

# Context Information in Guiding Visual Search: The Role of Color and Orientation

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**Abstract.** At work and at leisure people perform various visual search tasks, e.g. they search for a particular icon in software tools, on Web sites or on mobile phones. With an increasing number of items, visual search becomes difficult. Recently, it has been suggested that the so-called contextual cueing effect, which is known from psychological experiments, can be applied to improve visual search performance. Contextual cueing leads to decreased search times for target objects within familiar context configurations. It is assumed that associations between context configurations and target locations are learned implicitly and then used to guide the allocation of attention to the relevant object. In accordance with demands for interface consistency, this mechanism could be interesting for the development of user interfaces. The present study investigated which object features (e.g. color or orientation) can establish the learning process. The results show that implicit learning of color and orientation arrangements are possible, but the transfer to configuration with changed features depends on the recent learning history. Implications of these results are discussed with respect to the design of user interfaces.

**Keywords:** Interface Consistency, Contextual Cueing, Visual Attention, Learning.

## 1 Introduction

At work and at leisure people often have to search for certain visual objects in various contexts like software applications and Web sites. In general, humans are doing quite well in finding a task-relevant object (target) among other task-irrelevant objects (distractors), for example, a relevant menu button among a variety of irrelevant buttons within the taskbar.

However, with increasing numbers of icons on the desktop or of "apps" (applications) on the mobile phone, the difficulty to find a certain icon increases. Especially, if the icons are very similar to one another or very small, they are difficult to distinguish. The similarity of icons depends on their features, e.g. color, shape, and size. Depending on these features and their combinations, the icons are more or less easily to distinguish and the relevant icon can be found easily



**Fig. 1.** Example for icon list on a mobile phone (left: Apple<sup>®</sup> iPhone icons) and on the computer screen (right: Microsoft Windows<sup>®</sup> desktop icons)

or not. Fig. 1 shows examples of typical icon lists. The left icons are very similar because they share the rectangle shape. The right icons have different shapes but they are often rather small on laptop displays. Accordingly, the task to find a particular icon within these lists might be hindered. Users may facilitate their search of relevant icons by classifying and sorting them according to different purposes. However, this method can become rather time consuming depending on the number of icons. Here, another method is suggested that might facilitate user's search by applying a mechanism found in psychological research.

It is well-known that the human visual system is limited with respect to the number of objects which can be processed simultaneously. Therefore, objects have to be selected for further processing – a mechanism known as selective visual attention. Two mechanisms are supposed to allocate attention appropriately and efficiently to areas of interest. Bottom-up or stimulus-based mechanisms guide visual attention to objects with certain physical properties [1, 2]. For example, salient features, dissimilarities to other surrounding objects or abrupt onsets [3] can enhance target selection.

Moreover, also top-down or knowledge-based factors like familiarity [4] and novelty [5] can guide visual attention. Knowledge-based allocation of attention can be introduced by instructions or acquired without intention over time. The latter mechanism is known as implicit learning. Implicit learning occurs within a variety of daily life activities, for example in motor learning, in the control of complex situations, in language acquisition, or in sequence learning. The advantage of such an implicit mechanism is that it does not need additional processing capacities or any additional instruction of the user.

Accordingly, implicit learning is expected to be of relevance also for user interface design. As stated by Steve Krug in his book "Don't make me think" [6], Web sites and applications for human computer interaction (HCI) should be designed in an intuitive way. An implicit learning mechanism can help to

facilitate HCI, because this mechanism works completely effortlessly, i.e. without thinking about it.

One mechanism which makes use of implicitly learned information is known as contextual cueing. If people are asked to search for a target object and to identify it as fast as possible based on a certain object features like color or orientation, they are faster in a familiar environment, also called the visual context. In a typical experiment, the effect of the visual context is investigated by manipulating the spatial arrangement of task-irrelevant distractor objects, within which a task-relevant object has to be found. If these arrangements are presented repeatedly, the participants become faster in finding the target object compared to novel arrangements never seen before. It is proposed that this effect is based on learned associations between the target location and the surrounding context elements [7], which can be used to guide visuo-spatial attention more efficiently to the target location.

Applying this mechanism to the design of user interfaces touches the topic of interface consistency. The three-dimensional model of interface consistency [8, 9] distinguishes conceptual consistency, communicational consistency and physical consistency. The physical consistency includes visual features like color, size, shape, and location. These features typically describe properties of the target itself. Another possibility to enable interface consistency could be the consistency of context elements. In this sense, contextual cueing is expected to enhance search performance of certain interface elements which are embedded in a familiar context. So far, there are inconsistent results whether consistency really enhances performance [10, 11], but the investigation of the contextual cueing effect could shed more light to this question.

## 2 Contextual Cueing Based on Color and Orientation

A precondition to transfer this kind of learning mechanism to real world applications is the ecological validity of contextual cueing. So far, it has been shown that implicit learning occurs not only with artificial stimuli but also with pictures of real objects like LEGO<sup>®</sup> bricks [12]. However, in all previous contextual cueing experiments, the visual context was defined by the spatial arrangement of distractor objects, that is, all objects were arranged in a kind of matrix but not all possible positions were filled. Thus, it is impossible to decide whether object positions (i.e., the spatial arrangement of the objects) or other object properties (features, such as color, size, and shape) were learned. Although it has been shown that contextual cueing occurs if only the spatial arrangement and not the object features were informative for the target location [13], it is unclear so far whether visual contexts defined by object features can also establish the learning process. However, for the implementation of contextual cueing to HCI applications, it is essential to know which target properties can be used to enhance the search performance.

Because the object identity can be specified as the combination of different features, for example color and shape, it is important to know whether single

features of context stimuli can be learned as well as feature combinations. For example, certain icons could be distinguished by either their color, their form, or both. One interesting question is whether certain object features support the implicit learning process better than others.

Another important question is whether learned context information can be transferred if one additional feature is added to the context objects. So far, it has been shown that transfer is possible if one feature is missing and matches are incomplete, for example if object shapes remain but if color information is deleted [14]. Therefore, it seems as if object shapes can be learned separately, which can lead to an improvement of search performance.

One general problem in interpretations of contextual cueing effects is the assumed allocation of attention because other explanations are also possible. For example, it has been proposed that contextual cueing might also enhance response selection [15, 16]. If it is intended to improve visual search in HCI applications via contextual cueing it is important that the mechanism modulates attention allocation rather than the selection of button presses. One method to demonstrate the involvement of attentional selection is the recording of eye movements. Because saccades are typically preceded by attention shifts [17], eye movements can be used as indicator of attention allocation.

To summarize, the goal of the present experiment was to clarify whether contextual cueing occurs also without gaps or pattern in the context configuration. It was investigated whether the features color and orientation can be learned separately to form visual contexts and whether the implicit knowledge about these contexts can be transferred to a test phase, in which feature combinations are presented. Moreover, the involvement of attentional processes in the contextual cueing effect was tested by eye movement recordings.

## 3 Methods

### 3.1 Participants

Eight subjects (age 20-33 years, mean age 24.4 years) participated in this experiment. Six of them were right-handed and all had normal or corrected-to-normal vision according to self-report. All participants were naive as to the purpose of the study and received 8 Euro per hour for their participation. Most of the participants were students of the Ludwig Maximilian University.

### 3.2 Stimuli and Apparatus

The experiment was conducted in a dimly lit room to control for interferences from the outside. The experimental setup consisted of a table equipped with a LCD projector, which was mounted on top above the search area, a mirror system, and a remote eye tracker [18].

The participants sat on a (non-rotating) stool in front of the table. The height of the stool was adjusted individually, so that the unrestrained viewing distance

from participant's eye to the centre of the search area was approx. 60 cm. If necessary, participants were provided with a foot rest in order to maintain a comfortable position.

The stimulus displays were generated and displayed with MATLAB R2006b (The MathWorks Inc.) on a Dell Latitude D830 laptop running Microsoft Windows XP Professional. They were projected on the table (size: 100 x 80 cm) via the mirror and appeared in an area of approx.  $20^\circ \times 20^\circ$  of visual angle in the centre of the display.

The eye tracker was placed in an opening at the bottom part of the table. The lower edge of the display area projected on the table was adjusted to the same level as the upper edge of the opening for the eye tracker. During the experiment the left eye's gaze position and eye movement duration during the search was recorded via an Eyelink 1000 system (2007 SR Research Ltd.; sample rate 500 Hz, pacing interval 1000 Hz, 100% illuminator power) in remote mode. Eye movement data were recorded by a portable Host PC under DOS mode.

Two response buttons were located left and right of the eye tracker, and the participants were instructed to press the buttons with their left or right index finger, respectively.

All search displays consisted of 4 x 4 pictures of six different LEGO<sup>®</sup> bricks, which were created with LeoCAD (cf. Fig. 2). Lego bricks offer a good possibility to control item features in contrast to more complex items. The size of the bricks varied from approx.  $1.6^\circ \times 0.9^\circ$  to  $3.2^\circ \times 1.7^\circ$  of visual angle. Visual angles were adjusted to a natural view based on the real size of LEGO<sup>®</sup> bricks. The bricks were colored in either red or green, and they were oriented either horizontally or vertically. The participants were instructed to search for the brick with 1 x 3 units (target stimulus). All other bricks were task-irrelevant distractors. In the test phase, the stimuli were basically the same, but there was an additional either light grey (75% grey value) or dark grey (25% grey value) dot on one of the knobs.

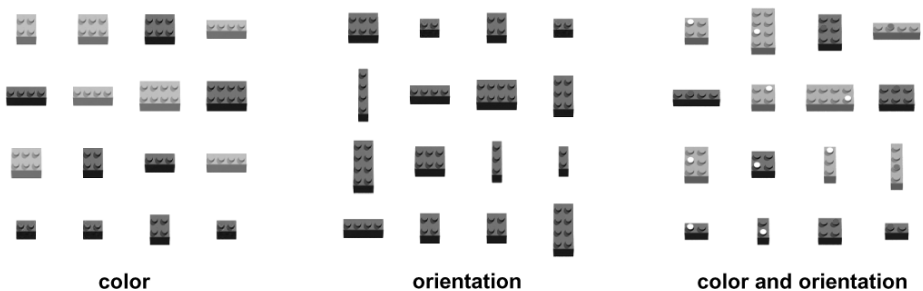
### 3.3 Design

The goal of the present experiment was to examine whether a visual context defined by object features can guide spatial attention. Similar to previous experiments, the visual context was defined as the arrangement of distractor objects. The advantage of a learned visual context is reflected by faster responses to repeated search arrays relative to novel ones. In the present experiment, the repeated set of stimuli consisted of 16 search displays, randomly generated at the beginning of the experiment and then repeated throughout the entire experimental session. It is important to note that the target (i.e. the 3 unit brick) always appeared at the same location within a particular repeated search array, but at different locations across different displays. The response-relevant target dimension (color or orientation) was selected randomly also in repeated trials, in order to ensure that the whole display is not associated with a specific response. The novel stimulus displays consisted of configurations that are shown only once in the entire experiment. These trials measured baseline search speed as a

control because search times may decrease in the time course of the experiment. To rule out location probability effects, the target appeared equally often at each of 16 possible locations throughout the experiment. Each location was used twice during one block, once in a repeated configuration and the second time in a novel configuration. All configurations were generated separately for each participant and presented intermixed.

As we were interested in whether specific object features can guide attention more efficiently, we varied the object feature defining the context. In one condition, only the color was task-relevant whereas the orientation was held constant (color condition, cf. Figure 2, left panel), in another condition the orientation was task-relevant whereas the color was held constant (orientation condition, cf. Figure 2, middle panel). In the color condition, displays consisted of red and green LEGO<sup>®</sup> bricks that were always oriented horizontally. In the orientation condition, displays consisted of bricks that were oriented horizontally and vertically and always colored in red. In both conditions, the objects used as distractors were the bricks consisting of 2, 4, 6, or 8 units, and the target stimulus was always the 3 unit brick. The participants were instructed to find the target brick as fast as possible and to press one of two buttons, corresponding to the target's color (in the color condition) or orientation (in the orientation condition), respectively. More precisely, the right button had to be pressed if the target was green and the left button if it was red in the color condition. In the orientation condition, the participants were asked to press the right button if the target had a horizontal orientation and the left button if it had a vertical orientation.

The effect of object features was assessed in two separate experimental sessions to exclude transfer effects. Furthermore, to control for sequence effects, half of the participants started with the color condition, the other half with the orientation condition. This part of the experiment – the learning phase – consisted of 20 blocks for each condition. Within each block, each of the 16 repeated displays



**Fig. 2.** Examples of search arrays. Each array consisted of 16 LEGO<sup>®</sup> bricks, arranged in a 4 x 4 matrix. The target was always a brick with 3 units, the distractors were bricks with 2, 6, or 8 units. Color condition (left): stimuli were always horizontal, red or green bricks, Orientation condition (middle): stimuli were always red, horizontal or vertical bricks, Test condition (right): stimuli were horizontal or vertical, red or green with a dark or narrow dot as response-relevant target feature.

was presented once, intermixed with 16 novel search displays for a total of 32 trials per block. The data of 4 subsequent blocks were grouped into an epoch, resulting in 5 epochs. Thereby, variations in response times and eye movements could be assessed depending on the time course of the experiment.

In a second phase of the experiment, we wanted to assess whether the context formed by one critical feature can be transferred to novel contexts that are defined by two features. Therefore, each of the previously described condition was followed by a test phase. In this test phase, search displays were presented that consisted of red and green LEGO® bricks that were oriented horizontally and vertically, each with one light or dark grey dot on one of the knobs. For the distractors, the dot appeared with equal probability on each of the knobs. Participants had to press one of two buttons, corresponding to the dot's color on the target (left button for a light grey dot, right button for a dark grey dot). Novel trials were again randomly generated. For the repeated trials, however, one feature was exactly as in the previous 20 blocks, one was randomly assigned to each stimulus: In the color condition (red and green horizontal bricks in the first 20 blocks), color patterns were taken from the 16 repeated trials from the first 20 blocks, but the orientation level was randomly assigned to each brick. In the orientation condition (vertical and horizontal red bricks in the first 20 blocks), orientation patterns were taken from the first 20 blocks, but the color was randomly chosen for each brick.

The whole experiment consisted of two sessions, conducted on two different days. Each session consisted of a learning and a test phase (cf. Table 1). In the learning phase only one object feature (color or orientation) was varied to establish the context configuration, and in the test phase also the previously absent object feature was added to the context stimuli in order to assess transfer of learning to novel contexts. In the learning phase, three main variables were manipulated: the visual context (repeated vs. novel search displays), the object feature (color vs. orientation), and the epoch (1-5). In the testing phase, the visual context (repeated vs. novel) was manipulated and analyzed depending on the condition of the learning phase.

### 3.4 Procedure

Each participant attended two sessions of the experiment, one for each condition. Half of the participants started with the color condition and the other half with

**Table 1.** Task design for the two experimental groups, who performed the color and orientation condition in balanced order

group	session 1		ca. 1 week later	session 2	
	learning	test		learning	test
1	color	color & orientation		orientation	color & orientation
2	orientation	color & orientation		color	color & orientation

the orientation condition. The two sessions were on average 7 days apart (min. 4, max. 9 days).

After being positioned at the workbench, the participants were given a written instruction projected on the display area. They were asked to search for the three-unit LEGO<sup>®</sup> brick among 15 other LEGO<sup>®</sup> bricks and to press one of the buttons, depending on the identity of the target. Importantly, participants were not informed about the repetition manipulation of trials.

For eye movement recordings, a 13-dot calibration and validation, and a drift check was conducted before the first trial. Then participants performed 20 blocks of the learning phase followed by 3 blocks of the test phase. After each block participants could take a short break to rest their eyes, but were instructed not to move too much.

They then could start the next block by pressing one of the buttons. A block consisted of 32 trials. Each trial started with the presentation of a black fixation cross in the center of the display area which remained for 1000 ms. After an interval of variable length (300-1000 ms), the stimulus array was presented on the search area. The variable interval prevents the prediction of the stimulus onset and the occurrence of rhythmic pressing of the response buttons. The participant searched for the target and pressed one of the buttons as fast and as accurately as possible, depending on the target's feature identity. The stimulus display remained visible for 500 ms after the button press, and participants were instructed to fixate the target until the display disappeared. The duration of one session of the experiment was about 100 minutes.

### 3.5 Data Analysis

Reaction times (RTs) were measured as the time from the onset of the search display until the participant's response. Eye movement data were analyzed with the Eyelink data viewer and the fixation counts were computed for each trial. Trials with wrong button presses were defined as errors and excluded from the further analysis. Outliers were defined as values of more than 2 standard deviations below or above the mean value within a subject and block and excluded. The 23 blocks were grouped in sets of 4 blocks each into 5 epochs for the learning phase and into the test epoch consisting of 3 blocks. For the learning phase, mean reaction times and fixation counts were entered into separate repeated-measures ANOVAs with the factors context (repeated vs. novel configurations), object feature (color vs. orientation) and epoch (1 to 5). An effect of epoch reflects changing RTs in the time course of the experiment (i.e. general learning or practice). More interestingly, if the context defined by object features is learned and affects the visual search for a target (i.e. contextual learning), this effect would be reflected by a statistical effect of context. An interaction between the factors feature and context would indicate different learning processes for the features color and orientation. To analyze transfer effects statistically, reaction times in the last epoch of the learning phase and reaction times in the test phase were compared.



## 4 Experimental Results

Reaction times and fixation counts of the color and orientation condition are shown in Fig. 3.

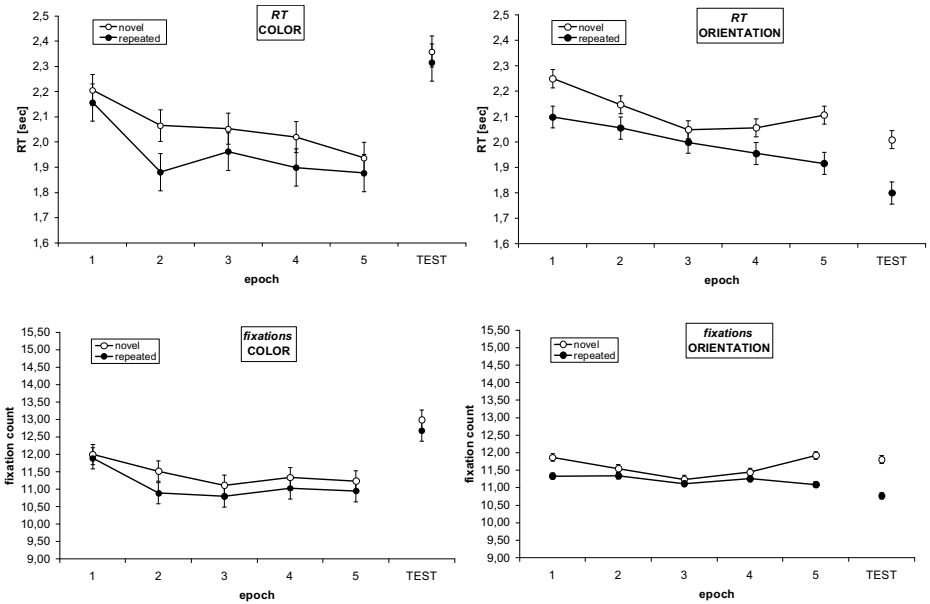
During the learning phase (epoch 1 to 5), reaction times decreased over time ( $F(4, 28) = 10.46, p < 0.001$ ). A significant contextual cueing effect occurred for the reaction times, that is, shorter search times in the repeated condition across all object features ( $F(1, 7) = 14.017, p < 0.01$ ). There was no significant difference in RT between color and orientation condition in the learning phase ( $F(1, 7) < 1$ ) and no interaction between context and feature ( $F(1, 7) < 1$ ). Regarding the transfer, the comparison of the last epoch of the learning phase and the test phase revealed a significant interaction between phase and object feature ( $F(1, 7) = 20.51, p < 0.01$ ). That is, in the color condition reaction times increased after adding orientation information to the distractors, whereas in the orientation condition reaction times decreased after adding the color to the distractor configuration. A further analysis of reaction times, which compared the first and last block of the test phase separately for the two feature conditions, showed no reliable effect of context in the color condition ( $F(1, 7) < 1$ ), but a significant benefit for the repeated trials in the orientation condition ( $F(1, 7) = 8.98, p < 0.05$ ).

The eye movement analysis in the learning phase revealed a decreasing number of fixations for both object features, which was only marginally significant ( $F(4, 28) = 2.146, p = 0.68$ ). A contextual cueing effect occurred during the learning phase across color and orientation, that is the fixation count was lower with repeated contexts ( $F(1, 7) = 8.35, p < 0.05$ ). Similar to the reaction times, no significant difference between the color and the orientation condition was obvious in the learning phase ( $F(1, 7) < 1$ ) and no interaction between context and feature ( $F(1, 7) < 1$ ). The last epoch of the learning phase and the test phase showed a significant interaction between object feature and phase ( $F(1, 7) = 11.53, p < 0.05$ ). That is, in the color condition the number of eye fixations necessary to find the target increased after adding orientation information. In contrast, adding color information led to an decrease of the number of fixations in the orientation condition.

## 5 Discussion of the Results

The aim of the present experiment was to clarify whether the object features color and orientation are learned differently in a contextual cueing paradigm with complex pictures of real-world objects. Moreover, the interesting question was whether implicit knowledge about context configurations based on color or orientation information could be transferred if an additional feature is added to the context configuration during the test phase. For evaluation of ecological validity it was tested, whether the contextual cueing effect occurs also without gaps in the contextual matrix.

First of all, a contextual cueing effect was present also with the use of a completely filled contextual matrix. This result demonstrates that object features and not only locations are learned. In general, the results show that context configurations based on the features color and orientation can be learned equally well. In both feature conditions a contextual cueing effect could be demonstrated during the learning phase. The benefit did not differ between both feature conditions. Moreover, also the use of more complex real-world objects enabled the development of a benefit for repeated displays over time. Overall, reaction times were longer than in previous experiments with artificial stimuli. Probably, the use of a greater number of distinct context elements together with the presentation of a completely filled matrix lead to longer search times. Interestingly, when the previously absent feature (color or orientation) was added to the context configuration in the test phase, impressive differences occurred in the two feature conditions. Reaction times decreased below the level of the previous learning phase and a benefit for repeated displays (that is displays with the same orientation configuration) was present, if color was added in the test phase. If, however, orientation information was added, reaction times increased in comparison to the learning phase and the contextual cueing effect disappeared. In other words, changing the orientation of context elements after having learned configurations based on pure color information seems to disturb the implicit learning effect. This result is unexpected from a real-world perspective: We have often experienced familiar objects to occur in



**Fig. 3.** Reaction times (top; mean and standar error) and fixation counts (bottom; mean and standard errors) for the two condition color (left) and orientation (right) as a function of epoch (x-axis) and context (filled vs. unfilled symbols)

different orientations, however, we would not expect them to suddenly change their color.

In contrast, adding the grey dot to the bricks seemed not to disturb the performance, at least not in the orientation condition. A possible explanation for performance differences can be found in the experimental setting. During the learning phase of the color condition the action-relevant dimension was color and the subjects had to decide whether the target object was colored in red or green. In the subsequent test phase subjects had to decide whether the grey dot was bright or dark. Again, the decision is based on some kind of color dimension, a fact that might lead to interferences in response selection processes because the previously learned color-response association has to be inhibited. However, this assumption can not be evaluated with the present data.

The eye movement pattern, that is the fixation count across epochs in the learning phase and the test phase, resembles nicely the pattern of reaction times. These similarities can be interpreted in favor of an involvement of attentional processes. In accordance to the reaction times, also the fixation counts in the test phase differed between the color and orientation condition.

It might be discussed whether contextual cueing is based on an implicit or explicit learning mechanisms. Although we did not perform an explicit memory test in the current experiment, previous experiments (e.g. [7]) have shown that participants are usually unable to distinguish repeated from novel displays in a memory test after the experiment. In a prestudy with identical stimuli and similar search displays compared to the current experiment, most participants reported that they did not have noticed the repetition of displays. In that experiment, an explicit memory test demonstrated no significant difference between the detection of repeated displays and false identification of new displays. This could be interpreted in favor of an implicit learning mechanism also in the present experiment.

The present experiment nicely shows that contextual cueing is due to a more efficient guidance of attention in repeated displays. However, some questions remain open. For example, the fixation counts show that also with repeated displays several fixations are necessary to find the target, that is, with repeated displays the necessary fixations are only reduced. In contrast to visual search of targets with homogenous distractors [19] the present task seems to be too difficult to be solved with peripheral vision. The stimuli resemble each other too much and focal vision is necessary in order to identify the relevant target as well as to discriminate the relevant target feature (color, orientation or dot color). Because of the similarities between target and distractors several stimuli must be scanned in succession before the target is found and several search strategies can be used [20]. Nevertheless, the benefit of repeated displays might have different reasons. If the familiarity of the context configuration has an immediate effect, the first saccade could already land at a position close to the target. Another possibility is that the context configuration turns to be familiar during the scanning process and therefore saccadic eye movements are directed to the target region after some saccades. Further experiments and more detailed analyses of eye scanpaths will

shed light to the mechanism of contextual cueing. Moreover, also the observed asymmetry of the transfer effect for color and orientation stimuli could be better understood if, for example, different eye scanpaths would be found.

In sum, the present study shows that implicit learning can occur in visual contexts based on simple features, such as color and orientation. However, the transfer to configuration with additional features depends on the recent learning history with respect to the order of context features to be learned.

## 6 Conclusions and Application

An important result for the application of the described implicit learning mechanism is the fact that it does not depend on gaps in spatial configurations. This is relevant for ecological validity and for possible fields of application. For example, the icons for "apps" on mobile phones often form a completely filled matrix without any gaps between the icons, if the maximal amount of icons per page is used (see Fig. 1).

Moreover, the results show that it is possible to use more complex pictures of real-world objects in the described paradigm. Objects in the environment, on Web sites, and in software applications differ in a variety of feature aspects. The generality of the contextual cueing mechanism is necessary, if it should serve for the enhancement of user interfaces.

It should be noted that although the participants of the present experiment were students with a relative low mean age, the results are expected to be generalizable. It has been shown that the contextual cueing effect is present also with older people, that is, it seems to be stable over age [21].

As stated at the beginning, it is essential to understand the underlying mechanism for deciding which features of the context elements can improve visual search performance. With the present study, it has been shown that separate features can be learned. However, how this knowledge is transferred to contexts with additional objects features depends on the feature type learned before. For physical interface consistency, this means that search performance could benefit from constant context elements, which are implicitly learned. The fact, that color and orientation of context elements can be learned equally well suggests that these features should be used for user interface design. Moreover, it seems that certain features can be added (i.e. color) without disturbing the representation of the previously learned context. This could enable a more flexible realization of interface consistency, depending on the task or environment. For example, one could imagine that, depending on a chosen menu, the color of an icon changes. But by keeping the form or orientation of the other icons constant, the target icon is still found more easily. In sum, the present results demonstrate, in contrast to other studies [11], a performance benefit for a specific kind of consistency, namely the consistency of the context. In the future, the implementation of a contextual cueing mechanism into user interface design may help to enhance performance and satisfaction of end users.

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