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Looking at Nothing Diminishes with Practice

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Abstract

People fixate on blank locations if relevant visual stimuli previously occupied that location; the so-called 'looking-at-nothing' effect. While several theories have been proposed to explain potential reasons for the phenomenon, no theory has attempted to predict the stability of this effect with practice. We conducted an experiment in which participants listened to four different sentences. Each sentence was associated with one of four areas on the screen and was presented 12 times. After every presentation participants heard a statement probing one sentence, while the computer screen was blank. More fixations were found to be located in areas associated with the probed sentence than in other locations. Moreover, the more trials participants had completed, the less frequently they exhibited looking-at-nothing behavior. Fixations on blank locations seem to occur when an attempt is made to retrieve information associated with a spatial location as long as it is not strongly represented in memory.

Keywords: Eye tracking, practice, spatial cognition, mental representation, working memory

Introduction

When processing information from the visual world, human cognition integrates visual and auditory input with abstract, higher level mental representations (Huettig, Olivers, & Hartsuiker, 2010). Reactivation of such a memory representation leads the gaze back to spatial locations or areas that were previously occupied by relevant information. For example, when we mention something about a table presented on a whiteboard, we might point towards the whiteboard, even if the table is no longer there anymore.

Richardson and Spivey (2000) were among the first to show a close link between eye movements, auditory information processing and semantic information processing, in an information-retrieval task. Participants were presented with a spinning cross in one of four equal-sized areas on a computer screen together with spoken factual information. After four facts were presented, participants heard a statement probing one of the presented facts and had to judge the truth of the statement. During this retrieval phase the computer screen was blank. Participants fixated more in the critical area where the sought-after information was presented compared to other areas on the screen.

This so-called 'looking-at-nothing' behavior (Ferreira, Apel, & Henderson, 2008) also occurs when the probed information is presented visually (Laeng & Teodorescu, 2001; Renkewitz & Jahn, 2010; Spivey & Geng, 2001), when information is anticipated (Altmann & Kamide, 2007), in light and in complete darkness (Johansson, Holsanova & Holmqvist, 2006), and for simple (Brand & Stark, 1997) and more complex pictures (Johansson, Holsanova, & Holmqvist, 2010).

Ferreira et al. (2008) assumes a memory representation of an object or event that integrates visual, auditory and spatial information and leads to a corresponding visual, linguistic, spatial, and conceptual representation. When one part of this integrated memory representation is reactivated, other parts are retrieved, as well. This in turn causes gazing behavior toward the location where the information was previously presented. For example, seeing a table on a whiteboard leads to the activation of a visual as well as conceptual representation of the figure. Additionally, spoken language leads to the formation of a linguistic representation. The visual world leads to the activation of a spatial index (Pylyshyn, 2001), which can be used later to direct our gaze back to the area on a whiteboard, where the figure was previously presented.

Huettig et al. (2010) recently proposed a general framework to describe how linguistic and visual representations are bound together in an integrated memory representation. Their model, like that of Ferreira et al. (2008), assumes the integration of information in a connected visual, linguistic, spatial, and conceptual representation. It further includes ideas proposed by Altmann and Kamide (2007), Knoeferle and Krocker (2007), and Spivey (2007). Here, we briefly introduce their framework. It is worthwhile to note that they include a detailed description of how integrated memory representations can be linked to existing theories of long-term and working memory (c.f., Baddeley, 2000). Huettig et al. (2010) propose that language–vision interactions are based on long-term memory, where conceptual representations (e.g., the concept of a figure or of a whiteboard) are derived from. Therefore, long-term memory serves as a stable knowledge base. It is then working memory that grounds cognition in space and time and leads to the formation of short-term connections between objects (e.g., spoken language, a figure, and a whiteboard). Contents of working memory are linked to contents of long-term memory via spatial indices. Because of this association working memory can instantiate a gaze back to the object. In describing connections between memory representations, Heuttig et al. (2010) assume that the stronger the association between the linguistic and conceptual representations the higher "the probability of triggering a saccadic eye-movement" (p. 5).

Richardson, Altmann, Spivey, and Hoover (2009) share Huettig at al.'s (2010) general idea of an integrated memory representation. In contrast, however, they suggest that only sparse internal representations are built during the encoding of information. They assume that during information retrieval, an eye movement can be launched to the associated area in order to gather more information. This occurs when the spatial pointer (i.e., the visual part of the integrated memory representation) does not include the searched information: "If the pointer's tag does not include the attribute, then the pointer's address to the external environment is the next obvious resource" (Spivey, 2007, p. 298). The link between information sampling from the environment and eye movements can be understood as the covert orienting of visual–spatial attention (Hoffman, & Subramaniam, 1995). Targeting a position makes it necessary to allocate attention towards that place. Because it is impossible to make an eye movement without an attentional movement (Shepherd, Findlay, & Hockey, 1986), attending to information stored in an integrated memory representation leads to eye movements towards associated spatial areas.

Summarizing, we conclude that during the encoding of information an integrated memory representation is formed from different modalities. However, theories diverge in terms of how much information is included in the memory representation and how this in turn affects the looking-at-nothing behavior. Ferreira et al. (2008) assume that the probability of triggering an eye movement increases with the strength of the association between the linguistic and conceptual representation. Consequently, one could predict that looking-at-nothing behavior becomes stronger with an increasing association between these representations. Spivey (2007), on the other hand, proposes that looking at nothing mainly occurs for the purposes of gathering information not yet included in the mental representation. In line with this one might conclude that looking at nothing diminishes as relevant information is included in the memory representation.

To test these assumptions we varied the degree to which information is included in memory representation. More precisely, we manipulated the degree of practice in a task, where auditory information, which is associated with contents from a visual scene, has to be retrieved from memory. With more practice, the strength with which retrieval-relevant information is represented in memory increases (e.g., Anderson & Schooler, 1991). If looking at nothing increases with practice, then Huettig et al.'s assumptions would be supported. On the other hand, if looking at nothing decreases with practice, our findings would support Spivey (2007) and conclude that looking at nothing varies with the degree of relevant information included in the mental representation.

Experiment

To test looking-at-nothing behavior under different levels of practice we conducted an experiment in which participants were presented with four different sentences. Each sentence described an artificial scene. The same set of four sentences was presented in each of 12 experimental trials. After every presentation trial a retrieval phase followed in which one of the four sentences was probed. In every trial each sentence was associated with the same spatial location on a computer screen.

Method

Participants. Eighteen students (14 female; age M = 22.8) from Chemnitz University of Technology participated in the experiment. All reported normal or corrected-to-normal vision with contact lenses. All participants were native German speakers.

Apparatus and material. Participants were seated in front of a computer screen at a distance of 630 mm and instructed to position their head in a chin rest. The eye-tracker system SMI iView REDpt was used to sample data of the right eye at 50Hz with a precision of 0.05°. Data were recorded with iView X 1.7 and analyzed with BeGaze 2.3 and MatLab 7.0.1 software programs. Stimuli in the experiment were presented using E-Prime 2.0 on a 380-mm × 305-mm computer screen with a resolution of 800 × 600 pixels.

The visual stimuli consisted of a grid dividing the screen into four equal-sized areas with a fixation cross at the center of the grid. Each set of four sentences was associated with the same symbol – a black circle with a white loudspeaker in it – which appeared in one of the four areas of the grid depending on the sentence that was presented.

The auditory stimuli presented in the presentation trial consisted of four prerecorded sentences each describing three attributes of an artificial scene (e.g., "There is a place with a purple lighthouse, a sickle bay, and a wooden church."). To test gaze behavior in the retrieval phase, we generated 24 statements: A true and a false version for each of the four statements multiplied by three attributes (The false statement probing the example sentence from above was "There is a place with a wooden cottage."). Figure 1 shows 1 of the 12 experimental trials.

Procedure. To mask study intentions, students were told they were participating in a study concerning pupil dilation that involved solving a memory task. No instructions concerning gaze behavior were provided. The eye tracker was calibrated using a 9-point calibration method. This procedure lasted between 5 and 10 min. Subsequently, the 12 experimental trials started. In each of the 12 trials, the same four sentences were presented in random order. Every sentence always appeared with the symbol in the same area on the screen with a presentation duration of 30 s.

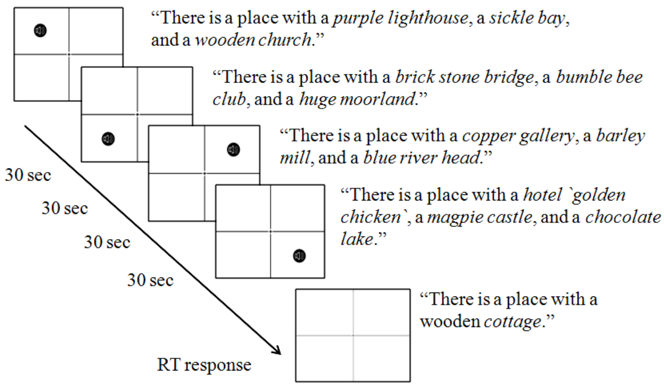

Figure 1: Example trial with the four experimental sentences (presentation phase) and a statement probing the first sentence (retrieval phase). Original material in German.

After presentation of the fourth sentence within a trial, the retrieval phase followed. Participants heard a statement, which referred to a fact from one of the four sentences, and judged it to be true or false. To observe participants' gaze behavior, they were intentionally not instructed to reply as soon as possible. Presentation of one statement lasted 4 s. Statements were randomly assigned to trials and participants with the restriction that every statement was probed once for each participant. Participants had to answer the true or the false version of a statement balanced across trials and participants such that every participant was presented with six true and six false statements. A true statement was recorded when participants responded verbally with 'right' and a false statement with 'wrong'. Immediately following this response, the investigator pressed a key signaling the start of the next trial. In this way, participants were not required to look at the keyboard (This procedure was chosen to prevent gazing away from the monitor towards the keyboard, which could have led to loss in quality of eye-tracking data). After depressing the key, the investigator noted the partícpant's response on a sheet of paper. During the 12 experimental trials and their retrieval phases, gaze data were recorded. Afterwards, participants filled out a questionnaire which interrogated demographic variables and the assumed goal of the study. Before leaving, participants were informed about the true nature of the study.

Analysis. To assess participants' performance, we collected data on the accuracy of their responses and response times (i.e., the time beginning with the retrieval phase and ending with a participant's reply as noted by the investigator). As reaction times are prone to error through outliers (e.g., when an investigator does not stop recording immediately upon a participant's response) we did not exclude outliers but used median reaction times for further analysis.

To assess looking at nothing, gaze data from the beginning of the retrieval phase to a participant's reply (i.e., analogous to response time) was analyzed. Four adjacent 'areas of interest' (AOIs) were defined corresponding to the four areas on the screen. Numbers of fixations in every AOI were counted per person and per trial. A fixation was defined as having a minimum duration of 100 ms and a maximum dispersion of 100 pixels (1.3° visual angle). The AOI associated with a probed sentence is called the 'critical area'. Gaze behavior was analyzed, whereby trials were discarded in which tracking data was missing for >40% of the trial duration (8% of all trials). Missing tracking data was caused by blinks, lost pupil or corneal reflectance, or looking away from the screen.

To test the independent variable practice, we aggregated the number of fixations in the AOIs as well as the performance data over sets of four experimental trials. This allowed us to compare three conditions of practice: block 1 (consisting of trials 1–4), block 2 (trials 5–8), and block 3 (trials 9–12).

Number of fixations and median reaction times were only analyzed for trials that were answered correctly.

Results

Performance measures. Overall, mean percentage of correct responses to the statements was M = 87.8% (SD = 20.8%), suggesting that the material was neither too difficult to memorize nor too easy to learn. A one-way repeated measures ANOVA revealed a significant effect for accuracy over the three blocks, $F(2,34) = 11.04$, $p < .001$, $\eta_p^2 = .40$. Bonferroni post-hoc tests showed an increase in performance from the first to the second block, M_{b1} = 73% vs. M_{b2} = 93%, p = .004, and from the first to the third block, M_{b1} = 73% vs. M_{b3}=97%, p =.005. There was no significant change in performance from the second to the third block, M_{b2} = 93% vs. M_{b3} = 97%, p = 1.00.

The median reaction time to the statement in the retrieval phase was 6206 ms (SD = 1617 ms). Over the three blocks of practice participants became faster in correctly responding, Greenhouse–Geisser-corrected $F(1,48;34)$ = 9.61, p = .002, $\eta_p^2 = .36$.

Bonferroni post-hoc tests confirm a decrease in the median reaction times from the first to the second block M_{b1} = 7211 ms vs. M_{b2} = 5798 ms, p = .016 and from the first to the third block, M_{b1} = 7211 ms vs. M_{b3}=5608 ms, p = .009. Again, there is no difference between the second and the third block, M_{b2} = 5798 ms vs. M_{b3} = 5608 ms, p = 1.00. Response accuracy and median reaction times showed that the practice manipulation was successful. With more practice, participants answered correctly more often and replied more quickly to the statements.

Mean number of fixations.

Exemplary gaze behavior of a typical participant. Figure 2 shows scan paths of a typical participant for the presentation and the retrieval phase of three trials, where the critical area was on the bottom right. Lines show saccades and circles represent fixations with bigger circles indicating longer fixations. Scan paths on the top left and right side of Figure 2 show a trial from block 1. In this trial, the sentence that was associated with the symbol in the bottom right area of the screen was probed for the first time.

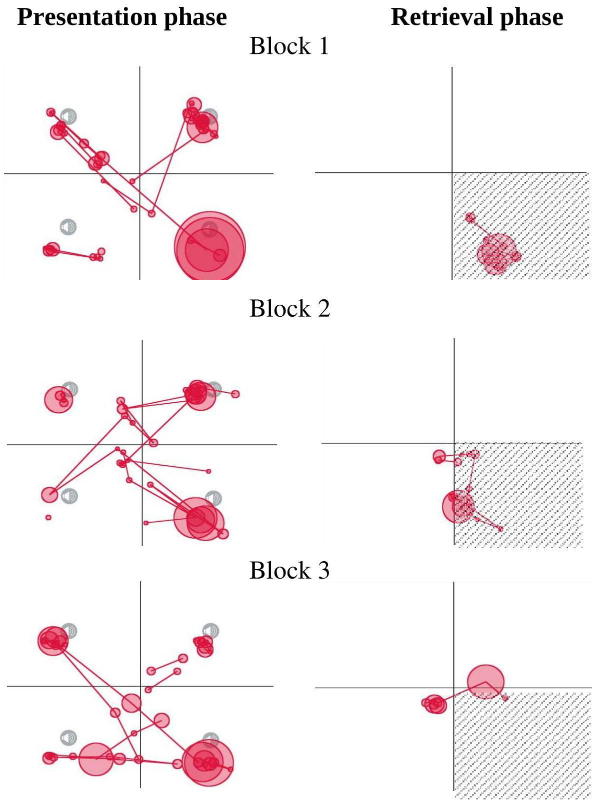

Figure 2: Scan paths of one participant for a trial in block 1 (top), a trial in block 2 (middle) and a trial in block 3 (bottom) with the critical area at the bottom right. Left: presentation phase (scan paths of four sentence presentations)[1], right: retrieval phase.

Scan paths on the left and right side in the middle of Figure 2 show a trial from block 2. In this trial, the sentence on the bottom right was probed for the second time. Scan paths on the left and right side on the bottom of Figure 2 show gaze behavior when the sentence was probed for the third time (block 3). Comparing scan paths from top to bottom on the left side of Figure 2, scan paths reveal that throughout the experiment the participant kept on following the symbols during the presentation phase. In comparison, gaze behavior in the retrieval phase (Figure 2, right) seems to change over the experiment. In block 1, the participant directs several gazes to the critical area (Figure 2, top right). With increasing practice, fewer fixations in the critical area are made (middle and bottom right).

Aggregated gaze behavior. Figure 3 shows the proportion of fixations in the critical area during the retrieval phase. Proportions were aggregated for each block and across participants. Participants showing looking-at-nothing behavior should fixate in the critical area during the retrieval phase. To test this, for each block, we compared the proportion of fixations in the critical area with a chance level of 25%. In block 1, the proportion of fixations in the critical area (37.2 %) is indeed above chance, $t_{b1}(17) = 2.09$, $p = .051$, $g = .99$. In blocks 2 and 3 the proportion of fixations in the critical area were at chance levels, mean proportion block 2: 17.9 %, $t_{b2}(17) = -1.73$, $p = .102$, $g = .82$; mean proportion block 3: 28.5 %, $t_{b3}(17) = 0.81$, $p = .426$, $g = .38$. These results suggest that looking at nothing diminished from block 1 to block 2 and that the proportion of fixations did not vary meaningfully from chance in block 3.

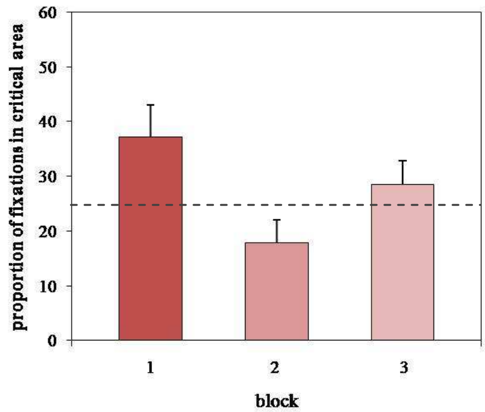

Figure 3: Percentage of fixations in the critical area across blocks. Error bars represent standard error, dotted line indicates chance level.

Discussion

Theories on the link between eye movements and auditory and semantic information processing (Huettig et al., 2010) assume that during the encoding of information an integrated memory representation is formed from different modalities. However, these theories do not agree on how much information is included in the memory representation. Using the looking-at-nothing paradigm, we tried to shed some light on this question.

Assuming an integrated memory representation as proposed by Ferreira et al. (2008), the probability of triggering an eye movement during retrieval of information from memory will increase with the strength of the association between the different parts of the representation. Spivey (2007), on the other hand, proposed that only sparse internal representations are built during the encoding of

[1] Longer fixations at the bottom right area are only shown by displayed data and not systematically. To control for gaze biases the critical area was randomized across trials.

information. Consequently, eye movements during memory retrieval occur mainly to gather information that is not yet included in the mental representation. According to Ferreira et al. (2008), looking at nothing should increase with practice, while for Spivey (2007) the same behavior should diminish with practice.

Practice was induced by presenting participants with a set of four sentences, 12 times. Each presentation phase was followed by a retrieval phase where one sentence was probed. To test whether the manipulation was successful, we first checked if participants showed increasing performance in the retrieval task. Results show that over the three blocks, participants indeed replied with increasing accuracy and speed to the facts probing the presented sentences. Accuracy as well as response times revealed that the performance increase was stronger from the first to the second block, than from the second to the third block. It seems that over the three blocks of practice memory associations for the sentences were strengthened leading to more correct and faster responses. Therefore, we conclude that the practice manipulation was successful.

The question we wished to answer was how looking-at-nothing behavior would be affected by the content of the memory representation. In block 1, participants looked more often to the critical area on the screen than a chance level of 25% would predict. In blocks 2 and 3 looking at nothing diminished. In both blocks, fixations in the critical area did not amount to more than that predicted by a chance level of 25%.

Results of the first block replicated results of Richardson and Spivey (2000), which showed a close relationship between gaze behavior and language processing. In block 1, information was not strongly represented in memory. Eye movements were launched to the critical area on the screen in order to collect information from the visual scene. For blocks 2 and 3 we assumed that the looking-at-nothing behavior would become stronger or diminish, respectively. Our results were not in line with the predictions of Huettig et al. (2010), which stated that looking at nothing becomes stronger as the association in memory is strengthened. While performance improved over the three blocks, looking at nothing did not increase in strength. Our results seem to support the assumption of Spivey (2007) that looking-at-nothing behavior is executed to gather more information from the environment. In blocks 2 and 3, the memory representation might have included all relevant information. Thus, addressing an eye movement to the critical area on the screen became 'unnecessary'.

We found that looking at nothing varies with the content of the memory representation. This supports the work of Richardson et al. (2009), who assume the existence of an internal memory story, whereby all relevant information is stored in an integrated memory representation, and an external memory store (O' Regan, 1992), which assumes only sparse memory representations and uses a spatial index to address the visual world. Moreover, these are not mutually exclusive abilities of the cognitive system. Instead, the cognitive system can use both. The question is, when do we rely on an internal memory representation and when on an external memory store? Hoover and Richardson (2008) and Johansson et al. (2010) suggest that looking at nothing helps to relieve working memory when information is retrieved from memory. For example, Johansson et al. (2010) presented participants with an auditory description of a complex scene while participants had to fixate the center of a whiteboard. In a second condition they saw the picture of a complex scene but again had to fixate on the center of the picture's scene. In both conditions, when they had to retell the information they had heard, and when they had to describe the visual scene, they drew the scene with their eyes on the whiteboard and did not maintain a central fixation. In contrast, in a study reported by Brand and Stark (1997), simple block patterns were used. During retrieval of the block pattern, participants were allowed to look freely around the scene but kept a central fixation. Therefore, Johansson et al. (2010) argue that looking-at-nothing behavior can relieve working memory load when task demands (e.g., a complex scene description) require it.

Applying the findings of Johansson et al. (2010) to our results suggests that when memory load is high, looking at nothing is shown. When memory load is low – because all relevant information has been learned – looking-at-nothing behavior diminishes. Indeed, in block 1 of our study, when the presented material was new to participants, looking at nothing was shown. Later, when the material was strongly represented in memory, looking at nothing diminished.

Decreased looking-at-nothing behavior might also be explained as the result of participants realizing over the course of the experiment that the visual area they refixate on no longer includes relevant information and therefore, this behavior becomes redundant. This implies that participants consciously control their gaze behavior. However, eye movements as described in the context of the looking-at-nothing effect are a highly automatic and unconscious behavior (Rayner, 2009). Furthermore, if change in gaze behavior were due to conscious control (i.e., participants realize that during the retrieval phase, nothing is present anymore), we would then expect looking at nothing to diminish within the first block. Looking at data of the first four trials, we could not find such a tendency. Moreover, in the post-questionnaire participants did not report that they controlled their gaze behavior.

We also realize that looking at nothing might not only diminish because participants have learned the material, but because they have given an automatic response to the stimuli that does not include fixations to the critical area. To rule out this alternative explanation one could present participants with the same sentences throughout the course of the experiment and sentences that change from trial to trial. If it is indeed the content of the integrated memory representation that is responsible for looking-at-nothing behavior, our results should be replicated in a way that looking-at-nothing behavior diminishes for stable sentences and does not diminish for new sentences.

From the results of this study it can be concluded that information is represented internally, and that under certain conditions the external world is addressed in order to gather more information (Spivey, 2007). We have further shown that both ways of retrieving information are not necessarily mutually exclusive (Richardson et al., 2009). But, when is knowledge presented internally and when do we use an external memory store? We propose that working memory load may influence the decision to use either an internal or external memory store. However, a distinct boundary need not be imposed between these two modes of storage. Spivey (2007) proposes that knowledge representations can be described in a vague manner. That is, information can belong to both internal and external storages. Bocklisch, Bocklisch, Baumann, Scholz, and Krems (2010) highlighted a relationship between the concept of vagueness and knowledge representations. This link could inform future research that tests the usefulness of this approach for the investigation of mental representations.

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