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Eye-tracking Analysis in Landscape Perception Research: Influence of Photograph Properties and Landscape Characteristics

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ABSTRACT *The European Landscape Convention emphasises the need for public participation in landscape planning and management. This demands understanding of how people perceive and observe landscapes. This can objectively be measured using eye tracking, a system recording eye movements and fixations while observing images. In this study, 23 participants were asked to observe 90 landscape photographs, representing 18 landscape character types in Flanders (Belgium) differing in degree of openness and heterogeneity. For each landscape, five types of photographs were shown, varying in view angle. This experiment design allowed testing the effect of the landscape characteristics and photograph types on the observation pattern, measured by Eye-tracking Metrics (ETM). The results show that panoramic and detail photographs are observed differently than the other types. The degree of openness and heterogeneity also seems to exert a significant influence on the observation of the landscape.*

KEY WORDS: visual landscape observation, eye-tracking metrics, view angles, openness, heterogeneity

1. Introduction

Landscape perception research became increasingly popular in recent years. This is partially stimulated by new international and formal definitions of landscape, like that formulated by the European Landscape Convention: "Landscape is an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors" (Council of Europe, 2000). According to this definition, people are put in the core of the landscape and are even part of it while observing the landscape. Furthermore, the Convention states that landscape is an important public interest which constitutes a considerable part of the quality of life for people everywhere. Consequently, an active participation of the public in landscape planning and management is strongly stimulated, for example, by the formulation of the public's aspirations with regard to landscape features of their surroundings by the competent authorities (Council of Europe, 2000).

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Considering these statements, it is important to gain insights into people's observation and perception of landscapes to include this knowledge into landscape planning and management. So far, different landscape perception paradigms have been formulated (Scott & Benson, 2002) and analysed using questionnaires and depth interviews. The most frequently used stimuli in these empirical researches are photographs or in situ observations (e.g. Hägerhäll, 2000; Ode *et al*., 2008; Palmer, 2004; Sevenant, 2010; Tveit, 2009). An objective way to measure people's observation of landscapes, however, is provided by eye-movement tracking. This technique allows the recording of the velocity and direction of eye movements (saccades) and the position and duration of fixations while observing images. Eye-tracking measurements are well known in the field of (environmental) psychology (e.g. Berto *et al*., 2008; Guerard *et al*., 2009; Muller *et al*., 2012; Patalano *et al*., 2010). It has, however, also been introduced in geography (e.g. Antonson *et al*., 2009), cartography (e.g. Ooms *et al*., 2012) and landscape science (e.g. De Lucio *et al*., 1996; Tveit *et al*., 2010). Because landscape photographs are often used in landscape perception research (Sevenant & Antrop, 2011), eye tracking is a powerful tool for analysing people's observation of landscapes when represented by photographs. In this study, a homogeneous group of graduate geographers were asked to freely observe landscape photographs. During the experiment the participant's point-of-regard was constantly recorded by an eye-tracker, so that his/her eye movements and fixations can be reconstructed and analysed. Examples of the recorded data are the number of fixations, the fixation duration, etc.

The aim of the experiment is to assess the impact of photographic properties and of landscape characteristics on the observation behaviour measured by Eye-tracking Metrics (ETM). In the photograph-based approach, we determine if the type of photograph, used to represent a landscape, has an effect on the observation pattern. In particular, the influence of the horizontal and vertical view angles and the difference between normal and panoramic photographs are investigated. The main objective is to examine if people observe the same landscape differently if presented with different photograph types, varying in view angle.

The landscape-based approach addresses the influence of two landscape characteristics on the observation pattern: the degree of openness and the degree of heterogeneity of a landscape. According to Weinstoerffer & Girardin (2000), openness is related to the ease with which an observer can obtain an extensive view over a landscape. Antrop (2007) defines open landscapes as landscapes which offer wide views in all directions, while enclosed landscapes are characterised by limited and obstructed views. In landscape studies, openness is often used as a criterion for landscape classifications (e.g. Meeus, 1995), landscape change (Van Eetvelde and Antrop, 2009) and visual landscape analysis and landscape preference analysis (Dramstad *et al*., 2006; Ode *et al*., 2008; Tveit *et al*., 2006). In this context, the degree of openness of a landscape is expressed as the proportion of open land (e.g. Palmer, 2004; Weinstoerffer & Girardin, 2000), the viewshed size (e.g. de la Fuente de Val *et al*., 2006; Germino *et al*., 2001; Gulinck *et al*., 2001) or the depth of view (e.g. Germino *et al*., 2001; Gulinck *et al*., 2001).

The heterogeneity or complexity of a landscape refers to the richness and diversity of elements in the landscape and their spatial organisation (Ode *et al*., 2010). At a given scale of observation, a landscape may be considered homogeneous when it is composed of few and mostly similar elements, while a heterogeneous landscape is composed of complex configuration of very diverse elements. The heterogeneity of landscapes is frequently described by landscape composition metrics for example richness, evenness, Shannon diversity (Uuemaa *et al*., 2009; Wu *et al*., 2002).

The approach of our study is twofold: it aims to detect differences in the observation pattern of open, semi-open and enclosed landscapes and of homogeneous and heterogeneous landscapes. In both approaches, the Eye-tracking Metrics are statistically analysed. In particular, we perform a comparison of means between the several groups (e.g. homogeneous and heterogeneous landscapes) to detect significant differences.

2. Methods

2.1. Materials and Stimuli

The stimuli for the eye-tracking experiment are photographs, representing different rural landscapes in Flanders (Belgium) (Figure 1). A distinction was made between open, semi-open and enclosed landscapes and between homogeneous and heterogeneous landscapes. For each landscape, five photographs with several focal lengths were taken: a panoramic photograph, a standard photograph, two detailed photographs (zoom 1 and zoom 2) and a wide-angle photograph (Figure 2). Consequently, each photograph type differs in horizontal and vertical view angle, summarised in Table 1. The standard photograph corresponds to the middle part of the panoramic photograph.

All photographs were taken over 10 days with similar weather and in the same season (spring 2011) to avoid effects of vegetation transparency that would occur if the photographs were taken in different seasons. Furthermore, the photographs were made using a tripod to assure a constant shot height (1.70 m).

In total, photographs of 56 landscapes were collected, of which finally 18 were selected for the experiment. As a result, the test consisted of 90 photograph stimuli in

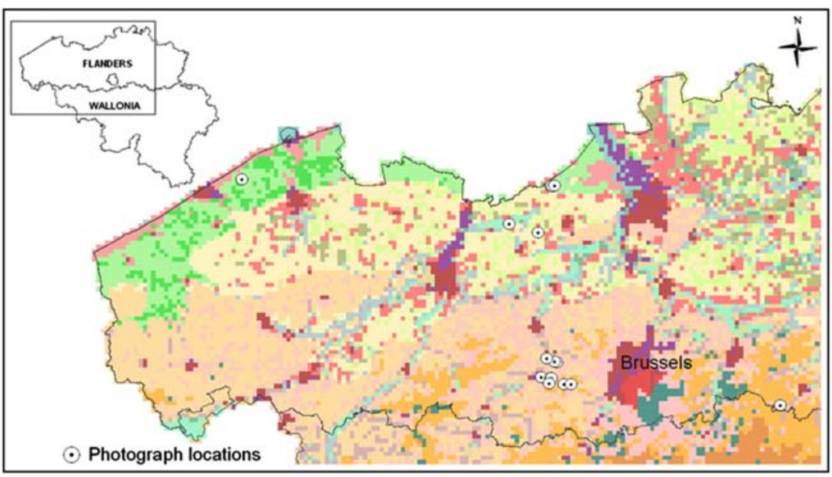

Figure 1. Photograph locations on the landscape characterisation map of Belgium (colours/grey tones represent landscape types) (Van Eetvelde & Antrop, 2009).

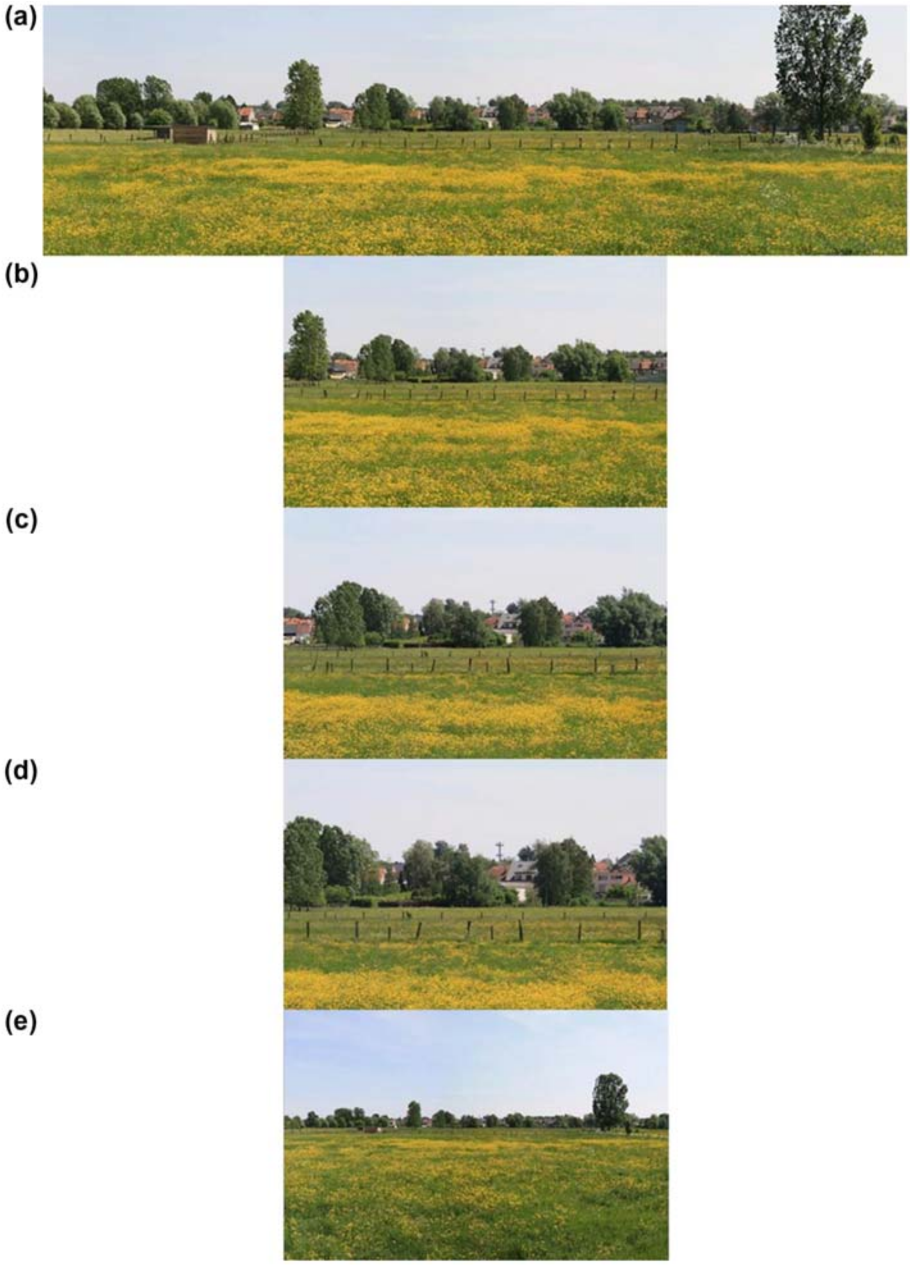

Figure 2. Example of five photograph types: (a) panoramic photograph, (b) standard photograph, (c) zoom 1, (d) zoom 2 and (e) wide-angle photograph.

total (five per landscape). Figure 2 presents a photograph series of one of the tested landscapes. For the experiment, all photographs were framed in the same 1280 x 1025 pixel dark grey background (Figure 3) to guarantee an identical display size (constant

Table 1. Photograph parameters

Photograpy type	Focal length	Horizontal view angle	Vertical view angle
Panoramic	50mm	70°	20.9°
Standard	50mm	31°	20.9°
Zoom1	70mm	22.4°	15°
Zoom2	100mm	15.8°	10.5°
Wide angle	18mm	75.1°	54.3°

height) and consequently allow a comparison between the different photograph types in the subsequent analysis of the recorded eye-tracking data. However, the statistical comparison between the panoramic photograph and the smaller photograph sizes may be complicated as the panoramic image covers a larger surface. To avoid this problem, an interest area, corresponding with what is represented in the standard photograph, was drawn over the panoramic photograph (Figure 3). This rectangle is invisible for the observer but allows the eye-tracker to separately collect information about the observer's behaviour within this interest area.

2.2. *Participants*

In order to limit the bias towards the cultural, social and educational background of the observers, a homogeneous group of participants was selected. As a result, 23 graduate geographers (male and female, aged between 23 and 52) of the Universities of Ghent and Leuven participated as unpaid volunteers. As eye-trackers are sensitive instruments, the participants were asked to wear contact lenses instead of glasses and forsake mascara in order to increase the accuracy of the eye-tracking measurements (mascara might lead the eye-tracking software to lock erroneously onto this dark area around the eye instead of onto the pupil; Holmqvist et al., 2011).

2.3. *Eye-tracking Equipment*

The experiment was performed using an Eye Link 1000, developed by SR Research (Ontario, Canada) and able to record the point-of-regard of the observer every millisecond. This allows a continuous registration of the participant's eye movements. In particular, low power infrared light is sent into the eye, where it is reflected by the cornea and the retina (Jacob & Karn, 2003; Poole & Ball, 2005). This reflection illuminates the pupil and cornea, which enables the signal processing unit to identify the centre of the pupil and the location of the corneal reflection. Subsequently, the vector between them is measured and the position of the point-of-regard is calculated (Poole & Ball, 2005) and expressed in a horizontal and vertical coordinate (Jacob & Karn, 2003). Due to the high sample rate (1000 Hz) and the duration of each session (15 seconds x 90 photographs), this procedure generates a large amount of raw data. However, these data allow a complete reconstruction of the observer's entire scan path, which is defined as a complete sequence of fixations and interconnecting saccades (Poole & Ball, 2005). In addition, it is possible to identify the areas in the image that

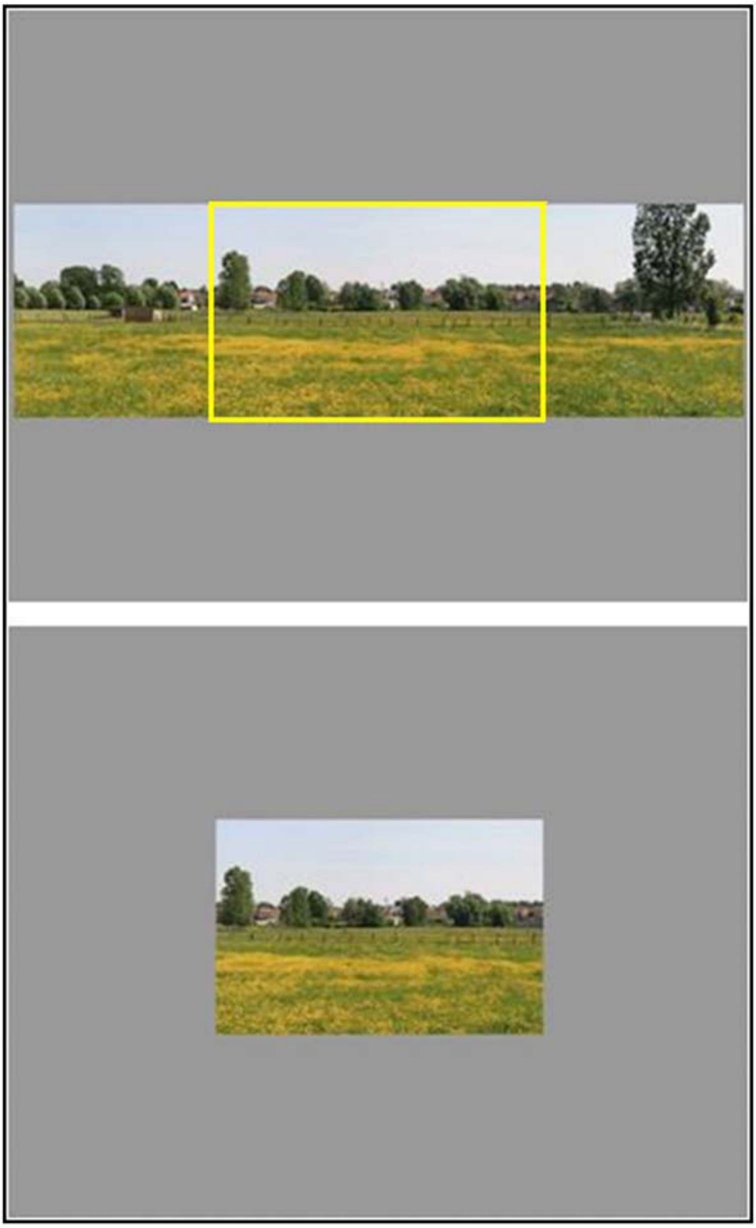

Figure 3. Photograph stimuli, framed in a dark grey background to assure an identical display height and allow comparison between classic photographs and panoramic photograph types. The yellow rectangle represents the interest area corresponding to the standard photograph below.

drew most attention, generally called centres of attention (Buswell, 1935). Although both eyes are used for viewing, the instrument only records movements of one eye (left or right depending on the subject's eye specifications). Furthermore, the observer's head was fixed on a chin rest to restrict head movements and increase the accuracy of the measurements (Holmqvist *et al.*, 2011).

2.4. The Eye-tracking Experiment

The experiment was performed over four days in July 2011 in an isolated room in a laboratory at Ghent University, so that participants could not be distracted. In addition, the room was darkened as the infrared light in direct sunlight would disturb the infrared illumination of the eye-tracker (Holmqvist *et al.*, 2011). Each test was preceded by a calibration procedure to match the pupil characteristics with the corresponding coordinates of the point-of-regard. This was achieved by a predefined calibration trial during which the subject was asked to fix nine dots appearing separately in an invisible, regular 3 x 3 grid (Holmqvist *et al.*, 2011). Only if a dot was precisely fixed for longer than a certain threshold time, the system recorded that pupil-centre/corneal-reflection relationship as corresponding to that specific x,y coordinate on the screen and moved on to the next dot. This was repeated for the nine dots of the regular grid to assure an accurate calibration over the whole screen (Goldberg & Wichansky, 2003). In addition, this procedure was repeated each time the deviation error increased due to unintentional small head movements or after a short break.

During the experiment, the subjects were seated 50 cm from the 1280 x 1025 pixel display screen and asked to freely view the photographs. In total, the test consisted of observing 90 randomly displayed photographs, each for 15 seconds. This specific display time is based on similar studies done by Berto *et al.* (2008) and De Lucio *et al.* (1996). The participants were given no specific tasks; no particular information needed to be extracted or remembered. Free viewing was chosen because in real life people do not observe landscapes with a task in mind. For example, during a walk people will mostly look at the landscape freely and unrestrictedly. In the free viewing experiment this condition was reproduced. Prior to each trial the subjects were instructed to fix a dot shown in the centre of a blank screen to check for increasing measurement errors and to provide consistency on the initial conditions of the observation path of each photograph. During the trials the system constantly recorded the point-of-regard of the subject. To assure full concentration of the participants and avoid errors caused by head movements, subjects were prohibited from speaking during the test. At each moment during the experiment, however, participants could interrupt the session in case of discomfort or tiredness. The next trial was then started after a recalibration.

2.5. Photograph Sorting

After the eye-tracking experiment, the subjects were asked to classify the 18 landscapes in order to create categories based on the degree of openness and heterogeneity. First, the participants were instructed to select the six landscapes with the widest views, followed by the six landscapes characterised by the absence of wide views. These categories respectively correspond to the ‘open landscapes’ and ‘enclosed landscapes’. The remaining six landscapes belong to the ‘semi-open landscapes’. Participants were not directly asked to select the most open and enclosed landscapes as their individual definition of open and enclosed landscapes may vary. A more objective criterion—the presence of wide views, based on Antrop’s (2007) definition of open and enclosed landscapes—was used to avoid this problem. Finally, three groups (open/semi-open/enclosed) of six landscapes each were obtained by attributing each landscape to the group in which the majority of the participants classified it.

Second, the exercise was repeated to divide the landscape photographs into homogeneous and heterogeneous landscapes. The participants were asked to divide the 18 landscape pictures into two equal groups, based on the amount of variety in the photograph. Again, no direct question was asked about 'homogeneous or heterogeneous landscapes' to avoid classifications based upon personal definitions of these concepts. The final two groups each consist of nine landscapes, either mostly classified as 'unvaried' (homogeneous landscapes) or as 'varied' (heterogeneous landscapes).

In both cases, the obtained groups were subsequently used to examine the difference in gaze pattern between open, semi-open and enclosed landscapes and between homogeneous and heterogeneous landscapes (landscape-based approach, see section 3.2). The sorting exercise was performed using the panoramic landscape photographs as these give the most complete idea of a landscape.

2.6. Data Processing and Statistical Analysis

Before starting the data analysis, the raw data needed to be converted into understandable and usable metrics. Most importantly, a distinction between fixations and saccades was required. Poole & Ball (2005) define a fixation as "the moment when the eyes are relatively stationary, taking in or encoding information". Jacob & Karn (2003) are more specific in their definition: "a fixation is a relatively stable eye-in-head position within some threshold of dispersion (typically 2°) over some minimum duration (typically 100–200 milliseconds) and with a velocity below some threshold (typically 15–100 degrees per second)". As there is no standard technique for identifying fixations (Jacob & Karn, 2003) and it is advised to set the lower threshold of a fixation on at least 100 milliseconds (Inhoff & Radach, 1998), we decided to define each stationary eye position, lasting for at least 100 milliseconds, as a fixation. Saccades are then defined as the eye movements occurring between fixations with the purpose to move the eyes to the next viewing position (Poole & Ball, 2005). The conversion from raw data into fixations and saccades was realised using the 'Data Viewer', a software program supplied with the equipment. Once the fixations are defined, this software produces Excel files containing complete, well organised and usable trial and fixation reports, in which numerous metrics like the number of fixations, the fixation duration and position, the number of saccades, the saccade velocity and amplitude, etc., are listed. As a result, these files were suitable for performing the statistical analysis, executed in the software package SPSS.

Not all metrics, recorded by the eye-tracking system are analysed in this study. Instead, we selected a number of basic Eye-tracking Metrics that provide information about the main observation pattern. These are fixations and saccades and their properties (Poole & Ball, 2005). Throughout the entire study the metrics of interest are therefore the following: the number of fixations, the fixation duration, the number of saccades, the saccade amplitude and velocity, the observed horizontal area and the observed vertical area. The latter are both derived from the fixation coordinates, using the principle of the minimum bounding rectangle. For example, the difference between the x-coordinate of the most extreme fixation in the right-hand side of the image and the x-coordinate of the most extreme left-hand side fixation provides the proportion of the photograph observed in the horizontal direction. Analogously, the difference between the y-coordinate of the most extreme fixation in the upper part of the image and the y-coordinate of the most extreme fixation in the lower part generates the proportion of the photograph observed in the vertical direction.

The first goal of the experiment is to test whether the photograph type has an effect on the observation pattern of landscape photographs (photograph-based approach). Therefore, a comparison of means between the different photograph types was carried out for the metrics measured by the eye-tracking system. It has been demonstrated that many eye-tracking measures do not follow a normal distribution (Holmqvist *et al.*, 2011). To test this, we first performed a Kolmogorov-Smirnov test. The results indicate that none of the ETM is normally distributed. Consequently, a Mann-Whitney test (2 samples) and Kruskal-Wallis test (k samples) for non-parametric data were used for testing the equality of means, based on ranks. Where the Kruskal-Wallis test indicated unequal means, further information about the comparative magnitudes of the means was obtained using a Dunn's test. Based on these tests, groups of similar means were formed and differing means were identified.

The influence of the landscape characteristics (degree of openness and heterogeneity) on the observation pattern was tested similarly. To avoid effects of the photograph type, the statistical analysis was only executed on the panoramic photograph type, because panoramic images offer the most complete view on the landscape.

2.7. *Data Visualisation*

The Data Viewer provides a tool to display all recorded data on the original photographs. This can either be created for one individual subject or for the entire group of participants. Although this does not enable a strong analysis of the data, it is a helpful tool to visualise the results of the statistical analysis. Different kinds of maps can be created. Figure 4 is an example of the visualisation of the fixations and saccades made by one subject. The circles represent the fixations, while the arrows illustrate the eye movements between two fixations (saccades). In both cases the numbers indicate the duration of the fixation/saccade in milliseconds. Figure 5 is an example of a 'heat map', derived from the fixation (and saccade) map and

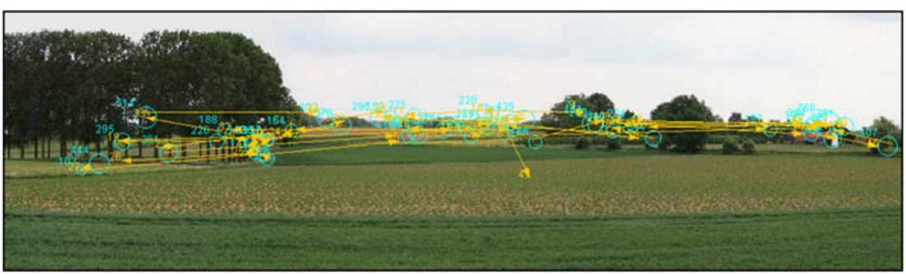

Figure 4. Visual output of one test person: fixations (circles) and saccades (arrows) indicating the eye movements.

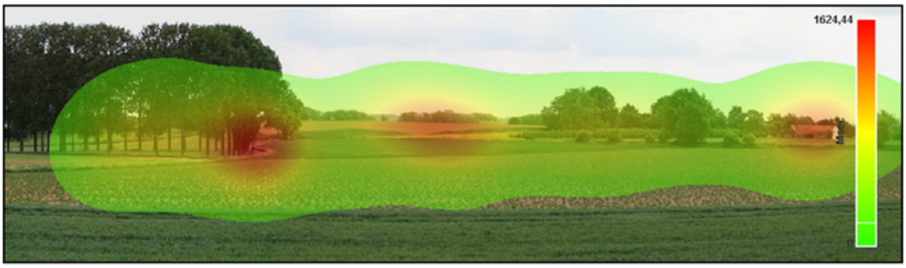

Figure 5. Heat map of entire test population, showing the centres of attention. Red zones correspond to the most frequently and intensively observed areas (mean fixation duration of 1624.44 milliseconds). Non-coloured areas have not been perceived by the participants.

introduced by Wooding (2002). This map shows the centres of attention, in this case of the entire group of participants. The red zones indicate the areas that have been observed most frequently and intensively.

3. Results and Discussion

3.1. Photograph-based Approach

First, the Kruskal-Wallis and Dunn's test indicate a significant difference in the number and duration of fixations and in the number, amplitude and velocity of saccades for the panoramic photograph compared to the other photograph types ($p < 0.05$) (Table 2). For these ETM, with exception of the saccade velocity (see further), no significant differences were found between the standard photograph, zoom 1, zoom 2 and the wide-angle photograph.

In particular, the experiment reveals that people generate more fixations in panoramic photographs. According to Duchowski (2007), a larger amount of fixations in the same observation time will increase the observer's capacity to recognise and memorise what is represented on the image. A number of factors may explain the higher number of fixations in panoramic photographs. In the first place, the higher number of fixations could result from the larger size and surface of panoramic photographs. As people tend to scan the whole image, more fixations will be generated in larger images. On the other hand, a panoramic photograph offers a broader view on a site or landscape, with a larger

Table 2. Results of the Kruskal-Wallis and Dunn's test per photograph type. The ranks are the results of the Kruskal Wallis test, grey tones indicate the outcome of the pairwise Dunn's tests. Per ETM, grey tones indicate groups of similar means, with, if significantly different, maximum values in darkest grey and minimum values in lightest grey. *N* gives the number of observations

Eye Tracking Metric	N	Mean rank per photograph type					P
		Panoramic	Standard	Zoom 1	Zoom 2	Wide angle	
Number of fixations	83,001	48,662	39,516	39,599	39,864	39,231	0.000
Fixation duration	83,001	38,469	42,468	42,077	42,284	42,474	0.000
Number of saccades	81,300	47,773	38,644	38,764	39,059	38,371	0.000
Saccade amplitude	81,300	49,054	37,964	37,732	38,422	39,153	0.000
Saccade velocity	81,300	48,116	38,327	37,835	38,928	39,202	0.000
Observed horizontal area	2,070	1,848	858	838	768	866	0.000
Observed vertical area	2,070	889	1,014	1,055	1,144	1,075	0.000

Table 3. Comparison between the interest area on the panoramic photograph and the standard photograph, based on a Mann-Whitney test. Per ETM gray tones indicate groups of similar means, with, if significantly different, maximum values in darkest grey and minimum values in lightest grey. *N* gives the number of observations. Absolute values of the mean ranks are smaller than in Table 2 because this test is performed on the mean values of the ETM of the interest area

Eye Tracking Metric	N	Mean rank		P
		Interest area on panoramic photograph	Standard photograph	
Number of fixations	828	584	245	0.000
Fixation duration	828	208	621	0.000

number of objects to observe. In order to know whether panoramic photographs are observed more extensively, as suggested by the higher number of fixations, a proper comparison with respect to the photograph surface needs to be established. This is achieved by comparing the middle part of the panoramic photograph (interest area in Figure 3) with the standard photograph. Both are identical in size and representation, except that the interest area is part of a larger photograph. The results of this comparison indicate that significantly more fixations occur in the interest area than in the standard photograph ($p < 0.05$) (Table 3). Thus, on the same photograph, a larger number of fixations are made when the photograph is part of a panoramic image. A landscape image might consequently be observed more extensively if a panoramic photograph is used. In addition, panoramic landscape photographs may be easier to recognise and to remember.

It is, however, not the number of fixations but the fixation duration that determines how easily photographs and images in general are processed and encoded. It is known that the fixation duration is an indication of a participant's difficulty extracting information from or interpreting an image (Duchowski, 2007; Fitts *et al*., 1950; Goldberg & Kotval, 1998) as it reflects the processing-time applied to the object being fixated (Just & Carpenter, 1976). In particular, it has been demonstrated that longer fixation durations indicate difficulty in extracting information (Just & Carpenter, 1976). Consequently, visual representations associated with long fixations are less meaningful to the observer than images associated with short fixations (Goldberg & Kotval, 1999; Just & Carpenter, 1976). Our results indicate shorter fixations in the entire panoramic photographs (Table 2) and in the interest area (Table 3), which suggests that information is extracted more easily from panoramic landscape photographs. This is explained by the broader context provided by panoramic photographs, which offers a more complete and holistic view on a landscape. As a consequence, the effort and time needed to identify and interpret potentially ambiguous landscape objects is expected to be less.

As fixations and saccades are complementary, a higher number of fixations results in a higher number of saccades in panoramic photographs. However, no encoding takes place during saccades, which means that this metric cannot be used to gain insight into the complexity of a landscape or landscape object (Rayner & Pollatsek, 1989). Instead, the number of saccades is related to the search pattern. According to Goldberg & Kotval (1999) more saccades indicate more searching. This means that people are searching or exploring more in panoramic photographs compared to the other photograph types. This tendency is explained by the broader horizontal view angle of panoramic photographs, which exposes a larger part of the landscape to the observer. As a result, the photograph represents a larger area with more landscape objects to be explored.

Furthermore, the saccades' amplitude and velocity seem to be higher in panoramic photographs. As saccades re-orient the eyes to the next viewing position and thus to the next fixation, the saccades' amplitude provides information about the distance from which the attention is drawn to an object. The larger this distance, and thus the larger the amplitude of the saccades, the more meaningful the cues in the image will be (Goldberg *et al.*, 2002). In panoramic photographs, objects seem to catch the observer's attention from a larger distance. In addition, re-orientations of the eyes are executed more rapidly, which suggests a higher readability of this type of photograph. It is possible that these larger (and faster) saccades are due to the larger image that is represented by the panoramic photograph. However, the saccades made in the interest area on the panoramic photograph—which thus start and end in the interest area—seem to be larger as well, compared to the standard photograph (Table 3). This means that the larger amplitude of the saccades occurring in panoramic photographs is independent from the image size. In the detailed photographs (zoom 1) significantly slower saccades were reported.

Another significant difference between panoramic photographs and the other photograph types is found in the observed horizontal and vertical area of the image ($p < 0.05$) (Table 2). Again, no significant differences were found between the other photograph types, except for the second zoom photograph. In panoramic photographs, the vertical proportion of the image that is observed is smaller. This is inherent to the characteristics of this kind of photograph, which subjects tend to scan in a mainly horizontal direction, apparently focussing less on the vertical dimension. The opposite applies to the detailed photographs (zoom 2), of which a larger vertical proportion is observed, compared to the other photograph types. This kind of photograph offers more details to the observer, and as a result, objects are represented in a larger size, covering a larger proportion of the photograph. As the participants observed these objects, automatically a larger vertical proportion of the image was explored.

3.2. Landscape-based Approach

The statistical analysis points out that the degree of openness of a landscape has a significant effect on the number of fixations and saccades, the fixation duration, the saccade velocity and the observed vertical area of the photographs ($p < 0.05$) (Table 4). In particular, open landscapes are associated with a smaller amount of fixations and saccades, while the fixation duration and saccade velocity are larger. Fewer fixations and saccades indicate less searching and thus less visual exploration of the landscape (Goldberg & Kotval, 1999). This is a consequence of the nature of open landscapes: objects, that may obstruct the view, are missing or only occur as small elements in the background of the landscape, creating its open character. Consequently, photographs of open landscapes do not exceed in variety and edges, but are rather monotonous, which apparently does not stimulate people to visually explore these types of landscapes. This is in line with Mackworth and Morandi (1967), who found out that subjects make more fixations in images or areas containing contours than in images composed of unbounded

Table 4. Results of the Kruskal-Wallis and Dunn's test per landscape characteristic, tested on the panoramic photographs. The ranks are the results of the Kruskal Wallis test, grey tones indicate the outcome of the pairwise Dunn's tests. Per ETM, grey tones indicate groups of similar means, with, if significantly different, maximum values in darkest grey and minimum values in lightest grey. *N* gives the number of observations

Eye Tracking Metric	**N**	**Mean rank** *Openness*			**P**	**Mean rank** *Heterogeneity*		**P**
		Open	Semi-open	Enclosed		Homogeneous	Heterogeneous	
Number of fixations	17,749	8,419	9,005	9,190	0.000	8,696	9,050	0.000
Fixation duration	17,749	9,105	8,854	8,672	0.000	8,888	8,862	0.734
Number of saccades	17,401	8,203	8,839	9,059	0.000	8,536	8,867	0.000
Saccade amplitude	17,401	8,919	8,539	8,651	0.000	9,059	8,357	0.000
Saccade velocity	17,401	8,961	8,524	8,625	0.000	8,934	8,478	0.000
Observed horizontal area	1,242	618	597	650	0.100	606	587	0.277
Observed vertical area	1,242	593	574	697	0.000	660	583	0.000

textures. Longer fixations suggest that information extraction and interpretation of the image is difficult (Just & Carpenter, 1976). Again, the unvaried character of open landscapes supports this finding. In addition, the potentially eye-catching larger objects only occur as small background elements in the photograph, which makes it difficult to obtain information about them and which may explain the longer fixations. In enclosed landscapes the opposite occurs: fixations are shorter. This suggests that enclosed landscapes may be easier to recognise as large objects are mainly situated in the foreground or middle plan of the photograph. In addition, larger objects can be experienced as 'threatening' or 'dangerous' (Appleton, 1975). When confronted with numerous large objects in their field of view, people might make short fixations on each of these objects to quickly determine which of them are really important or indeed threatening. This also supports the shorter fixation durations in enclosed landscapes. Furthermore, these view-obstructing objects, like trees, forests or buildings seem to be observed from top to bottom, which explains why enclosed landscapes are dominantly observed in a vertical direction.

The degree of heterogeneity of a landscape also influences the observation pattern ($p < 0.05$). Table 4 shows that homogeneous and heterogeneous landscapes differ in the number of fixations and saccades, the saccade amplitude, the saccade velocity and the observed vertical area. Homogeneous landscapes are associated with fewer fixations and saccades compared to more heterogeneous landscapes. In addition, the participants made longer and faster eye movements in homogeneous landscapes. These findings indicate a weaker visual exploration of this type of landscape, which can be explained by its more monotonous character and the scarcity of interesting objects within the field of view presented by the photograph. However, the saccades are longer and faster, which suggests that people quickly glance through the entire scene without finding interesting elements to fix upon. This also enlarges the vertical area of the image that is observed.

Finally, nor the openness, nor the degree of heterogeneity of a landscape seems to have an influence on the observed horizontal area of a photograph ($p > 0.05$).

4. Conclusions

The aim of this study was to test the effects of the photograph properties and landscape characteristics on the observation pattern of landscape photographs, measured by Eye-tracking Metrics. The photograph-based analysis points out that the photograph properties, and in particular the view angles, do influence the visual observation of landscape photographs. Panoramic photographs seem to be observed in a significantly different way than standard, detailed and wide-angle photographs. In panoramic photographs, more but shorter fixations are generated, suggesting that this type of photograph is observed more extensively and that information extraction may be facilitated. Consequently, a landscape image may be easier to recognise and memorise when presented as a panoramic photograph. This conclusion is particularly important for studies using landscape photographs in combination with questionnaires. Responses will probably be more adequate and detailed if panoramic photographs are used.

In the landscape-based approach, we tested if the degree of openness and heterogeneity of a landscape affects the observation pattern. The analysis clearly reveals that both landscape characteristics do have an influence. The long fixation durations suggest that the visual exploration of open landscapes is less extensive and that information extraction is hampered. The opposite conclusion applies to enclosed landscapes, which seem to be easier to interpret. Furthermore, homogeneous landscapes are expected to be explored less intensively compared to more heterogeneous landscapes due to their rather unvaried character. Instead, the entire landscape photograph is quickly scanned because of the absence of attractive or interesting objects. Heterogeneous landscapes are more diverse and thus more 'entertaining', which explains the stronger visual exploration of this kind of landscape.

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