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Evaluation forest educational boards based on eye tracking analysis in a pilot study

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A thorough understanding of the visual behaviors of the audience interacting with the content on informational boards is crucial for developing training programs and facilitating communication between land managers, such as foresters, and the public. The aim of the study was to assess the extent of perception of information presented on educational boards in the forest by school-aged youth, thereby determining the usefulness of these panels in the environmental and forestry education of young people. We analyzed the variable eye movement of the respondent students using the Tobii Pro Glasses 2 eye tracker. We generated heat maps to identify the elements on the boards that most strongly attracted the participants' attention. For the determined areas of interest (header, description, image, footer), we generated standard fixation metrics. The fixation time for the image was consistently significantly longer than that for the header. The number of fixations was higher on the descriptions than on the images. School youth experienced slightly more difficulty in assimilating information conveyed through images that required deeper analysis compared to reading text or following diagrams. An effective design for an educational board may involves placing diagrams in a sequential layout with accompanying descriptions underneath.

Keywords Visual tracking, Environmental education, Outdoor education, Urban forests, Ecosystem service, Education research

Forests in Europe cover nearly 44% of the land area[1]. They are an integral part of the landscape of human life, performing a wide variety of functions. Growing urban populations and the increasing interest of their residents in recreational activities in forests[2,3] have made the social functions of forests a priority in many areas of broad economic management, particularly in urban and suburban forests[4,5]. The social functions of forests encompass a range of issues, including human health[6,7] culture, history and religion[5,8] tourism and recreation[9,10] and environmental education[11,12].

The latter was initially defined as an educational approach that takes place in the environment, focuses on environmental issues, and aims to promote environmental stewardship[13]. According to Monroe et al.[14] the definition of environmental education fundamentally focuses on providing "opportunities to acquire knowledge and skills that can be used to defend, protect, conserve, or restore the environment." In the context of forestry, nature and forest education is identified as a part of environmental education, that specifically addresses the forest as the subject of teaching and the pedagogical process aimed at shaping an individual's ecological awareness[15]. Regardless of how environmental education is defined in the context of environmental protection, it is ultimately human actions and perspectives that play a critical role. These elements cultivate awareness and shape daily behaviors.

In many European countries, forest education primarily focuses on the goals of sustainable development pursued through forest management, as is the case in Germany[16] Finland[17] the Czech Republic[18] Slovakia[19] and Poland[20]. In most countries, education related to forest areas is conducted informally, outside of schools and universities, by various agencies, associations, forest districts, and national parks. In Poland, the situation is similar; informal forest education is conducted through various means, including books, brochures,

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advertisements, films, social media, and school lessons. The main organization involved in informal forestry education is the State Forests National Forest Holding, which manages 78% (7.2 million hectares) of forests in Poland[21]. The most popular form of forest education in Poland are field lessons led by foresters on educational trails. Educational trails are typically accompanied by various infrastructure elements, such as shelters, benches, tables, railings, and wooden animal figures. Educational boards are a crucial and integral part of these trails. They typically present a variety of topics directly related to forest management, nature conservation, as well as the fauna and flora of the specific area[22].

In Poland, studies have been conducted in the past on the accessibility of texts displayed on informational boards[23] graphic composition[24] and surveys involving forest users to gather their opinions on the use of boards in nature and forest education[25]. Research has also illustrated the impact of such boards during field activities on the psychological well-being of young adults, as well as the duration of users' attention on the boards[26]. However, many questions remain to be explored, such as determining the extent to which attention is captured based on the layout of the board, the mode of content delivery (text, graphics, images), the type of information conveyed (environmental, forestry-related), and the influence of gender. This is particularly relevant in forests because, as Ballantyne points out, in the outdoors[27] educational boards must be particularly effective at communicating due to the presence of many random sensory stimuli that interfere with concentration. On the other hand, several studies have indicated that forests improve concentration and memory[28,29]. A thorough understanding of the visual behaviors of the audience interacting with the content on informational boards is crucial for developing training programs and facilitating communication between land managers, such as foresters, and the public. The recognition of visual information, its categorization, and the monitoring of the most relevant elements can be effectively achieved through eye-tracking studies[30].

Eye-tracking research involves tracking the movement of the eyeballs when interacting with the analyzed product or object. The aim of eye tracking is to determine the duration of fixations and saccades, and to create heat maps and visual scanning paths of the scene observed by the subject[31,32]. Eye movement analyses, initially focused solely on the reading process, are currently applied in various fields of knowledge, including developmental psychology, cognitive science, social media, human-computer interface (HCI) systems, medicine, education, and commerce[33–36]. In forestry, eye-tracking technology was until recently applied only sporadically in studies on the working environment of forestry machinery operators[37–39]. According to Jarodzka et al.[36] eye tracking is playing an increasingly important role in educational sciences, as it sheds light on the initial stages of cognitive information processing in humans (i.e., visual intake, integration, and active information seeking). Research[40] suggests that the more features are encoded through extended viewing time, the stronger the memory of the image becomes. This is particularly important in the context of effective forestry education, which is currently focused primarily on imparting knowledge to younger audiences. Therefore, the aim of our study was to assess the extent to which school-aged youth perceive the information presented on forestry educational boards, and thus to evaluate the usefulness of these boards in the teaching process. Additionally, we aimed to determine whether content related to forest management is as engaging as nature-related content and whether there are significant differences in how boys and girls perceive this information.

Materials and methods

We conducted the research using educational boards set up at two locations:

- In the Bór Nature Reserve, where forests are protected, and no management activities are conducted. The boards displayed nature-related content (Fig. 1A,B).
- In the forests of the Głogów Forest District, specifically in the Turza Forest, where forest management practices are implemented. The board presented content related to forest management (Fig. 1C).

Fig. 1. Board **A**, nests of various bird species; Board **B**, Autumn and mushrooms; Board **C**, method of growing oak in gaps.

The sizes of the boards were comparable, and the height of the content presented on them allowed all participants to observe individual fields without the need for large head movements. The eye-tracker used in our study was equipped with accelerometer and gyroscope sensors, which enabled us to distinguish between head and eye movements. This approach eliminated the influence of head movements on the recorded eye movements.

The pilot study included 21 students aged 14 to 19, comprising 12 girls and 9 boys. Twenty individuals is the recommended minimum group size to maintain high statistical reliability of results[41] especially when analyzing distinct subgroups within a population[42]. Ideally, more than 50 participants should be used[43] but if a participant repeats the experiment in different configurations, the number of participants may be smaller. This solution was used in our study. We obtained informed consent from all individuals participating in the study and their legal guardians. The students were supervised by their school teachers during the study. Students were informed about the purpose, duration, and methodology of the study. They were also informed that they could withdraw from the study at any time. After putting on and calibrating the eye-tracking glasses, each participant was individually guided to the signs. The order in which the boards were viewed was also kept consistent for all study participants: first, the boards presenting content related to conservation, followed by those related to forest management. The authors ensured the protection of personal data under the GDPR in accordance with the law[44] for participants in the experiment. Participation in the study was voluntary. The authors affirmed that all procedures in this study complied with the ethical standards of the Polish Committee on Ethics in Science and the 1964 Declaration of Helsinki[45] as amended. Ethical approval was waived by the Code of Scientific Ethics[46] of the Polish Academy of Sciences.

We examined respondents' variable eye activity using the Tobii Pro Glasses 2 reflective eye tracker (Fig. 2; Table 1). The nearly contactless interface, which tracked gaze positioning on the information board, minimally distracted and disrupted the viewers' concentration. We recorded the reflection of infrared light from the eye and subsequently processed it in real-time, enabling us to identify the points at which the study subjects were looking at. The equipment, connected to WiFi, was linked to the Tobii Pro Glasses Controller software installed on a laptop. Once the glasses were calibrated, we began the recording session and each person undergoing the test observed the information boards without any interruptions.

Each recording lasted 5 min. In eye tracking studies, the exposure time should exceed 1 min to allow participants to achieve average fixations lasting between 200 and 300 milliseconds[47,48]. After each session, we paused the analyses, concluded data recording, and after another calibration of the equipment, commenced the next recording with a different participant.

The footage obtained during the field trial was processed using the Tobii Pro Lab software – Analyzer Edition 1.102.

We conducted the eye-tracking analyses in a bidirectional manner. Firstly, we determined the spatial resolution of the participants, i.e., their ability to distinguish areas within the visual scene that the user is looking at. Secondly, we assessed the temporal resolution, which refers to the number and duration of points of regard (PoR) measured over a given time period.

In order to determine which elements within the tables most strongly attracted the attention of the study participants, we created heat maps (Fig. 3). In order to automate the analysis of heat map data, we used the Python language along with Matplotlib, Pandas and OpenCV libraries. The Pandas library gave the ability to process data contained in files of ".xlsx" and ".csv" format, loading the contents, filtering and processing the data, and save it to the format of choice so that the data is available for further action. The Matplotlib package has made it possible to draw all kinds of graphs including graphs that are actually images. The OpenCV library provides many ready-made algorithms used in image analysis and processing. The algorithm for finding points of a certain range and color intensity was as follows:

Fig. 2. Eye-tracker Tobii Pro Glasses 2.

Sample rate	50–100 Hz (for eye-tracking devices, sampling frequency refers to how many fixation point positions are recorded each second. This parameter directly influences both the precision of measurements and the reliability of the obtained data.)
Cameras	4
Scene camera FOV	82° horizontally, 52° vertically
Scene camera parameters	h.264; 1920 × 1080 pixels; @25 fps
Field of view	160°
Diagonal of scene camera FOV	90°; 16:9
Sound recording	Yes
Weight	45 g
Battery life	120 min.
Recording station	
Connection	HDMI, Micro USB, 3.5 mm Jack
Frequency	2.4 GHz & 5 GHz band
Dimensions	130 × 85 × 27 mm
Weight	312 g

Table 1. Technical data eye-tracker tobii pro glasses 2.

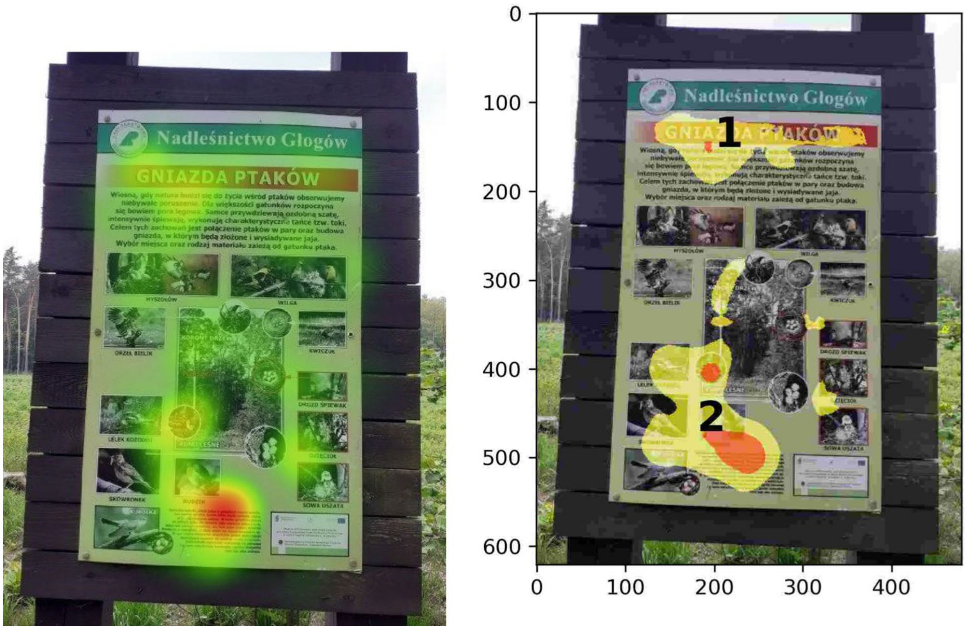

Fig. 3. Example of the original heat map developed for one person (left side) and after averaging the data for the entire research sample (right side).

- Loading an image,
- Transformation to hsv color space. Data in this space is easier to interpret because of the color - because one of the components corresponds precisely to the color,
- Determining the desired color range,
- Selecting points from the specified color range - creating the so-called mask,
- Visualization of the resulting mask for validation,
- Saving in a file the coordinates of the found points.

After performing a cluster analysis using the k-means method, averaged heat maps for selected groups of subjects were superimposed on the base photo. A similar set of tools was also used for this purpose. The image created, along with the superimposed result in the form of a patch of the appropriate color (yellow or red), was saved using the Matplotlib library. Everything was realized in the Jupyter Notebook environment. This environment provides the ability to easily create computer documents in almost any language - in this case Python was chosen.

In order to identify the parts of the vision scene that are characteristic because of their content, we identified the following on snapshots representing the Areas of Interest (AOI) arrays: image (photos or figures), text (verbal description to the photos or figures), header (placed at the top of the array: name of the array, forest district), footer (given at the bottom of the array: funding information, etc.). For individual AOIs for each participant in the study, we generated the most commonly used measures of location and variability of fixation points. The normality of the distributions of fixation times on individual AOIs was analyzed using the Shapiro-Wilk and D'Agostino tests, while the significance of differences was examined by performing the Kruskal-Wallis rank sum test.

In addition to this, we determined the durations of individual consecutive fixations and saccades from the imported full database for randomly selected film excerpts representing the average scanning conditions of the video scene. The durations of individual saccades and fixations took a small number of different values, relatively to the sample size: saccades – 6 values for more than 78 thousand observations, fixations - about 100 values for more than 413 thousand observations. For this reason, we analyzed the results by treating the data as categorical data. When analyzing the counts, we took class ranges as categories: 5 classes for saccades and 47 classes for fixations. We analyzed the variation in fixation and saccade duration within board type and gender using the χ^2 independence test for the respective pairs and all traits combined. We also calculated V Cramer coefficients of effect strength.

Results

The research material comprised 42 recordings for nature-related boards (A and B) and 18 recordings for the board with forest management content (C). The initial database, from which we created heat maps and analyzed areas of interest (AOI), encompassed over 750,000 changes in respondents' eye activity for nature-related boards and more than 300,000 for the board focused on forest management.

The fixation duration statistics for the highlighted parts of the arrays are shown in Table 2. In all cases median is exceeded by average (in one case they are equal) which suggest that the corresponding distribution is right skewed, so not normal. In most cases standard deviation exceeds or is about average which, by non-negativity of the data, also yields non-symmetrical dispersion and in turn skewness of the distribution. Dominant in most cases is equal 0, it does not exist for picture - Board 1 and heading, description, picture - Board 2.

The distribution of mean fixation times for individuals on each AOI of the A and B arrays is depicted in the violin charts (Fig. 4).

The graphs above suggest that the data may have truncated normal distributions, where for "heading", "description", "footer" the cutoff is for a value of 0, while for "photo" the cutoff is for a value of 0.2. It is therefore reasonable to expect that the distributions will not be normal, in particular they will be right skewed. This was confirmed by Shapiro-Wilk and D'Agostino normality tests, with $p < 0.05$ in all cases.

In view of the above results, to test the existence of differences in fixation durations between the considered AOIs, we applied the Kruskal-Wallis test. The resulting $p = 0.003235$ indicates the rejection of the null hypothesis of equality of fixation times in all AOIs in favor of the alternative hypothesis. We next performed pairwise comparison tests with various adjustments for multiple testing (Bonferrroni, Holm, Hochberg, Hommel, Benjamini & Hochberg, Benjamini & Yekutieli, none). Since the conclusions in all cases are the same (the same homogeneous groups) we present only boundary results, that is: without adjustment (none) and with Bonferroni adjustment – Table 3.

In all cases, we got two homogeneous groups: group "a" to which the "photo" area belongs, and group "b" to which the other areas belong, i.e. "heading", "description", "footer". The effect size η2 is moderate – 13,5% (H(df = 3, n = 84) = 13,77).

Statistics	Board area			
	Heading	Description	Photo/figure	Footer
Board 1				
Average	220	190	370	270
Median	180	160	290	200
Variance	70	30	50	110
Standard deviation (n-1)	260	180	210	320
Board 2				
Average	300	500	580	410
Median	270	470	580	380
Variance	70	80	70	180
Standard deviation (n-1)	260	270	270	420
Board 3				
Average	40	180	160	140
Median	0	160	150	40
Variance	3	20	10	50
Standard deviation (n-1)	50	140	10	210

Table 2. Fixation time (ms) – statistics.

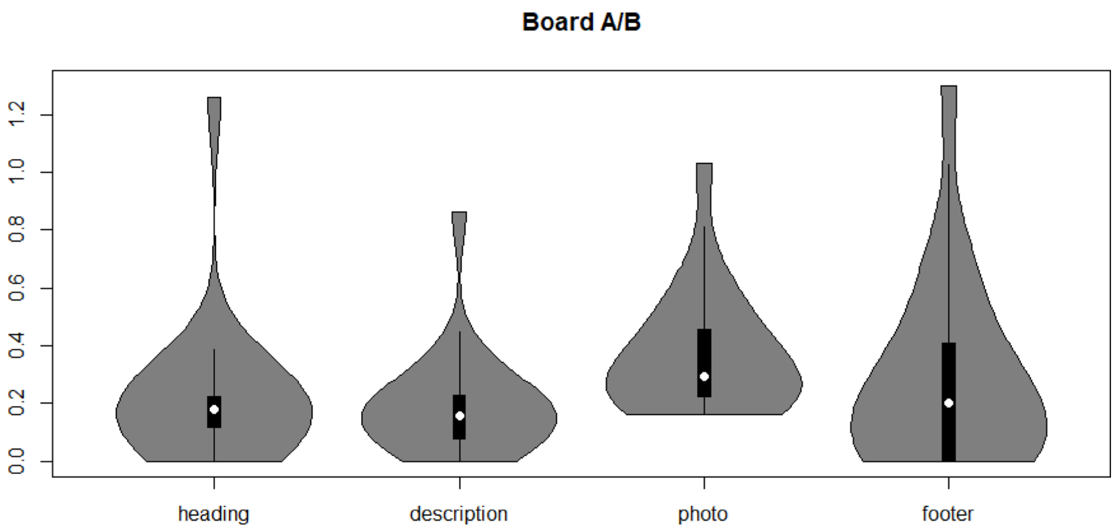

Fig. 4. Violin plot of individuals mean fixation time - AOI board A and B.

		Board area		
		Heading	**Description**	**Footer**
None	Description	0.82413		
	Footer	0.8438	0.72341	
	Photo	0.00152	0.00029	0.04387
Bonferroni	Description	1		
	Footer	1	1	
	Photo	0.0091	0.0017	0.2632

Table 3. Pairwise AOI comparision with two multiple testing adjustments.

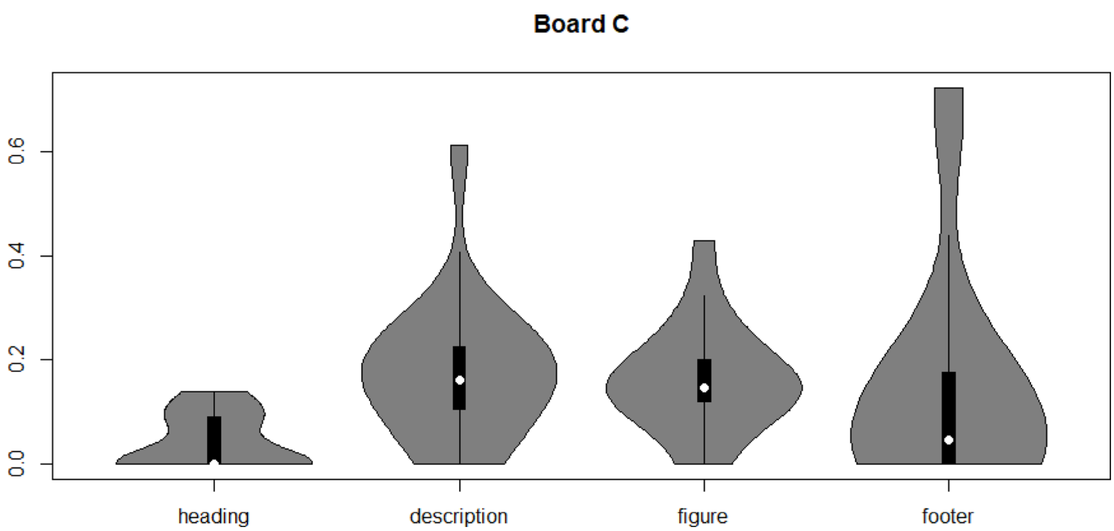

Fig. 5. Violin plot of individuals mean fixation time - AOI board C.

Also in the case of board C, based on the graphs, it is reasonable to assume that the data for "description", "figure" and "footer" may have normal truncated distributions. In the case of "heading", the cutoff value at "0" is also the median, hence the graph rather suggests a bimodal distribution (Fig. 5). In all cases, it is reasonable to assume that the distributions are not normal, as confirmed by the Shapiro-Wilk test. In all cases except for "figure," a $p < 0.05$ was obtained. Due to a sample size of less than 20, the d'Agostino test was waived. The positive

		Board area		
		Heading	Description	Footer
None	Description	0.00016		
	Footer	0.16450	0.08171	
	Photo	< 0.001	0.83686	0.09198
Bonferroni	Description	0.00093		
	Footer	0.98700	0.49029	
	Photo	0.00033	1	0.55187
Benjamini & Hochberg	Description	0.00047		
	Footer	0.19740	0.13797	
	Photo	0.00033	0.83686	0.13797

Table 4. Pairwise AOI comparision with various multiple testing adjustment.

Features compared	Value χ^2	*p*-value	V Cramer ratio
Saccades, gender	120.2241	< 0.001	0.03925531
Saccades, board	223.3928	< 0.001	0.05351028
Saccades, gender, board	28.6446	9.230558e-06	0.01916126

Table 5. χ^2 independence tests among saccad, gender and board type.

result in the case of "figure" can be explained by the cutoff at a distance of about two standard deviations from the dominant, and consequently the disorder cut off a relatively small part of the probability.

In view of the above results, to test the existence of differences in fixation durations between the highlighted areas of the forestry-related array, we performed the Kruskal-Wallis rank sum test, obtaining a p-value of 0.0002502. Thus, also in the case of board C, the test indicates the rejection of the null hypothesis of equality of fixation durations in all areas in favor of the alternative hypothesis. The result of the pairwise comparison test for board C, on the other hand, depends on the choice of multiple testing correction. Specifically, the assignment of the "heading" area to the homogeneous group changes depending on the choice of correction. Various adjustment was performed, the same as previously. The three of adjustments results representing all cases of homogeneous group are collected in Table 4.

In the case of "none" we get three homogeneous groups: "a"-to which 'description' and 'figure' belong, 'b'-to which 'footer' belongs, and 'c'-to which 'heading' belongs. In the case of the Bonferroni correction (and other considered adjustments not included in Table 4), we got two homogeneous groups: "a" - to which 'description' and 'figure' belong, 'b'- to which 'footer' belongs, while 'heading' lies between groups - 'ab'. In the case of the correction made using the Benjamini & Hochberg correction, we distinguished two homogeneous groups: "a" - which includes 'description' and 'figure', 'b' - which includes 'footer' and 'heading'. Based on the above analyses, it should be assumed that there are at least two homogeneous groups, one of which includes "description" and "figure" to the other includes "footer". On the other hand, the results obtained do not allow to conclude clearly in relation to "heading". The effect size η^2 is large – 23.8% (H(df = 3,n = 72) = 19.20).

The average duration of saccades for boys (43.59 ms) was slightly longer than for girls (43.40 ms) for the board with forestry-related content and the board with nature content (44.70 ms and 43.58 ms, respectively). In Table 5, we present the results of the χ^2 independence test along with the V Cramer coefficient of the strength of the effect for the respective pairs and for all features combined. The observed differences should be considered statistically significant, but the strength of the effect indicates a weak association between the traits.

The average fixation time for nature boards (563 ms) was 1.4 times longer than for a forest management board (402 ms). The average fixation time for boys (484 ms) was 1.5 times longer than for girls (326 ms) for the forestry content board and 1.2 times longer for the nature content boards (615 ms and 523 ms, respectively). The average fixation time for the image was 370 ms, and for the text 289 ms. For girls it was 337 and 245 ms, respectively, and for boys 416 and 348 ms. In the case of fixation, we observed significant differences between nature boards (A, B) and forest management board (C) arrays for long fixation durations (greater than 1000 ms). More than half of the class intervals (lengths of 20 ms - before merging) for classes with fixation durations above 1000 ms show zero abundance for board C, which is not the case for boards A and B. This is a factor indicating that there is a dependence of time length on board type. For the χ^2 independence test, the corresponding intervals were merged, yielding the 47 class intervals mentioned earlier. The results of the χ^2 independence test confirmed the relationship observed directly in the data. In the case of fixations, the strength of the effect as measured by Cramer's V coefficient is significantly higher than in the case of saccades, but values at most slightly exceeding 0.2 should still be interpreted as a weak strength of the effect. The test results are shown in Table 6.

In summary, we observed a dependence of the duration of saccades and fixations on gender and on the type of board. The strength of the effect for saccades is very small, for fixations it is small.

Features compared	Value χ^2	*p*-value	V Cramer ratio
Fixations, gender	13432.44	< 0.001	0.1802095
Fixations, board	17336.45	< 0.001	0.2047295
Fixations, gender, board	5748.05	< 0.001	0.1178855

Table 6. χ^2 independence tests among fixation, gender and board type.

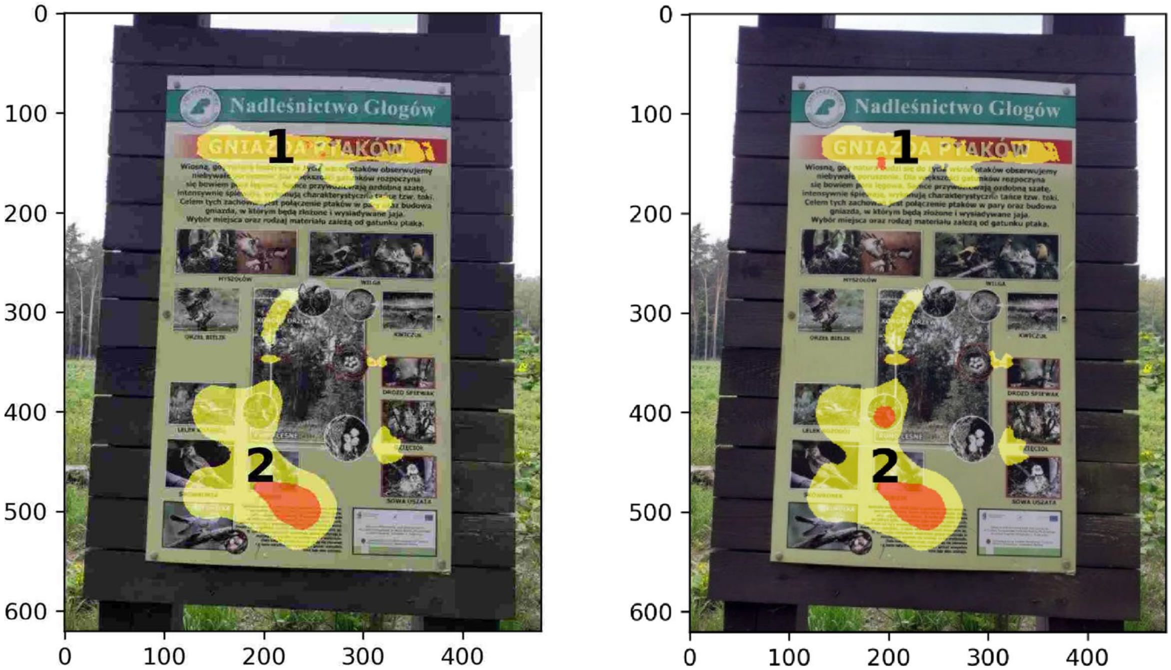

Fig. 6. Heat maps of the duration of fixation of the observation of the board with the nature content presented (A and B) for boys (left side) and girls (right side).

In Figs. 6 and 7, we present heat maps showing the zones (1 and 2) of the boards in which we observed the longest fixation durations. In both types of boards, these are the zones in which the descriptions are placed, with in board C, for boys, the focus shifts additionally to the placed diagrams (Fig. 7).

Discussion

Fixation time is a key indicator of visual attention and cognitive processes, making it a valuable measure of the learning process[49]. The study found that fixation time for images was consistently significantly longer than for headings, and for nature-themed boards; it was also significantly longer than for text. The average fixation time for images was 2.3 to 3.6 times longer compared to diagrams. A longer fixation time suggests more extensive processing of the information currently within the visual field[32] and could be indicative of information assimilation problems[50,51]. One possible reason for these results could be that the school-aged youth participating in our study had difficulty processing information presented through images, which required deeper analysis compared to reading text. However, we cannot conclusively determine this based solely on the eye-tracking data. What is certain is that the students spent more time looking at the images, but drawing further conclusions would require more detailed data, preferably obtained through interviews. A study by Bax[52] showed that students who exhibited longer fixation times while completing tests were more likely to fail their exams. It is important to note that visual learners (visualizers) tend to spend more time viewing images, while verbal learners (verbalizers) focus more on text when learning[53]. Longer fixation times may also reflect deeper engagement or visual preference, especially for visual learners[54,55]. The heat map analysis in our study indicated that boys tended to focus their attention more on viewing images, while girls concentrated more on the text. Additionally, the study revealed significant differences in fixation duration based on gender: the average fixation time for boys was longer than for girls. The observed relationships were consistent with scientific reports on gender differences in signal processing[56,57]. In studies conducted in the USA involving two groups (working professional, experts in their field, and students) that utilized eye-tracking technology to assess websites, similar patterns were observed to those in our study, i.e., men focused more on maps, while women concentrated on text and search bars[58]. Conversely, Djamasbi et al.[59] conducted an eye-tracking experiment and analyzed heat maps, and found no significant differences in information reception between women and men. On the other hand,

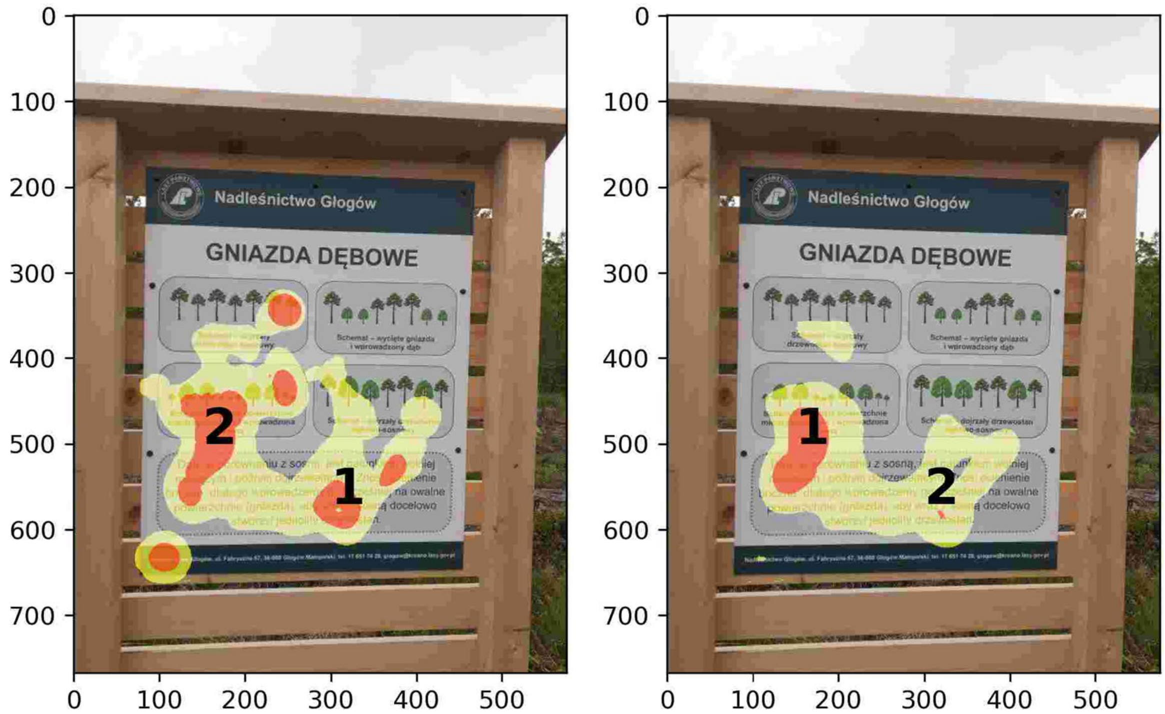

Fig. 7. Heat maps of the duration of fixation of the observation of the board with the presented content on forest management (C) for boys (left side) and girls (right side).

their analysis of self-assessment surveys indicated that male users regarded boards with images as significantly more attractive than those without images.

We found that the fixation time for boards with environmental content was significantly longer than that for boards related to forest management. The boards with nature content had a noticeably darker background compared to the white background of the board related to forest management. However, research by Djamasbi et al.[59] showed that background color had no significant effect on the visual appeal of the boards, and there were no substantial differences in perception between men and women. Another study found that red, yellow, and aqua colors conveyd information on a map more effectively than other color shades; however, it was determined that the size of the elements used was more beneficial than color tones[60]. Therefore, the background color can be ruled out as a factor contributing to the difficulty in assimilating information presented on the nature-related boards (indicated by the longer fixation time). Instead, differences should be sought, for example, in image size or content layout. The board related to forest management (C) featured four large diagrams of the same size, whereas the nature board (A) contained a greater number (18) of mostly small images. Reasons may also be found in the positioning of individual elements within the boards (top, bottom, left, right side). A study by dos Reis and Merino[48] demonstrated that changes in image positioning influenced the observer's perception. The authors observed a higher frequency of attention in the central area, as well as in the lower and left halves of the boards. Conversely, Faraday[61] identified the upper left area as having the highest concentration of visual fixations. Our analysis of the heat maps suggests that the type of element used (image or text) is more significant than its position. The number of fixations was higher on the descriptions-text-than on the images, while the situation was reversed for the fixation time. For the forestry-related board (C), a higher observation frequency was recorded in the left and lower sections of the board (where the description was located), while for the nature-related board (A), it was concentrated in the upper section (where the main description was placed). It should also be noted that differences in the perception of the boards by boys and girls were observed, as already discussed.

The second measured indicator of visual attention and cognitive processes was the duration and frequency of saccades. The number of saccades is closely related to the spatial organization of information. Frequent leaps are forced by unclear organization or improper organization of the environment of functionally related elements[62]. Klein et al.[63] on the other hand, found that participants were more likely to revisit information that was difficult to remember. The average number of saccades for boys (1,344 saccades for the nature board – averaged from boards A and B, and 780 for the forestry board C) was shorter than that of girls (1,477 and 1,210, respectively), regardless of the type of board. Conversely, the average duration of saccades was longer for boys, although the differences were minimal. The lower number of saccades for the forestry-related board, along with the shorter average duration of saccades, indicates a better spatial organization of information compared to the nature-related boards. Thus, a more effective approach is to place diagrams in a sequential arrangement with the accompanying description below them (board C), rather than using a large number of small images with the description above (board A) or having a description that occupies most of the board with two images placed below it (board B).

Holsanova et al.[64] reported that a sequential layout enhanced the integration of text and graphics for readers, making it more effective than a radial layout. In addition, a diagram provides an opportunity to convey more detailed information than photographs. Research by Liu and Chuang[65] indicated that illustrations included in educational materials should be detailed, particularly when they complement the text. These authors also pointed out that an excessive number of graphic elements (18 pictures on board A) distracted learners from the core message and increased cognitive load.

Limitations of the study

The main limitation of our study is the small group of participants (21 people), which makes extrapolating the results/conclusions from the sample to the population risky. However, this is a pilot study and the results/conclusions should be treated as preliminary guidelines, laying some foundations regarding this topic. Another limitation lies in the exclusive reliance on the eye-tracking method. While this technique is highly objective—minimizing the influence of researcher bias during data interpretation—it may not capture the full scope of participants' cognitive processes or reasoning. To develop a more comprehensive understanding, additional data would be beneficial, ideally collected through complementary methods such as interviews.

Conclusion

- The results suggest that school youth may have experienced difficulties assimilating information conveyed through images requiring deeper analysis, compared to reading simple text or reviewing diagrams.
- Boys tended to focus more on viewing images, while girls directed their attention toward text.
- The type of element used (image, diagram, text) was more important for conveying information than its position.
- The graphic layout of the boards with nature content differed from that of the forestry-related board, thus it cannot be concluded that the observed differences in perception were due to the type of information presented. The arrangement of the content may be more significant in the perception of educational boards placed in forests than the type of information conveyed.
- An optimal design for educational boards may involve arranging diagrams in a sequential layout with accompanying descriptions placed underneath. This format appears potentially more effective than layouts featuring numerous small images with descriptions above, or a large block of text occupying most of the space with two images positioned below.

The findings of our study should provide valuable insights for forest managers and educators in the effective design of content for educational boards installed in forests. The implementation of our recommendations when designing the content of educational/informational boards may improve their reception by the youth actively participating in environmental education programs conducted in forests. Consequently, this may increase the effectiveness of these boards in the process of educating young people about nature. In addition to showing forest biodiversity, forest managers can also explain the role of forest management in shaping the functions and appearance of these ecosystems.

Data availability

Data sets generated during and/or analysed during the current study are available from the correspondent author upon reasonable request.

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T.D.: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Supervision, Writing - original draft, Writing - review & editing. G.S.: Data curation, Methodology, Software, Visualization, Writing - original draft, Writing - review & editing. N.K.: Data curation, Visualization, Writing - original draft. Z.B.: Methodology, Software. M.R.: Visualization, Software. Z.S.: Methodology, Software. R.F.: Software. A.J.: Software. The authors read and approved the final manuscript.

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Declarations

Competing interests
The authors declare no competing interests.

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