the changed objects, an increase of approximately 1200 msec. This finding suggests that having prior experience with the environment indeed increases the likelihood that participants will look at a change in the scene. On the other hand, it is not possible to say that the differences between the gaze durations for stable and changed objects were different for the three types of object change. All change types showed a significant difference from those fixation durations on their respective baselines for control conditions (see Figure 10).

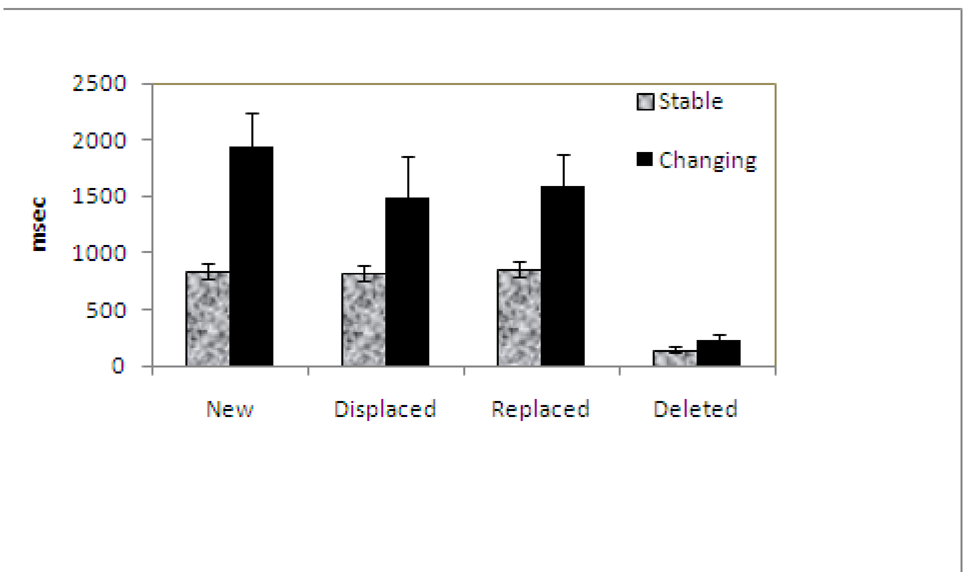

Figure 10. Mean gaze durations on Stable and Changing Objects for Different Change Types (*For the Deleted-object condition, the possibility of fixating on the empty spot of the deleted object is used instead of the stable object)

3.2. Fixation Latencies on Changed Objects

In this experiment, another variable, the time duration before the first fixation on the changed object after it became visible to the participant, was also examined. Here, the aim was to further investigate the effects of familiarity and change types on the nature of the detection process. These durations were calculated again by analyzing the videos in a frame-by-frame manner. First, the time of the change (i.e., the time that the change became visible to the participant) was noted. Then, the time of the first fixation on that changed object was noted, and the duration between these two times was calculated for the analysis. Average fixation latencies for new, displaced, and replaced objects in the Experienced and Inexperienced groups can be seen in Figure 11 below.

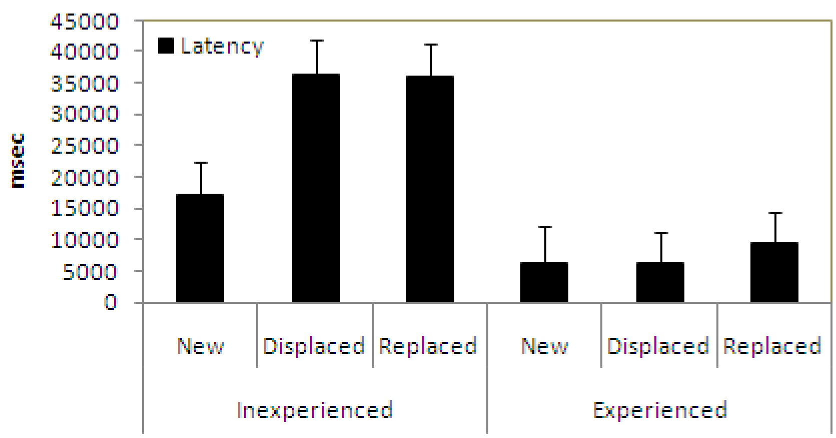

Figure 11. Mean fixation latencies

Fixation latencies were analyzed in a separate ANCOVA in which type of change (new, displaced, replaced), amount of experience (inexperienced, experienced), and gender of the participant were independent variables. Total viewing time and age of the participant were covariates. Total time was related to fixation latency (F (1, 82) = 9.34, $p < .005$) and there was also a main effect of familiarity (F (1, 82) = 25.84, $p < .001$). Participants fixated on a changed object much sooner if they were familiar with the environment compared to unfamiliar participants.

All of the participants also tended to fixate on new objects faster than on displaced or replaced objects, but the difference was not significant because of the very large variability in the fixation latencies (see Table 1).

Table 1 - Variability of fixation latencies

Familiar	**Mean**	**Std. Error**
Inexperienced	30 sec	4,335
Experienced	6 sec	0,451

3.3. Gaze Durations on the Place Formerly Occupied by Deleted Objects

In a 3 (change type) by 2 (gender) ANCOVA with total viewing time and age of the participant as covariates, gaze durations on the places formerly occupied by deleted objects for the Experienced (378 msec on average) and the Inexperienced groups (64 msec on average) were compared to the gaze durations on empty spaces that were to be occupied by new objects in the *new-object* group in the 6^{th} turn (135 msec on average). The results of the ANCOVA showed that the average gaze durations for these three groups were significantly different (F (2, 40) = 7.89, p < .001). Comparisons made between pairs of means using t-tests adjusted according to the Bonferroni procedure showed that the participants in the Experienced groups gazed at the location previously occupied by a deleted object longer than the participants in the Inexperienced groups gazed at such a location and participants in the new object group looked at empty spaces.

3.4. Fixation Latencies on the Locations Formerly Occupied by Deleted Objects

The Experienced and Inexperienced participants were compared in terms of how soon they fixated the former location of a delete object by means of another ANCOVA with group and gender as independent variables and total viewing time and age of the participant as covariates. It was found that participants fixated on the former locations of deleted objects (21 msec on average) faster than the Inexperienced participants (72 msec on average, F (1, 26) = 19.35, $p <$ .001). Gender and the covariates did not have significant effects.

3.6. Gaze Distribution

We also examined how the participants directed their eye gaze in the environment. The location of the fixations was classified into fixations on the path, on the surrounding environment (for example the grass, the monument, or into the distance), on the pedestrians, or on objects—either changing or stable. The times spent in fixation on each of these regions are plotted in Figures 12 and 13, for the Inexperienced and Experienced groups respectively.

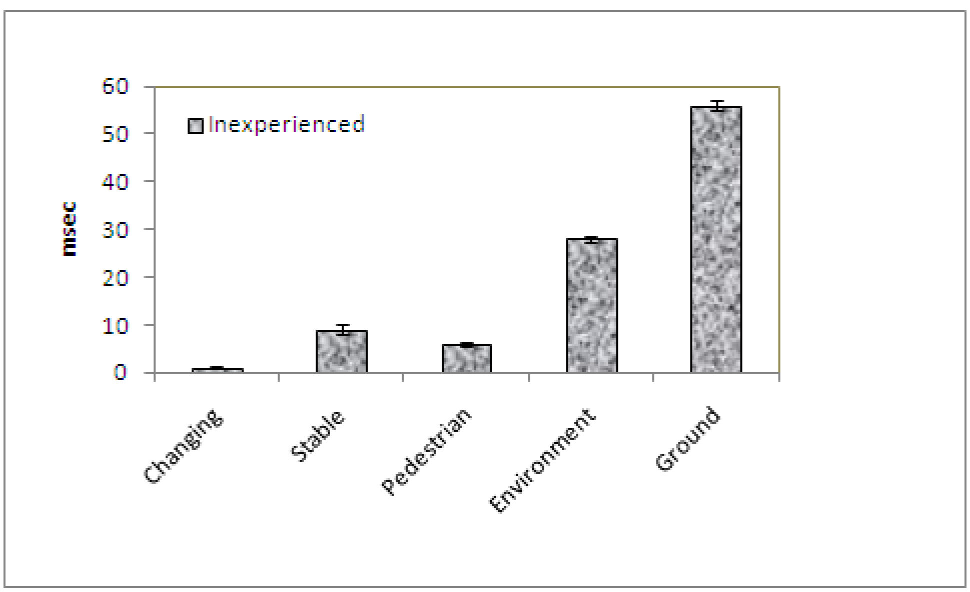

Figure 12. Fixation Distributions for the "Inexperienced" Groups

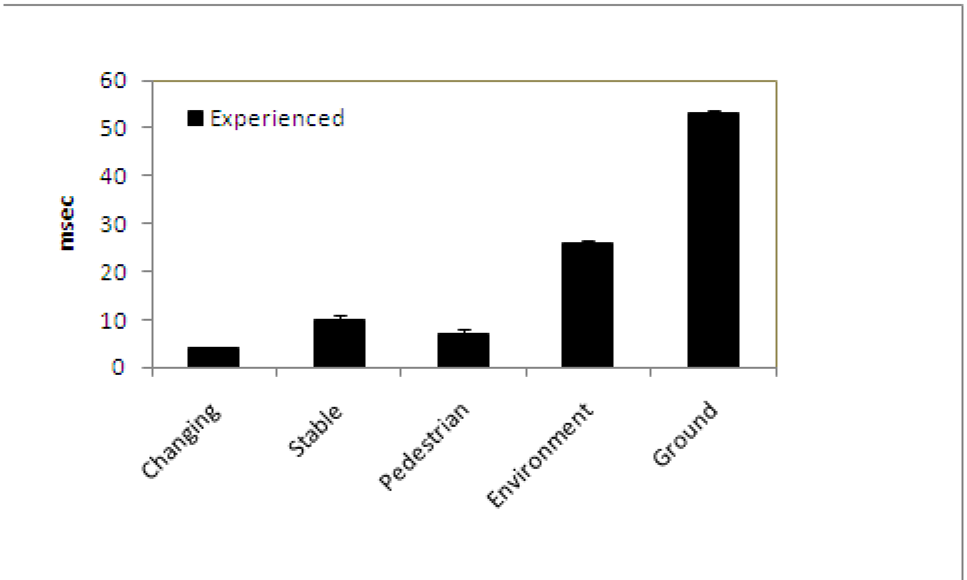

Figure 13. Fixation Distributions for the "Experienced" Groups

Most of the fixations were located on the walking path for both the Inexperienced and the Experienced groups (56% and 53% respectively). This may reflect the ongoing demands of walking and staying on the path.The Inexperienced groups devoted 28% of their total gaze duration to the surrounding environment. This was almost the same for the Experienced groups; their percentage was 26%.

The smallest amount of time was spent on the objects and pedestrians in both main groups. The percentage of the fixations on stable objects (9% and 10% for the Inexperienced and Experienced groups respectively) and on pedestrians (6% and 7% for the Inexperienced and Experienced groups respectively) were also close to equal between the two types of groups. The only difference in gaze direction between the two groups was for the changed objects. The percentage of fixation on the changed object was 1% for the Inexperienced groups, while that of the Experienced groups was 4 %.

3.7. Correlations between participant reports and eye fixations

After completing the experiment in the Virtual Environment, the participants were asked whether they had noticed any change that had occurred in the environment during the experiment. If their response was positive, they were asked to verbalize their explicit knowledge about those detected changes. Table 2 shows the number of participants in each main group that detected the different kinds of changes explicitly.

Table 2 - Number of the Participants that Detected the Changes Explicitly

Changes / Groups	Object Appeared	Object Displaced	Object Replaced	Object Disappeared
Inexperienced	6	2	3	0
Experienced	11	9	11	5

When we compared these verbal reports with their eye fixations, we found that there was a high correlation between the two (Spearman's rho = .422; N=128; p<.01). The average fixation durations on changing objects were longer for the participants who reported that they had recognized the change. This suggests that the fixations were accompanied by an awareness of the change. Therefore, either the participants looked at the changing area because they noticed that something had changed in that specific spot in the environment, or their longer fixation durations on the changing objects provided them with the awareness of that specific change.

4. Discussion

The results of this study reveal that familiarity with the environment is an important factor in the direction of gaze in the environment. In particular, participants spent more time fixating on changed objects if they were familiar with the environment. Those who were familiar with the environment fixated on changes on average 1200 msec longer than the participants who were less familiar with the environment. The time duration for the participants' first fixation on the changed object after it became visible was another indicator of the effect of familiarity on change perception. The Experienced participants looked at the change much more quickly than the Inexperienced ones.

In this study, the effects of familiarity, gender and the type of change that was applied were combined, and we found that the Experienced groups fixated longer on every type of changed object than the Inexperienced groups. When we look at the numerical data for the fixation durations, the *New-object* condition was observed to be the change type that most attracted the gaze of the participants in both main groups. The *Replaced*, *Displaced* and *Deleted* object conditions followed the *New-object* condition in descending order of attraction. This finding is similar to previously reported results (Karacan & Hayhoe, 2008). The average fixation duration for the *Deleted-object* condition was shorter than the fixation durations on other types of changes, but it must be noted that this is because of the cognitive nature of the process. Looking at a present object is much more informative than looking at an empty space. After the disappearance is recognized, the viewer may not need to look at that empty spot to gather further information. This is not the case for other types of changes.

Despite these numerical differences, the statistical analyses show that the average fixation durations on each type of changed object were not significantly different from each other, though all of the change types showed a significant difference from those fixation durations on their respective baselines for control conditions. This result indicates that the only important differentiating factor for change detection was the participants' familiarity level. The type of change they observed was not significant. This is contradictory with previous results claiming that it is the nature of change which attracts attention (Mondy & Coltheart, 2000; Boot et al., 2005; Brockmole & Henderson, 2005). We can infer from this finding that people can learn where to attend and any type of change in the surrounding environment can attract attention while the level of familiarity increases.

Previous results from a study by Brockmole and Henderson have shown that object additions and deletions were fixated upon at rates greater than those which might be due to chance, which suggests that both types of scene change cues are used in the human visual system to guide attention during scene exploration. However, appearances were fixated upon twice as often as disappearances in their study, indicating that new objects are more attention-grabbing than deleted objects (Brockmole & Henderson, 2005). Other results reported in the literature also suggest that participants are less likely to detect deletions than additions (Pezdek et al., 1988). In the experiments of this study, we further investigated this issue by adding two different change types—replacement and displacement. The results helped us to develop a clearer understanding of the nature of this distinction as well as the prioritization of the other two change types (i.e., replacement and displacement). Our results show that object deletion is also an attention attracting change type, like the other three. The previous underestimation of deletions by researchers may be due to the control groups that were used for comparisons, since empty spots that occurred after deletions had been applied were compared with objects in those studies. Comparing the gaze directions toward empty places with those toward objects is not cognitively profitable, because empty places cannot be as informative as visible objects.

Even if the type of change seems to have no interaction with change detection, it actually does have a significant effect on both the Experienced and the Inexperienced groups when we look at the average time durations for the first fixation on the changed object after it became visible to the observer. This means that familiarity influences change detection across every type of change, even if the nature of these changes are very different from each other. This finding also demonstrates the adaptability of human learning, since familiarity has an effect on the attention paid to each type of change regardless of its nature.

It is also important to note that these changes (i.e., appereance, disappearance, replacement, and displacement) occurred while the objects were out of the field of view of the participants, and so were not accompanied by a retinal transient. Thus their prioritization in terms of attention paid to them must be a consequence of the difference between the current image and the participant’s stored memory representation of the scene. This is consistent with Brockmole and Henderson’s (2005a) result, which was that changes occuring during a saccade could attract fixations when the participants had the opportunity to construct a memory representation of the scene during a prior 15 second exposure to the image.

The results also revealed an interesting gender difference according toparticipants’ change detection performance. The gaze durations of female participants on changing objects were found to be significantly longer than that of male participants. It seems that the visual awareness level of females is higher or they tend to look at changed objects rather than stable ones. At this point, it should also be noted that the effect of familiarity on change detection performance occurs independent from this effect of gender.

5. Conclusion

The results of our experiments reveal that people are more likely to fixate on changed objects if they are familiar with the environment. Participants familiar with the environment fixated on changes for a significantly longer time period than participants who were less familiar with the environment. These results support the hypothesis that we learn the structure of natural scenes over time, and that attention is attracted by deviations from the normal state. Our results also show that familiarity influences change detection across every type of applied change, even if the nature of these changes is very different. This finding also demonstrates the adaptability of human learning, since familiarity has an effect on the attention paid to each type of change regardless of its nature.

6. Limitations and Further Study

In order to be able to generalize the results of an experimental study, the number of participants and their demographic diversity should be as large as possible. In this study, the main limitation was the lack of demographic diversity, as only university students participated in the experiments. Though the number of participants was large enough to observe significant effects, more participants might allow us to find different trends.

In a further study, different media or visualization technologies, such as CAVE, can be used to evaluate their possible advantages and disadvantages. More change types can be added to the procedure to investigate different natural tasks. The feeling of presence can also be compared between different experimental settings in order to obtain more detailed findings concerning effects on change detection performance. Finally, these results can be compared with real-world cases if future improvements can be made in eye-tracking technology, so that the technology can be used in large-scale outdoor environments.

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