

2. Methods

This second section will give details on how the virtual environment was built up and how eye movement data were collected. It will further give a description of what the virtual room looked like and what the subjects had to do to accomplish the given tasks. Additionally, it will outline the experimental design and the procedure. First, the sample of participants is described.

2.1. Sample

Twelve subjects participated in the present experiment. The six males and six females were on average $M = 19$ years old ($Min = 18$, $Max = 26$). All of them had normal or corrected-to-normal vision by contact lenses. Persons wearing glasses were excluded from participation beforehand. Ten subjects were college freshmen at The University of Texas at Austin and were paid in participation hours, which they had to collect as credits for their psychology class. The two remaining subjects (one graduate student and one research associate) participated voluntarily. All participants, except for the research associate – whose data did not differ profoundly from those of the other participants' – were naïve about the research question and had no experience with virtual reality experiments.

2.2. Equipment

The experiment took place in a laboratory at The University of Texas at Austin. Customary computers were used for programming the experiment as well as for conducting, storing, and analyzing the data.

For the construction of the interactive virtual environment and for rendering the graphics throughout the experiment, the Vizard Virtual Reality Software Toolkit by Worldvizard® was used.

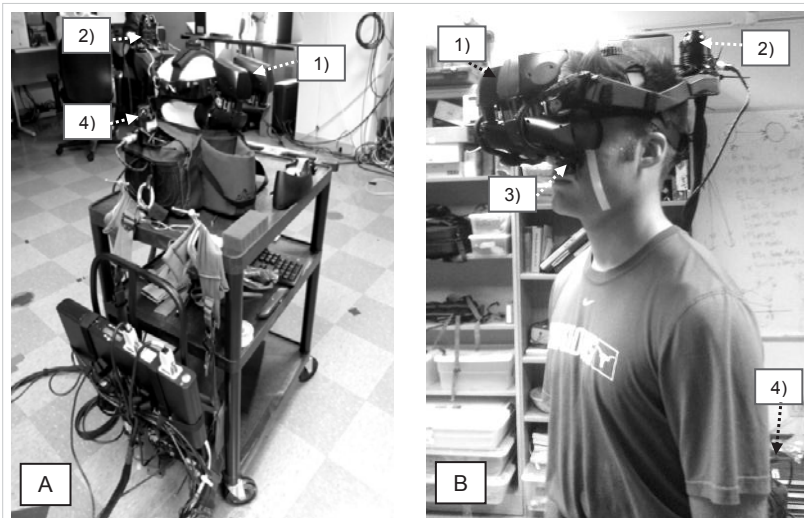


Figure 2. A) The technical equipment used in the present experiment and B) subject EM wearing it. 1) The two screens of the nVisor SX111 wide field-of-view head-mounted display, giving the subject an impression of a 3-D image. 2) One HiBALL™-3100 Tracker (head position) attached to the backside of the head mount. 3) The camera of the View Point Eye Tracker® below the subject's left eye. 4) The second HiBALL™-3100 Tracker (body position) put into a belt bag (blue in A), which the subject wore around the waist.

To enable the participants to freely move through the virtual environment, the subjects wore an nVisor SX111 wide field-of-view head-mounted display by NVIS Inc. (resolution: 1280x1024pixel; spatial resolution: 3.6arc-min/pixel; contrast: >

100:1; total horizontal FOV: 102°; total vertical FOV: 64°; overlap: 50° $\pm$ 66%). It compassed two screens (one for each eye) to create the impression of a 3-dimensional image (see Figure 2). Attached to the backside of this helmet was one of two HiBALL™-3100 Tracker by 3rdTech™ to record the subject's head movements (i.e. turning to the left or right). The second HiBALL™-3100 Tracker was put into a belt bag, which the subject wore around the waist, recording the subject's movements through the room. Both trackers are necessary to align the subject's actions and the rendering of the current image, and therefore, to allow the subject to interact with the virtual environment.

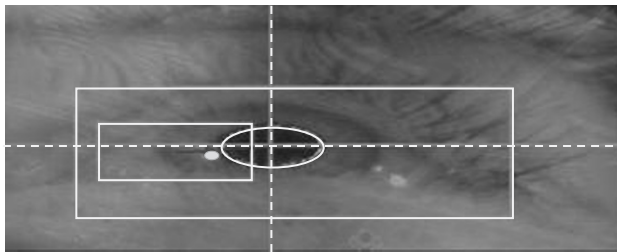


Figure 3. View of the eye tracking camera on the subject's left eye. The eye tracking software calculated the gaze position by using the pupil-glnt vector. The bigger white box marks the area in which the pupil should be detectable; the smaller white box marks the area in which the glint (= cornea reflection of an infrared light attached to the eye tracking camera; represented by small white spot) should be detectable. The bigger circle indicates size and movement of the pupil. From these parameters results an estimation of gaze location shown by the white cross-hairs (dashed lines), respectively by those in Figure 7.

The optical sensors of the HiBALL™-3100 Tracker are 7.3cm tall (5.4cm in diameter) and consist of six lenses and photodiodes. They have a maximum update rate of 1000Hz each (resolution of position: 0.2mm RMS; resolution of orientation: 0.01° RMS) with a latency of less than 1msec. Using infrared signals the sensors communicate with about 3000 infrared LEDs attached to the ceiling to cover the area of the laboratory, which the subjects could freely walk through. Eye movements of the left eye were recorded with a View Point Eye Tracker® by Arrington Research, Inc. The provided calibration software was adapted to in-

house requirements, which resulted in a nine-point calibration screen. The pupil-glint vector was used as a reliable measure of eye movements (see Figure 3).

Auditory feedback when subjects made contact with a virtual object was given via customary speakers.

Eye movement data and video sequences from the subject's point of view during the experiment was stored and analyzed off line.

2.3. Stimuli and Task

The environment used in this study was a virtual replica of the actual real-world laboratory in which the experiment took place. The size of the virtual room was 7.3 x 7.9 meters and had comparable objects, such as desks and shelves, standing on the wall (see Figure 4).

The path, on which the subjects were instructed to stay on during the trials, was indicated by a light grey diagonal on the floor (length: 6.1 meters, width: 1.5 meters) between two opposite corners of the room (see Figure 5). A virtual elevator, which took the subjects up to the next room, was displayed by a green disk at the end of each path.

Arranged along the path were pink and blue cubes (size: 0.23m^3). From now on, these cubes will be referred to as *objects*; other visible objects, for instance desks on the wall or the elevator disk on the floor, are interpreted as being part of the room, because they were not relevant to the subject's task and therefore not included when talking about objects. The cubes were stationary, hanging in the air and adjusted to the subject's individual eye height (about 0.5-0.6 feet less than subject's body height).

The subject's task was to collect and/or avoid objects of a certain color as instructed before each block of trials. They were told by one of the examiners, if they were about to collect blue or pink targets, to avoid blue or pink obstacles or to collect the one *while* avoiding the other color. The color, representing the type and task relevance of an object, remained the same within a subject, but was balanced across subjects.

To collect an object the subject had to walk through it until it disappeared. As point of reference served the HIBALL™-3100 Tracker, which the subject was wearing on the backside. More precisely, the body tracker's coordinates were shifted 0.4 meters forward to represent the subject's horizontal center of body. Thus, when the subject's body coordinates and the object coordinates were aligned (range: ± 0.381 meters) the system recognized the object as being contacted by the subject and the object disappeared. Additionally, whenever subjects made contact with an object they heard an acoustic feedback: a fanfare, when collecting a task-relevant target; a buzzer sound when accidentally making contact with a task-relevant obstacle; or a bubble pop when walking through a task-irrelevant cube of either color.



Figure 4. The view into the virtual laboratory, with desks (wooden ashlar in the back right corner), cupboards (upright block on the back wall), and shelves (on the right wall). The furniture was sited to the positions of the actual furniture in the real laboratory.

The idea of giving an acoustic feedback was to remind the subjects of the type of objects and the task they were doing in the experimental trials. More important than that was to reinforce the subject according to the implicit reward approach: A cheerful fanfare sound as a positive feedback when collecting a target; an unpleasant buzzer sound when making contact with an obstacle they should have had avoided; or a neutral bubble pop when the object was not task-relevant in this particular block of trials.



Figure 5. The viewpoint of the subject when arriving in the room via the elevator in the back corner. Virtual simulations of the real furniture are visible on the walls. The path the subjects had to stay on during the trial is indicated by a light grey strip on the floor; the elevator to the next room is indicated by the disks. The cubes (originally pink and cyan) were adjusted to the subject's individual eye height and the subject was instructed beforehand which color represented a target and which represented an obstacle, respectively, which ones were relevant in the current task.

These sounds were learned by the subjects in a practice room before each block, in which they were told to make contact with each type of object. This practice room was also the virtual replica of the laboratory, but did not have the grey path on the floor and the objects were distributed randomly across the whole room.

2.4. Design

The total number of objects arranged along the path varied between 6, 8, 10, 12, or 14 objects in total. The division of the two colors was kept constantly on 50%

cyan and 50% pink objects throughout the trials. For each number of objects, two rooms with different collocations of the objects were designed, which results in ten different rooms that were used for each task in random order. In this randomization, the direction was held constant, that means for each number of objects the subjects started one room in corner A and the other one in corner B.

To control for salience effects and implicitly existing interpretation of the two colors (e.g. reddish means danger), their meaning regarding the type of object (target vs. obstacle) was balanced across subjects (manipulated by verbal instructions): Half of the subjects faced pink targets and blue obstacles while the other half faced blue targets and pink obstacles.

Also balanced across subjects was the order of the three tasks to avoid order effects: Half of the sample started with the collecting targets (CT) task, while the other half started with the avoiding obstacles (AO) task. For both groups, the task in which they had to do both tasks at once (BOTH) was always the last one.

In total, each subject ran 30 trials: Ten for each task in three consecutive blocks separated by the practice room for each task.

Balancing the meaning of the two colors (pink targets and blue obstacles vs. blue targets and pink obstacles) and the order of the task (CT, AO, BOTH vs. AO, CT, BOTH) resulted in four different groups to which the subjects were assigned randomly, so that three subjects were in each group.

Emerging from the methods described above, the data analysis considered three within-subject factors: (a) The *Task* which the subjects had to accomplish, namely collecting targets (CT), avoiding obstacles (AO) or collecting targets while avoiding obstacles (BOTH); (b) The *Type of Fixated Object*, either target or obstacle; and (c) the *Type of Neighbor*, target or obstacle. The ensuing $3 \times 2 \times 2$ design was completely crossed, but since fixations depended on the subjects' behavior (i.e. where they were looking) the number of situations for each combination of factor levels has not been balanced (see section 3. Results).

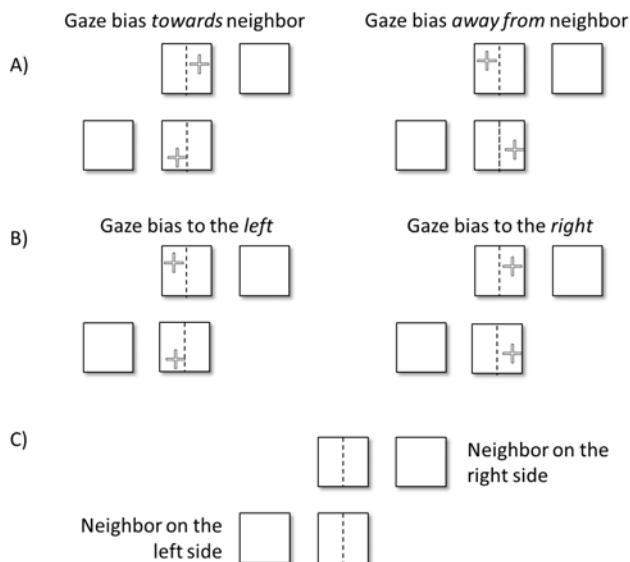


Figure 6. Illustration of the dependent variable (A) and the two confounding variables (B and C). A) On the left side, two situations are depicted in which the gaze position (cross) is biased in the same direction, in which the neighbor was present. Whereas on the right side, two situations are shown, in which gaze is biased in the opposite direction. B) The two figures on the left demonstrate a gaze preference towards the left side of the fixated objects, independent of the position of the neighbor. Analogously, the figures on the right show a gaze tendency towards the right side of the fixated object independent of the neighbor's position. C) The lowest figure simply depicts the two situations of object configuration regardless of relative fixation position: The neighbor can be either on the right or on the left side of the fixated object (= cube with dashed line indicating the center).

The dependent variable, used here to examine the expected gaze bias (for details on research questions see section 1.6. Hypotheses and Implementation) was the frequency of how often the subjects were fixating on an object with a tendency either *towards* or *away from* the neighboring object. Figure 6A illustrates these two cases for situations in which two objects were present in the subject's visual field. Fixations on an object were counted as 'biased towards neighbor', (a) if the neighbor was visible on the right side of the fixated object *and*

the gaze position was on the right side of the center of the fixated object or (b) if the neighbor was visible on the left side of the fixated object *and* the gaze position was on the left side of the center of the fixated object. Fixations ‘biased away from the neighbor’ were defined as gaze positions being on the right side of the center of the fixated object while the second object was present on the left side of the fixated object or vice versa.

2.5. Procedure

The next two paragraphs will provide a description on how the experiment was conducted as a whole (see section 2.5.1. Procedure of the Experimental Conduct) and what a single trial looked like (see section 2.5.2. Procedure of a Trial).

2.5.1. Procedure of the Experimental Conduct

At first, the participants signed a general informed consent form (approved by the Institutional Review Board of the University of Texas at Austin) on participating, possible risks, and their rights and they completed a short demographic questionnaire. Then, they were verbally briefed about the used equipment, the procedure of the experiment, and their task (see Appendix A¹) by one of the examiners. Nevertheless, the subjects remained naïve about the research questions until after the experiment.

Several arrangements needed to be made for each subject before the experiment could be carried out. First, the head-mounted displays and the position of the eye tracking camera needed to be adjusted to the participant’s head, so that the camera could get a good track of the subject’s eye, but did not block the subject’s view on the two displays. Second, the subject buckled on a

¹ The appendix is available on the book’s product page on www.springer.com.

belt bag around the waist carrying the second body tracker on the back. Third, the height of the virtual cubes was aligned to the participant's individual eye height. Last, the eye tracker was calibrated using Viewpoint® software (see section 2.2. Equipment).

Throughout the experiment, two examiners were present in the laboratory. One read a set of standardized instructions (see Appendix A) to the subjects before the experiment and gave further instructions about the subsequent task in the practice rooms. In addition, this examiner followed the subject through the laboratory making sure the subject did not run into real-world objects, such as cords for example. The other examiner was keeping track of the subject's eye movements and calibration accuracy during the experiment.

The experiment was conducted in three consecutive blocks, one for each task, consisting of ten trials with one preceding practice trial. This practice room contained randomly arranged objects of both colors. Participants were instructed verbally about the subsequent task and were given time to familiarize with the virtual room and what it feels, sounds, and looks like when making contact with the cubes by walking through them. Besides that, they heard the sounds when making contact with the objects depending on the task of the subsequent block. For instance, assuming the subject was confronted with pink targets and cyan obstacles and the subsequent task was to avoid obstacles: The subject got the instruction to avoid the cyan obstacles in the following block and that the pink cubes were not task-relevant. That means, it made no difference for the accomplishment of task, if the pink cubes were contacted or not. Then, the subject was asked to walk around the practice room and to make randomly contact with objects of both colors. When the subject walked through a task-relevant obstacle, an unpleasant buzzer sound was played via speakers. When the subject walked through a not task-relevant pink cube, a neutral bubble pop was audible.

Once the subject felt comfortable enough in the virtual environment and was familiar with the task, the subject was allowed to step on the green elevator disk to get to the next room and start the actual experimental trials.

The accuracy of the eye tracker was checked and calibration was renewed if necessary at the beginning, between blocks, and at the end of the experiment.

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A Virtual Reality Study on Gaze Allocation in Naturalistic
Tasks

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