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“Eye-tracking” for assessment of image perception in gastrointestinal endoscopy with narrow-band imaging compared with white-light endoscopy

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Background and study aims: Narrow-band imaging (NBI) is a new imaging methodology for improving the detection rate of gastrointestinal lesions. We aimed to evaluate perception of images by NBI and corresponding standard white-light-endoscopy (WLE) using a computer-guided eye-tracking system.

Methods: A total of 23 NBI images of various lesions with the 23 corresponding WLE images were assessed in random order by 18 subjects with various endoscopy experience. Before evaluation, a teaching set of three NBI and corresponding WLE images was shown to highlight the characteristics of lesions. An eye-tracking system (Tobii X series with integrated 17-inch monitor) was used to record the eye movements of the subjects while they examined respective images. The following parameters were measured: total time spent on image, time until first fixation of lesion, total number of fixations per image and per le-

sion, and number of fixations until finding the lesion.

Results: In total, 828 experiments were conducted. Lesions could not be detected in 6.5% (NBI) and 4.1% (WLE) of images ($P = \text{NS}$). The total number of fixations and total time spent on respective figures as a whole were significantly greater for NBI images compared with WLE images ($P < 0.003$). However, the number of fixations until the lesion was found, the number of fixations on the lesion, and the time until first fixation of the lesion did not differ between the two image groups ($P > 0.1$).

Conclusion: This is the first study using eye tracking to evaluate image perception in gastrointestinal endoscopy. Significant differences in the interpretation of NBI and WLE images were observed, which may be relevant for the detection and characterization of lesions during endoscopy.

Introduction

Narrow-band imaging (NBI) was developed to increase the diagnostic yield for the detection of neoplastic lesions during upper or lower endoscopy. It has been shown to enable better visualization of mucosal morphology and the vessel structures that are the hallmark of neoplastic lesions [1–3]. However, the data available show divergent results: for the detection and differentiation of colonic polyps, for example, NBI has been shown in some studies to be significantly better than standard white-light endoscopy (WLE) [4–6], whereas other studies have found no difference [7–9]. In a further study, NBI performed similar to WLE; however, the learning curve was faster when NBI was used to detect colonic adenomas [10] making it a useful tool for endoscopy trainees. Nevertheless, when summarizing these data, many open questions remain to be answered before NBI can really be recom-

mended as being superior to WLE. To date, the risk of bias due to inter-individual variations applying such a new imaging modality is still high and objective data on its true benefit are still lacking.

With the aim of overcoming some of these shortcomings, the present study used “eye tracking” as a more objective tool to further assess the potential differences between NBI and WLE. Eye tracking is an established technique in laboratory experiments, where human perceptions are tested in attention, learning, memory, and other tasks such as scene-analysis, reaction-time experiments using eye-movement responses, face perception and recognition or face-to-face communication experiments. This technology makes it possible for computers to measure exactly where and when users are looking. Currently, such a tool is mainly being used in cognitive psychology, neuropsychology, ophthalmology, and media and market research. To the best of our knowl-

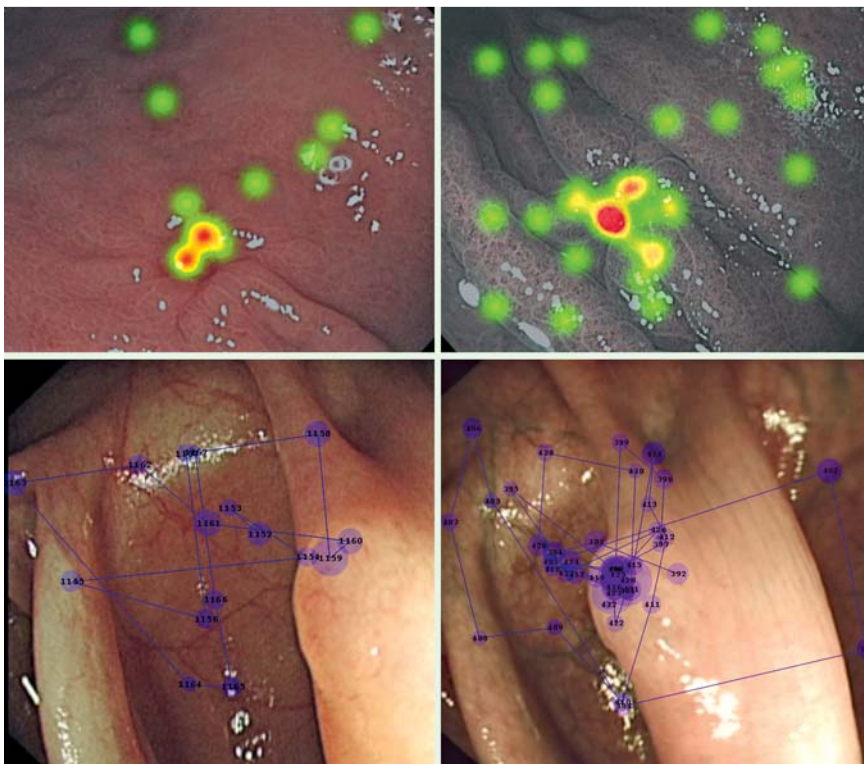


Fig. 1 Examples of narrow-band imaging (NBI) images (right) and standard white-light endoscopy (WLE) images (left) with “hot spots” expressing numbers of fixations (top), and “gaze plots” showing fixations in a time-related manner (bottom). The NBI images are apparently more appreciated by the study subject with more details perceived, whereas respective lesions are similarly perceived by both modes of NBI and WLE (upper row shows an early gastric cancer, lower row shows a serrated adenoma in the cecum).

edge, there are no data on eye tracking in relation to different endoscopic image modalities. Hence, we aimed to further elucidate the accuracy of various examiners with different levels of endoscopy experience with respect to the number of fixations and time needed to find lesions in both NBI images and their corresponding WLE images.

Methods

Endoscopic images

Endoscopic images were selected from upper and lower endoscopic examinations using Olympus endoscopes (GIF H180 or CF H180). All endoscopic examinations were performed by a single experienced endoscopist (A.M.). Freeze images of areas suspected to resemble neoplasia were taken using NBI mode or standard WLE from identical areas with the endoscope in an identical position. All images were stored as .jpg files. In total, 26 NBI images of various lesions with 26 corresponding WLE images were acquired, from which three NBI images and three corresponding WLE images were selected for teaching purposes (see below). Among the 23 respective areas imaged, two were in situ carcinomas of the squamous esophagus, 10 were neoplastic Barrett's esophagus, seven were early gastric cancers or gastric adenomas, and four resembled colonic polyps.

Study subjects

A total of 18 individuals participated in eye-tracking experiments. Among those, five had sufficient NBI experience with more than 500 endoscopic examinations performed. A further four subjects were familiar with endoscopy (more than 200 examinations) but had never applied NBI. The remaining nine subjects were inexperienced with respect to both NBI and standard WLE. All subjects were blinded to any endoscopic or histologic diagnosis.

Eye-tracking experiments

For the experiments the Tobii X series eye tracker with integrated 17-inch monitor was used to record the eye movements of the subjects while they examined the images. The accuracy of the system (i.e. the typical deviation between the measured gaze direction and the actual gaze direction) and the spatial resolution (i.e. frame-to-frame variation of the measured gaze point) are reported to be less than 0.5 degrees and 0.25 degrees, respectively. Before the experiments, each subject was shown a training data set containing three image pairs. Each pair of images, which showed the same area (one in NBI and one in WLE), were displayed simultaneously and studied by the subjects with no time limit being set. During the experiments the subjects were told to focus on the lesions in the test dataset, which consisted of 46 images (23 WLE and 23 NBI) that were shown in random order. The experiment was performed without any time limit; however, the subjects were asked to focus on the lesion as fast as possible and to move to the next image once the lesion had been seen. For each of the 46 images of the test dataset, five measurements were conducted: first fixation on the lesion in milliseconds (ms); total time (spent on this image) in ms; number of fixations until finding the lesion; number of fixations on the lesion; and number of total fixations (on this image). To this end, the ground truth for the area of each region was marked by an experienced endoscopist (A.M.) who was not involved in the eye-tracking experiments. Ground truth refers to the area under investigation (i.e. gastrointestinal lesions in the present study). By marking the ground truth sites (lesions), the accuracy of the classification method used (i.e. eye tracking in the present study) can be assessed after the respective experiment is finished. A fixation was detected if the subject focused on a location for at least 100 ms. Furthermore, a fixation was determined to be on a lesion if the area of fixation overlapped with the area of a lesion in the ground truth. In order to assure that no bias was introduced due to po-

Table 1 Parameters assessed with the eye-tracking system for images from narrow-band imaging (NBI) and corresponding standard white-light endoscopy (WLE).

	NBI	WLE	P-value*
Total time spent on image, mean \pm SD, ms	4825.0 \pm 241.1	4152.5 \pm 156.3	0.002
Time until first fixation of lesion, mean \pm SD, ms	648.5 \pm 48.9	644.1 \pm 49.5	0.636
Total number of fixations on image, mean \pm SD	13.2 \pm 0.7	11.4 \pm 0.5	0.003
Number of fixations until finding lesion, mean \pm SD	2.1 \pm 0.1	2.1 \pm 0.2	0.892
Number of fixations on lesion, mean \pm SD	6.2 \pm 0.4	5.2 \pm 0.2	0.183

* Paired *t*-test

tential random fixations, the sizes of ground truth lesion areas were evaluated with both imaging modalities.

Statistics

The differences between NBI and WLE were tested with the chi-squared test (diagnostic yield for lesion detection) and paired Student's *t*-test (numbers of fixation, time for fixation). ANOVA was used to check for potential differences between the three groups with different levels of experience. A *P*-value below 0.05 was regarded as statistically significant. The SPSS 17.0. software package (SPSS inc., Chicago, Illinois, USA) was used for analysis.

Results

In total, 828 experiments were conducted. All experiments were completed within 30 minutes per study subject. **Fig. 1** shows examples of NBI images and WLE images with "hot spots" correlating to the number of fixations and "gaze plots" showing eye movement in a time-dependent manner.

According to the ground truth location of each lesion, lesions could not be detected at all in 27/414 NBI images (6.5%) and in 17/414 WLE images (4.1%) (chi-squared *P*=NS). **Table 1** summarizes all data of the eye-tracking experiment. Compared with WLE images, NBI images required both a greater total number of fixations (13.2 \pm 0.69 vs. 11.4 \pm 0.46; *P* = 0.003) and a greater total time spent on respective images as a whole (4825.0 \pm 241.11 vs. 4152.5 \pm 156.31; *P* = 0.002). By contrast, the number of fixations until the lesion was found, the number of fixations on lesion, and the time measured until the lesion was first fixed did not significantly differ (paired *t*-test: *P* > 0.1; **Table 1**).

With respect to the different levels of experience for all assessed parameters, experts spent significantly less time on the respective images and numbers of fixations were also significantly fewer (ANOVA *P* < 0.001; **Fig. 2**). However, time and number of fixations needed to find the lesion did not differ between the three groups with different levels of experience (ANOVA all *P* > 0.2). This was observed for both NBI and WLE.

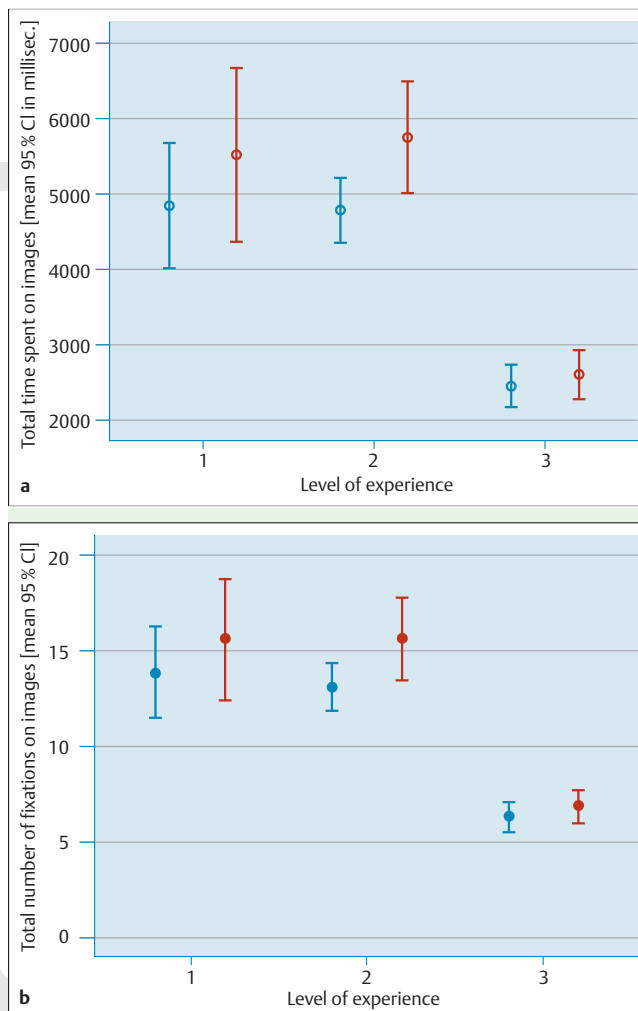


Fig. 2 Effect of endoscopy experience on image perception. **a** Total time spent on images. **b** Total number of fixations on images. Levels of experience: 1 = no endoscopic experience; 2 = no experience with narrow-band imaging (NBI); 3 = experience with NBI. As shown there are significant differences with respect to the level of experience for NBI (green) and white-light endoscopy (blue).

Discussion

In general, image interpretation in gastrointestinal endoscopy is highly subjective, and the overall quality and amount of information shown on images or videos are differently perceived. This holds true for both novices and experts. Potential benefits of any new imaging modality are therefore difficult to measure.

In the present study, which applied a computer-guided eye-tracking system, we have shown that NBI does not accelerate the detection of gastrointestinal lesions. In addition, no significant differences between NBI and standard WLE could be observed with respect to the overall detection rate. Hence, we were not able to confirm the theory that NBI leads to faster and better image recognition due to better demarcation of mucosal and vascular structures. This holds true for both inexperienced examiners and those familiar with NBI. Of interest, NBI was associated with a significantly increased total time spent and total numbers of fixations on respective images compared with WLE. Despite the fact that these aspects did not lead to a faster recognition of lesions one might assume that NBI images appear to be better perceived by the human eye and might be more appealing than WLE.

However, there are also certain limitations that deserve to be mentioned. We selected still images from different regions (i.e. Barrett's, gastric, and colonic lesions). Hence, the database was rather heterogeneous making it difficult to draw further conclusions on the respective imaging methodology for detection and differentiation of abnormalities. Analysis of still images can also substantially differ from a real-life situation. Moreover, all assessors were aware that all images showed abnormalities. Even assessors with little or no endoscopic experience detected the lesion in over 95% of images. The fact that the assessors were aware that all images would show abnormalities and the fact that virtually all lesions were already visible on WLE makes it difficult to show an additional value for NBI in this respect. Our dataset did not include a set of images with no abnormalities or images with subtle abnormalities, which might have resulted in a different outcome. We observed that the total number of fixations and the total time spent on respective figures were significantly longer for NBI than for WLE. It is unknown whether, in the artificial setting of our study, the increased time spent looking at images and having more fixations reflects that the NBI image is better in the sense of "containing more information" or worse in the sense of "containing more detail and/or irrelevant, confusing information". Perhaps, the overall information on a respective image is similar for both modalities (NBI and WLE) causing no differences in detecting the "essentials". However, the unusual greater color contrast of green and brown created by NBI might cause curiosity and provokes a more detailed inspection of the image as a whole compared with the more familiar reddish color tone of an image obtained by WLE. This agrees also with our finding that NBI-experienced study subjects spent significantly less time examining respective images (● Fig. 2). In our opinion, the "different" image features of NBI become less interesting as one gains experience with this image modality. Beauty, it seems, is in the eye of the beholder: we see the same but perhaps appreciate NBI more than WLE. This has also been indirectly confirmed in a recent study from the Amsterdam group [11]. The authors further evaluated a proposed classification system on mucosal patterns in Barrett's esophagus using NBI. Interobserver agreement and the additional value of NBI over WLE were assessed. Although NBI was rated more highly than WLE for image quality, this did not result in improved interobserver agreement or increased yield for identifying early neoplasia in Barrett's esophagus. Again, this applied to non-expert as well as expert endoscopists. Nevertheless, a meta-analysis of recent data on NBI for further detection and differentiation of neoplasia in the upper and lower gastrointestinal tract showed promising results [12, 13]. It is not clear whether these good results are indeed explained by better image resolution highlighting neoplastic features or due to a better perception of images, with respective examiners taking a closer look while performing endoscopy. According to our data one might speculate that the latter at least potentially explains some of the good results reported with NBI. Whether this also holds true for other new imaging modalities such as the Fujinon Intelligent Color Enhancement (FICE) [14], i-Scan [15] or autofluorescence endoscopy [16] deserves further examination. In addition, comparisons of different imaging modalities using eye tracking might be useful.

In summary, this is the first study to use eye tracking for the evaluation of image perception in gastrointestinal endoscopy. Significant differences in the interpretation of NBI and WLE images were observed that may be relevant for the detection and characterization of lesions during endoscopy. The clinical implications of eye-tracking results, however, require further evaluation.

Competing interests: None

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