International Journal of *Geo-Information*

Article

Virtual Prospecting in Paleontology Using a Drone-Based Orthomosaic Map: An Eye Movement Analysis

Tanya Beelders * and Gavin Dollman

Computer Science and Informatics, University of the Free State, Bloemfontein 9301, South Africa; dollmangj@ufs.ac.za
* Correspondence: beelderstr@ufs.ac.za

Abstract: Paleontological fieldwork is often a time-consuming process and resource intensive. With unexplored and remote areas, the satellite images, geology, and topography of an area are analyzed to help survey for a site. A drone-based orthomosaic map is suggested as an additional tool for virtual paleontology fossil prospecting. The use of an orthomosaic map was compared to the use of a typical satellite map when looking for fossil sites to prospect. Factors were chosen for their impact when prospecting for a fossil site and availability of data. Eye movement data were captured for a convenience sample of paleontologists from a local university. Each band within the satellite map measures 7741 × 7821 with a ground resolution of 30 m/pix, and the ground resolution of the orthomosaic map is 2.86 cm/pix with a resolution of 52,634 × 32,383. Experts displayed a gaze behavior suggestive of high analysis levels as well as being able to identify and analyze features rapidly—this is illustrated through the presence of both longer and shorter fixations. However, experts appeared to look at both maps in more detail than novices. The orthomosaic map was very successful at both attracting and keeping the attention of the map reader on certain features. It was concluded that an orthomosaic-based drone map used in conjunction with a satellite map is a useful tool for high spatial density virtual prospecting for novices and experts.

Keywords: eye tracking; eye movements; paleontology; orthomosaic map; satellite map

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Citation: Beelders, T.; Dollman, G. Virtual Prospecting in Paleontology Using a Drone-Based Orthomosaic Map: An Eye Movement Analysis. *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 753. https://doi.org/10.3390/ijgi10110753

Academic Editors: Stanislav Popelka, Zdeněk Stachoň, Peter Kiefer, Arzu Çöltekin and Wolfgang Kainz

Received: 2 August 2021
Accepted: 23 October 2021
Published: 9 November 2021

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1. Introduction

1.1. Prospecting within Paleontology

Paleontological fieldwork is often a time-consuming process that requires expert knowledge, is resource intensive, and has a high failure rate when prospecting. Generally, paleontologists devote resources to areas known to contain many fossils rather than using maps to identify fossil sites within a given region [1]. However, if an area is unexplored and remote, the satellite images, geology, and topography of an area are analyzed to help survey for a possible site [2]. Then, resource permitting, a paleontologist will go to the location and do a preliminary prospect. If there is evidence of fossils to be extracted, these locations will be marked with a GPS point, and a team of paleontologists and assistants will then come and extract the fossil from the ground. A drone-based orthomosaic map will allow much quicker virtual prospecting of a larger area using fewer resources via a drone survey. There are existing studies on how a paleontologist interacts with Geographic Information System (GIS) software such as ArcGIS but no information on how paleontologists interact with the GIS software to determine a likely site to prospect for fossils [3]. When virtual prospecting, a paleontologist will look for high erosion areas as eroded ground will allow a portion of the fossil to be visible to the paleontologist. The factors considered when prospecting on a satellite map are vegetation, land cover, elevation, slope, aspect, and drainage [4]. For a drone orthomosaic map, the factors considered are vegetation, elevation, slope, and land formations representing high erosion—in this case, dongas (also known as gullies). These factors were chosen for their impact when prospecting for a fossil site and availability of data.

1.2. Eye Movements and Eye-Tracking

The human eye is a complex organ consisting of multiple layers and fluid chambers [5]. The innermost layer of the eye, called the retina, contains photosensitive cells or photoreceptors, called rods and cones [6]. These receptors capture light to convert to electrical signals that are transmitted to the brain [6] via the optic nerve [7]. The fovea is the central region of the retina and is very densely packed with photoreceptors [7]. Consequently, the fovea has the highest visual acuity and to see an object clearly, and the eye must be moved so that the fovea is placed on the object of interest [8]. Saccades are high velocity, ballistic movements that are used to position the eye over an object of interest [7]. Visual acuity is suppressed or reduced during saccades and hence in order to "see" the eye must be held still or relatively still [8]. These periods of relative stability are called fixations and typically last between 200 and 300 milliseconds, although the duration is dependent on the task—for instance, during visual search, the mean fixation duration is 275 ms, and during scene perception, fixations last on average for 330 ms [8].

In any given scene, there could be multiple objects or areas competing for the attention of the viewer. The process of visual selection determines which of the competing objects is ultimately focused on, which was generally accepted as being either voluntary or automatic (involuntary) [9]. Top–down processing refers to voluntary visual selection, which is entirely under the control of the viewer, while bottom–down processing is automatic and governed by the features or saliency of objects within the scene [10]. For example, color, motion, or luminance are regarded as salience features, which can attract the attention of a viewer. Bottom–up processing is fast, as studies have shown that the fastest eye movements go to the salient elements, while the slower ones go to the target or less salient element [10]. Top–down processing is characteristically slow based on the notion that some form of information processing must occur to direct or control attention [10]. In the seminal work conducted by [11], it was concluded that eye movements, or gaze patterns, change because of the task the viewer is currently undertaking, which would suggest that given a task, there is some modicum of control over eye movements.

1.3. Eye Tracking in Cartography

Since map features influence correct decision making, it is essential to conduct usability testing on them [12]. Thus, numerous studies have focused on usability aspects of map reading and the use of eye-tracking metrics enhances the robustness of usability studies, which can lead to the design of better maps [13]. Map reading skills can be deduced through analysis of the first fixation (time to first fixation and first fixation duration), fixation count and duration, and also saccade count and saccade length [14]. Fixation count and duration are classified as a measure of processing, while the saccadic measures are classified as a measure of search [14]. A higher number of fixations indicates a low level of search efficiency [15], while a longer scan path is also indicative of less efficient searching [16]. Other metrics that are considered useful are the number of fixations and the visit length (also referred to as dwell time). Sequence charts can be used to illustrate transitions between different areas of interest (AOIs) [12]. A visit is the total time spent within the bounds of an AOI. If the gaze leaves the bounds of an AOI and returns, it constitutes a unique visit. A single visit can consist of many fixations. However, some researchers caution that eye-tracking metrics may not be suitable indicators of map complexity [17].

Map-reading efficiency is significantly positively correlated with color distance [18], but deviating colors attract the attention of map readers, which could influence the interpretation of the map [19]. The quality of map symbols, such as the number of colors used and the design of symbols [12], influences the usability of a map, but different classes of symbols used to signify landmarks do not significantly affect fixation duration [20]. The hierarchy of the legend entries also significantly impacts the usability of a map [12], and while experts and novices display similar gaze patterns when using a color-ordered legend, the visual behavior of experts is more deliberate when using alphabetically ordered legends [21].

In a study cited by [22], expert map readers were found to be far more efficient than novices who needed more time to interpret the map image. Later studies contradict this by finding that expertise does not affect map interpretation in terms of speed, correctness, and approach, but that these factors are instead influenced by the map design [23]. These findings were confirmed when it was found that neither the number nor the duration of fixations differ significantly between experts and novices when studying or drawing maps [24]. However, experts displayed a higher interest in functionalities available on web maps than novices [25] and have shorter fixation durations and hence more fixations when reading maps.

See [22] for a comprehensive review on eye movement analysis in map reading, summarizing multiple studies that investigated aspects such as cartographic symbolization and comparisons between 2D and 3D representations.

This paper discusses the results of eye-tracking analysis on different map mediums for use by paleontologists for prospecting purposes. The maps used will be a satellite map and a proposed orthomosaic map, which to the best of our knowledge has never been used for prospecting tasks.

2. Methodology

2.1. Equipment

An eye-tracker is a piece of hardware that can capture eye movements while participants look at stimuli [26]. A discussion on the various types of eye-trackers is beyond the scope of this paper, but please refer to [26] for a detailed discussion.

A Tobii T120 eye-tracker was used to capture eye movement data using a screen resolution of 1280 × 1024. The T120 has a sampling frequency of 120 Hz, which means that it captures eye data 120 times per second or every 8.3 milliseconds. All data were collected in the same venue using the same setup and lighting conditions. Tobii Studio v 3.4.8 was used to extract the eye movement data using a velocity-based algorithm with a velocity threshold of 30 degrees/second and a minimum fixation duration of 60 milliseconds. The facilitator used a secondary screen to monitor eye position throughout the test, and the screen was turned away from the participants so as not to distract them.

2.2. Participants

The sample was a convenience sample, as the study used paleontologists from a local university. Nine of the participants were males, six were females, and all were post-graduate or post-doctoral students or staff members of the paleontology department. This severely limited the sample size, which consisted of 10 experts and 5 novices. Participants were classified as expert or novice based on the number of years of experience they had practicing in the field of paleontology. The size of the sample is considered a limitation of the study but was governed by access to suitable participants. Additionally, the difference in expertise group size is a limitation on the interpretation of the results. However, the paper will still report the differences as it is deemed of interest to determine how the different expertise groups from this limited field of participants interact with the different maps.

2.3. Method

Instructions were issued verbally to the participants following a predefined protocol. This included a short welcoming, a brief description of the research being conducted, a short explanation on how an eye-tracker works, and a step-by-step walkthrough on utilizing the GIS software. Participants were asked to inspect a satellite map and an orthomosaic map in turn and identify potential fossil sites based on features they might recognize in the maps. Both maps are shown in Appendix A—these maps were shown in sequence to the participants but without the AOI overlay shown in Appendix A. The satellite map is the typical way in which paleontologists will visually scout an area to pinpoint potential dig sites. None of the participants had seen the orthomosaic map prior to the study. Both maps were displayed in QGIS (https://www.qgis.org/en/site/ accessed: 25 October 2021) software, which was familiar to the participants. Participants could interact with the maps and software as they wished, which included zooming and moving the map. A reference map of the area was available when the participants were using the satellite map. They could switch/transition to the reference map as much as they wanted to assist them in using the satellite map. Participants were instructed to identify potential fossil sites by placing a virtual pin (available in the QGIS software) on an area they believe should be prospected for fossils. Zooming and panning tools were available via a mouse movement or a toolbar press. Participants were asked to complete a short questionnaire aimed at eliciting their subjective satisfaction experienced while interacting with the orthomosaic map, which was unknown to them.

2.4. Stimuli

The satellite map was acquired from the United States Geological Survey (USGS), using bands 2 (Blue), 3 (Green), and 4 (Red) from the Landsat-8 low orbit system. The satellite map chosen was a map of the Eastern Cape, near Sterkspruit in South Africa, bordering southern Lesotho. Landsat-8 is a long running collaboration between NASA (National Aeronautics and Space Administration) and USGS that has been producing images since 2012 with spectral bands that contain visible, near-infrared, short wave, and thermal infrared [27]. Each band measures 7741 $\times$ 7821 with a ground resolution of 30 m/pix. Photogrammetry (also known as stereophotogrammetry) derives three-dimensional information based on points, lines, and areas on objects from a sequence of images [28]. The created data can be used for measurements and the interpretation of objects by providing precise three-dimensional point coordinates and other semantic object information. The data can be used to create maps, charts, and overlays. The use of photogrammetry has become established within the field of paleontology to create three-dimensional models of important specimens. These techniques have become known as virtual paleontology, which is the study of three-dimensional fossils through interactive digital visualizations [29]. With the availability of drone technology, orthomosaic models of larger geographical areas have become more prevalent [30–33]. The orthomosaic map was derived from a site known as the Qhemegha Bone Bed and is a rural area consisting of shales, red, or purple mudstones and red to white sandstone. The RGB (red, green, blue) images were acquired 31 July 2019 using a DJI Mavic Pro 2 (https://www.dji.com/mavic-2 accessed: 25 October 2021) from an altitude of 80 m. The ground resolution of the resulting orthomosaic map is 2.86 cm/pix with a resolution of 52,634 $\times$ 32,383. The DEM extracted from the model has a ground resolution of 1.15 m/pix and a resolution of 1858 x 1210. The Qhemegha Bone Bed is an area within the satellite map and is located near a rural village called Qhemegha within the Eastern Cape, South Africa. Both maps are placed within the Elliot formation, and the area is known to contain prospectable fossils. The area was chosen based on landscapes that have desirable features when prospecting for fossils. While the maps are of different areas and different resolution, they contain the same features used by prospectors to identify possible fossil sites and these features are of interest to the study. Therefore, it is hypothesized that the different areas will not influence the results of the study unduly as the common features are the factors of interest.

Features on the satellite map where fossil sites were located were a combination of low/steep slope, high/low drainage, rural/mountainous land cover, and low/medium vegetation. For the orthomosaic map, fossil sites could be identified using a combination of low/steep slope, high drainage, low or no vegetation, and the presence of a donga (a dry gully, formed by eroding action of running water) and sandstone. These features are indicative of sites that are prospectable for fossils and, while prospecting on a map, paleontologists should ideally be able to identify these features and mark the area as a site that can potentially be prospected. As with any visual search task, bottom–up and top–down processing is relevant and should be considered during interpretation. Some of the features mentioned may be more salient than others on the presented map, and hence, saliency could play a role in attention allocation during the task. However, there are no areas on either maps that are highly salient: for example, no glaringly stand-out colors and this, together with the assumption that the overarching task and the knowledge of the participants on site selection would take precedence, led to the belief that the task would be conducted in a more top–down selection process.

2.5. Data Analysis

Areas of interest (AOIs) were created for each potential fossil site on both maps. Appendix A shows both maps with their respective AOIs and the AOI number that was used to identify each AOI. The AOIs were known fossil sites in the area depicted or were identified by experts in the field as areas that should be prospected. Since participants could zoom and pan when interacting with the maps, dynamic AOIs were used: namely, the AOIs were adjusted accordingly (size and position) when the map image was adjusted in any way. The reference map itself was an AOI, and any AOIs on the map that were obscured during viewing of the reference map were disabled for the duration they were obscured. The eye-tracking metrics that were analyzed were fixation duration, number of fixations, numbers of visits, and visit duration. Since the study is particularly interested in the identification of potential fossil sites, the results and statistics used only the fixations that fell within AOIs.

Statistical analysis was conducted using the Statistica software package. Since eye gaze data are rarely normal, normality tests were conducted on all datasets. If the dataset was not normal, a Log10 transformation was performed on the data, as this often results in a dataset that is more normalized. In this case, normality tests were again conducted on the transformed data. If data were normal, then the ANOVA parametric test was used to analyze the data (either the original or transformed). If neither the original nor the transformed data were normal, a non-parametric equivalent was used for analysis.

For each analysis, the dependent variable was selected as the eye-tracking metric that was being investigated, for instance fixation duration, while the independent variables were expertise (novice or expert) and the AOI. The study was a within-subjects design to answer the hypotheses below:

- There is no difference in the eye gaze metric between novices and experts.
- There is no difference in the eye gaze metric between the satellite and orthomosaic maps.

For each of these stated hypotheses, the relevant eye gaze metric, such as fixation duration, was inserted.

3. Results

3.1. Fixation Duration

Novices had a mean fixation duration of 220.4 ms and 220.6 ms for the orthomosaic and satellite map, respectively, while experts had a mean fixation duration of 215.1 ms and 224.8 milliseconds on the satellite map. The mean fixation durations for both maps and groups are slightly shorter than the typical fixation duration for visual search. At an α-level of 0.05, there was no significant difference between the fixation durations of experts and novices ($F(1, 371) = 1.98$, $p > 0.05$), and none between the various AOIs ($F(50, 371) = 1.07$, $p > 0.05$). The graph below (Figure 1) shows the fixation duration metrics for all participants for the two maps. Experts are prefixed with "E" in their participant's name, and novices are prefixed with "N". The box plot for the satellite map is on the left, and the orthomosaic map is on the right.

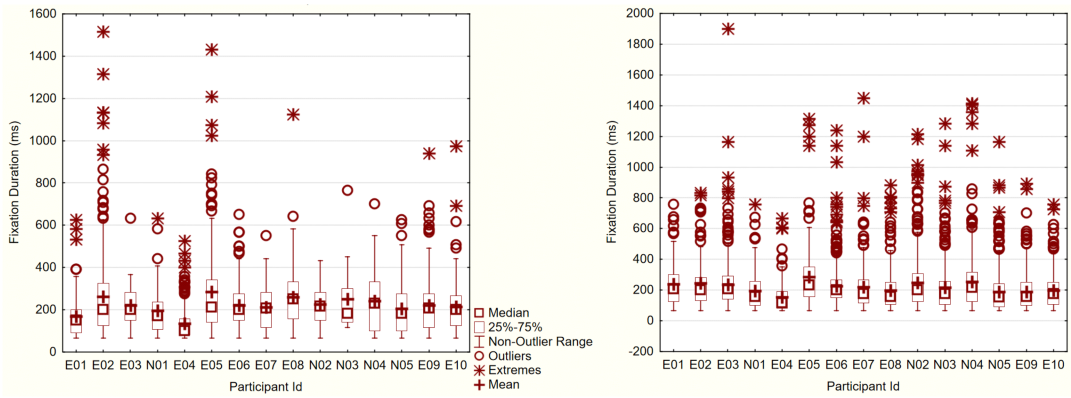

Figure 1. Average fixation durations for each participant on the satellite (**left**) and the orthomosaic (**right**) map.

As can clearly be seen, the fixation durations follow the same general trend for all participants. Interestingly, the two participants with the shortest and the longest mean fixation duration are both experts. Only one expert had a mean fixation duration typical of visual search or scene perception.

Heat maps of fixation duration are in Figures 2 and 3 for each participant group and for each map type. When a heat map is drawn, warmer colors denote more fixations; hence, the warmer the color, the more fixations there were in that area, and the cooler the color, the less fixations there were in that area. Note that when the heat maps were drawn, only the fixations that fell within the marked AOIs were used for the sake of simplicity. In both cases, the heatmap for the novices is shown on the left and that of the experts is shown on the right.

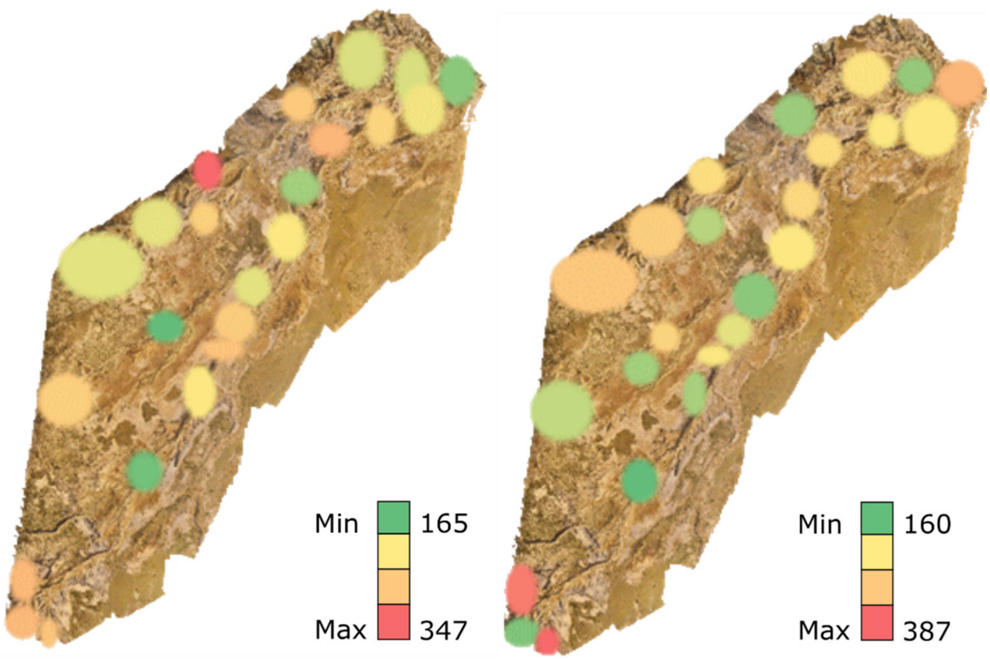

Figure 2. Heat map for average fixation durations in milliseconds for novices (**left**) and experts (**right**) on the orthomosaic map.

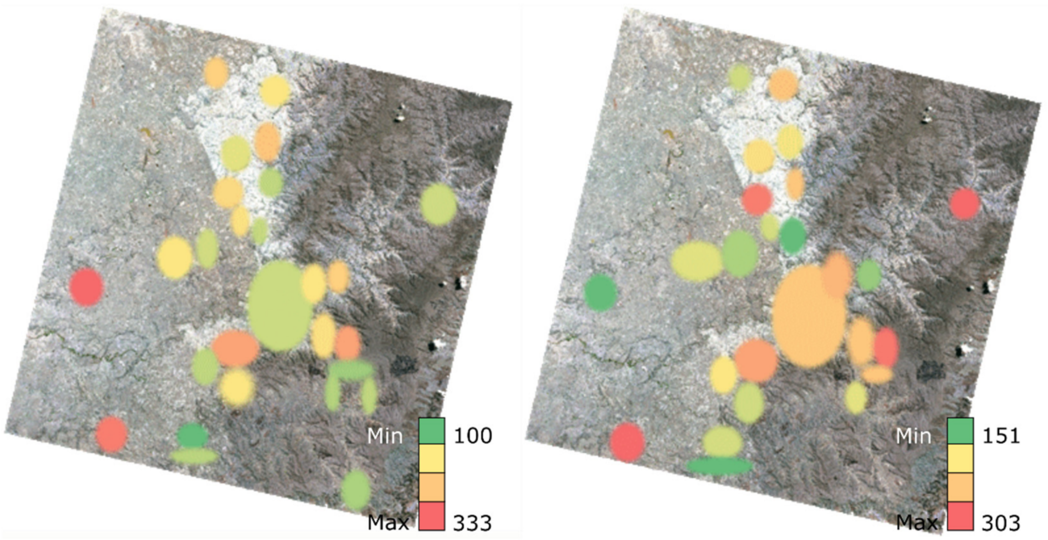

Figure 3. Heat map for average fixation durations in milliseconds for novices (**left**) and experts (**right**) on the satellite map.

By and large, the intensity of the fixation duration between the groups was similar, while in isolated instances, such as the two bottom sites on the orthomosaic and the two right-hand sites on the satellite garnered, on average, longer fixation durations (as indicated by the red patch on that AOI) by the experts. The areas on the right have the right geology, near a river, so a high erosion zone and low vegetation cover. It may be that experts look more carefully than novices for suitable spots within a satellite map and were able to identify and inspect the areas more intensely based on the correct features.

3.2. Number of Fixations

The number of fixations were determined per map and per expertise level. On average, novices had 1847 fixations on the orthomosaic map and 324 on the satellite map, while experts had, on average, 3071 fixations on the orthomosaic map and 1631 on the satellite map. Clearly, the orthomosaic map resulted in many more fixations than the satellite map within the designated AOIs, while experts had many more fixations within the AOIs for both maps. The orthomosaic map has much more detail than the satellite map, and it was productive for a participant to zoom into an area and then spend time analyzing an area, resulting in more fixations. Even zoomed out the orthomosaic map has significantly more detail than the satellite map, allowing for features to be identified better. As previously noted, the mean fixation duration on the two maps was in the same order. The experts have better identification abilities, meaning that they were able to interpret and identify possible sites much better than novices and thus had more fixations in these areas than novices (for both maps). It is worth noting that all participants reported preferring to virtually prospect on the orthomosaic map.

The number of fixations did not differ significantly between expertise levels ($F(1, 371) = 0.6$, $p > 0.05$), but there were significantly ($F(50, 371) = 3.3$, $p < 0.05$) more fixations on AOI Drone 1 (top left corner of the orthomosaic map) than on any other AOI. This is evident when inspecting the heat maps for the orthomosaic map (Figure 4) where both the experts (right) and the novices (left) had many fixations in that area.

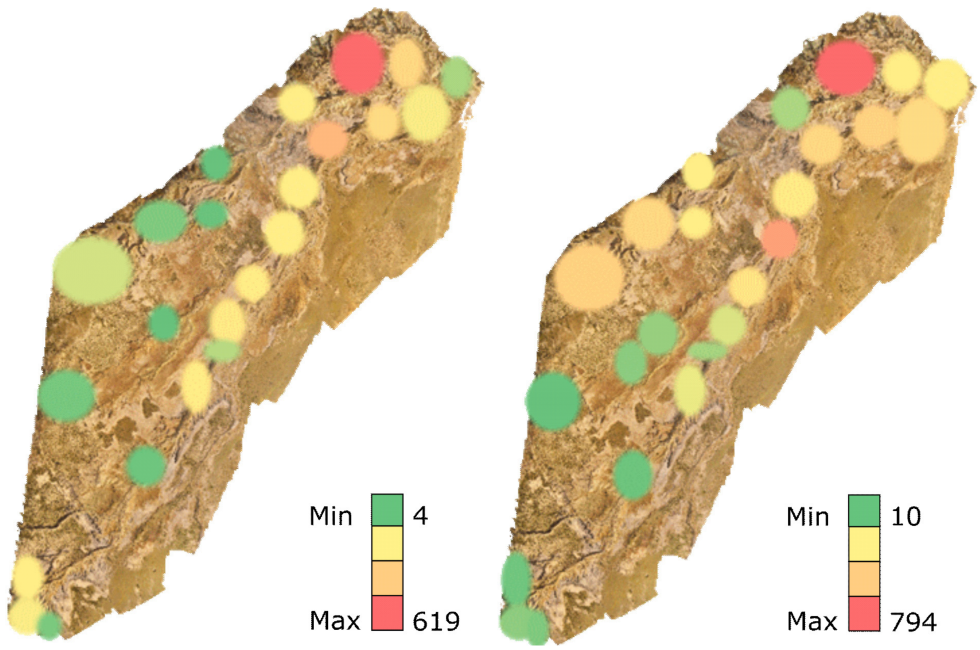

Figure 4. Heat map for number of fixations for novices (**left**) and experts (**right**) on the orthomosaic map.

While fixations were more in this area, the durations were not significantly higher, which would indicate that it is a high area of interest but not that it required more concentration or cognition to interpret. The number of visits will indicate whether it kept drawing the attention of the participants.

For the satellite maps as shown in Figure 5, the heat maps are comparable for novices (left) and experts (right).

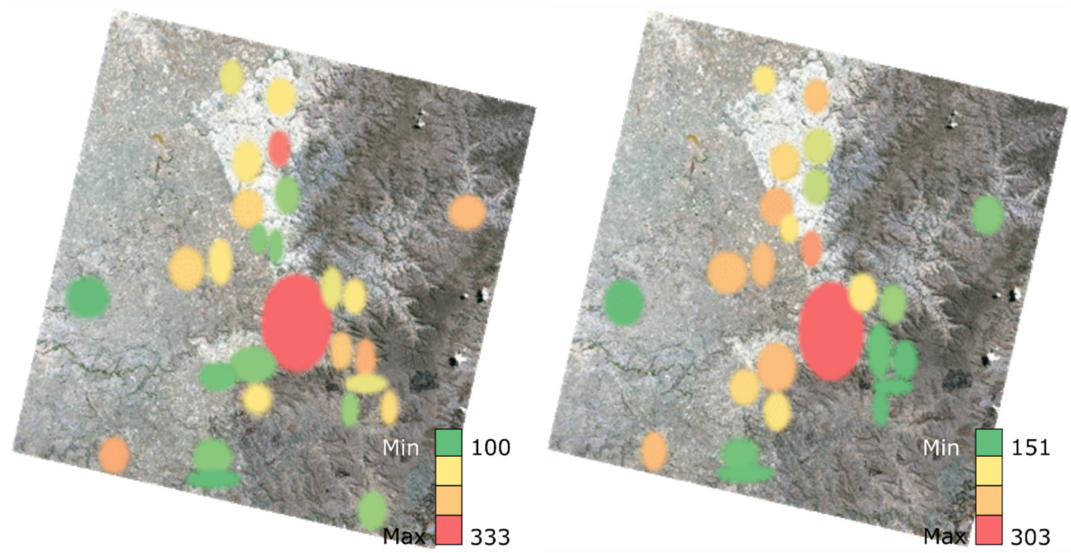

Figure 5. Heat map for number of fixations for novices (**left**) and experts (**right**) on the satellite map.

Both groups had a high number of fixations in the center AOI. This AOI was also the one with the largest surface area relative to the other AOIs. This area has the right geology, low vegetation, and contains many rivers, so it is a high erosion zone which is ideal for prospecting for fossils. This mountain range also dominates the center of the map, so it likely drew the gaze of the participants. However, it must be borne in mind that the center of an image often shows higher gaze intensity simply because it is the middle of the image.

However, due to the extended interaction the participants had with the map, it is more likely in this instance that the area was of interest to the participants as a potential fossil site. Additionally, since the map could be moved, this AOI would not have remained in the center. The AOI was also large relative to the others, and further analysis could be conducted that takes the size of the AOI relative to the number of fixations into account. This analysis is beyond the scope of this paper.

Figure 6 shows the number of fixations data for each participant on both maps.

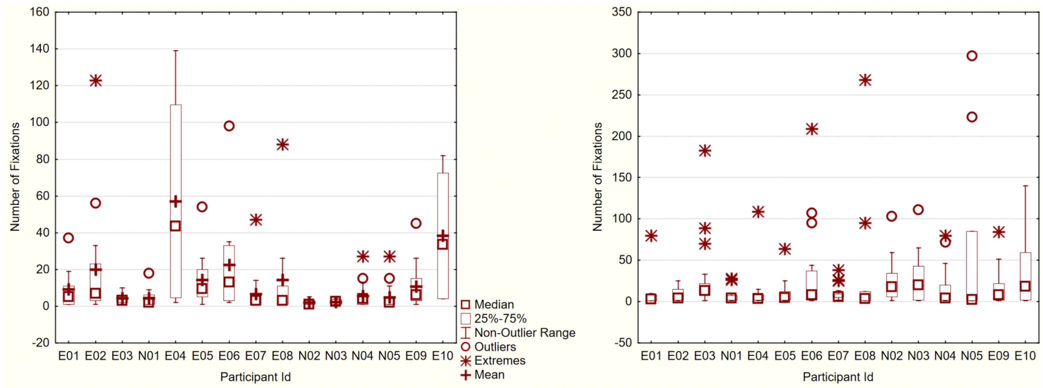

Figure 6. Number of fixations for each participant on the satellite (**left**) and the orthomosaic (**right**) map.

In all but three instances—all experts—the orthomosaic map resulted in a higher mean number of fixations.

3.3. Number of Visits

Recall that a visit is defined as the entire time spent within the bounds of an AOI without leaving the AOI. Hence, each visit can constitute several fixations. Analyzing the number of visits will give a clearer idea of which AOIs kept attracting the attention of the participants and to which AOIs they kept returning.

The heat map for the number of visits in each AOI is reproduced in Figure 7. As before, the novices are on the left and the experts are on the right.

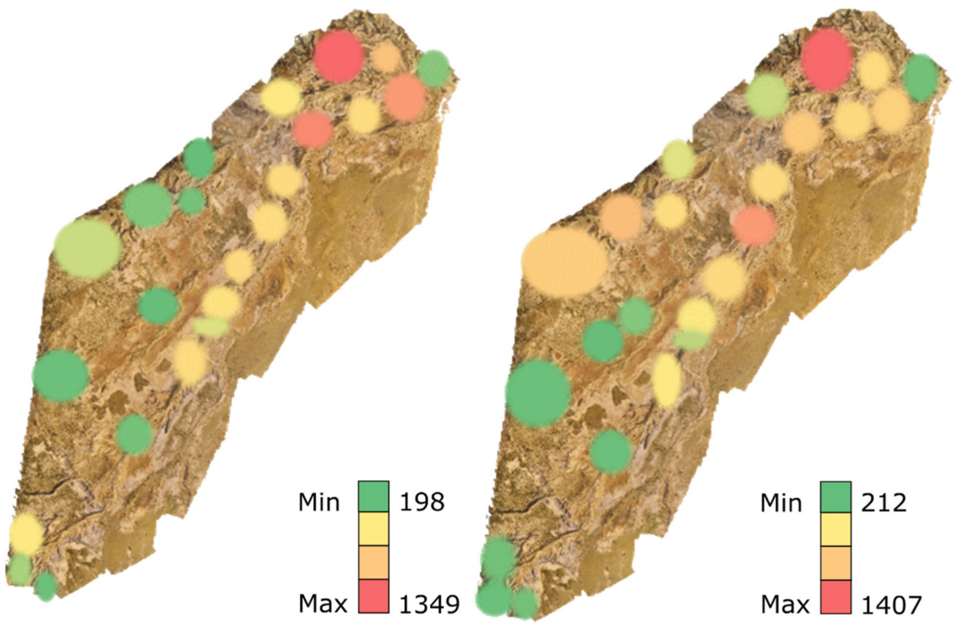

Figure 7. Heat map for number of visits for novices (**left**) and experts (**right**) on the othomosaic map.

The number of visits for the top left most AOI is high for both novices and experts, as with the number of fixations. Therefore, the participants returned to the AOI multiple times as it kept drawing their attention. Coupled with the fact that the mean fixation duration was not atypically high for this AOI, it can be said that while it attracted repeated attention, it did not cause an increase in cognition or difficulty for map interpretation.

Similarly, the number of visits to the center AOI on the satellite map (Figure 8) was also very high for both novices and experts, which correlates with the high number of fixations.

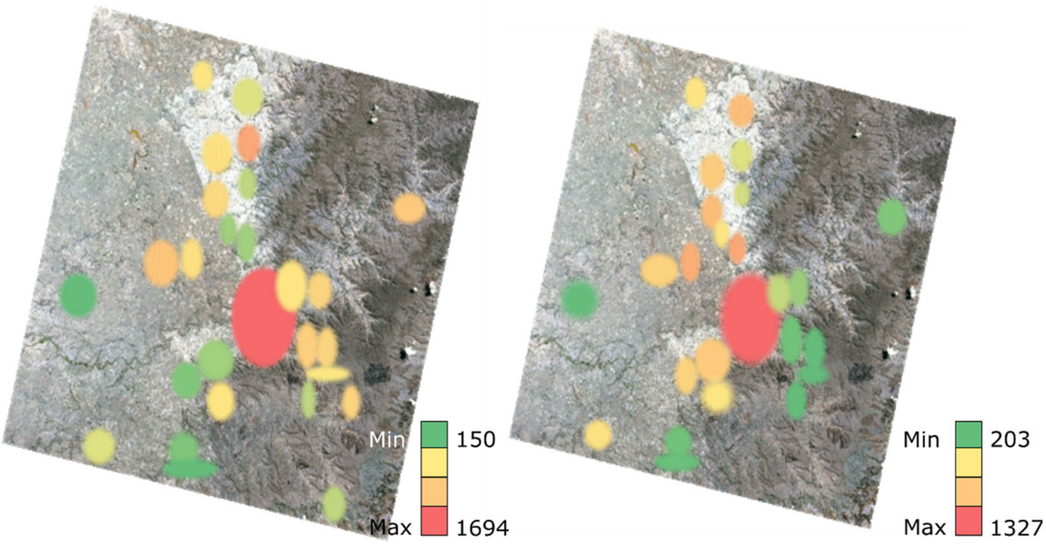

Figure 8. Heat map for number of visits for novices (**left**) and experts (**right**) on the satellite map.

At an α-level of 0.05, there was no significant difference between expertise levels ($F(1, 371) = 2.02$, $p > 0.05$); however, Drone 1 had significantly more visits, on average, than any other AOI ($F(50, 371) = 2.2$, $p < 0.05$).

The number of visits is shown in Figure 9 for each participant and each map.

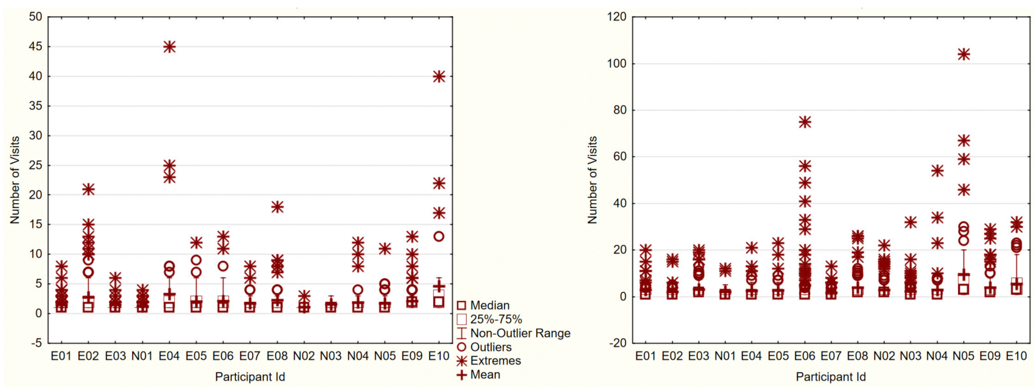

Figure 9. Number of visits for each participant on the satellite (**left**) and the orthomosaic (**right**) map.

There are disparate behaviors between the map mediums, with participants, in general, returning to areas more often on the orthomosaic map than on the satellite map. This is confirmed by the mean number of visits which are 535 and 203 for the novices on the orthomosaic and satellite map, respectively, and for the experts' 917 and 695 for the orthomosaic and satellite map, respectively. Interestingly, the experts had many more visits than the novices, showing they returned to areas numerous times to inspect the area again or to confirm prior findings.

3.4. Visit Duration

The duration of a visit is the total length of the time spent within the confines of an AOI. The mean length of a visit will allow clearer insight into how long the AOI managed to hold the attention of the participant in a single visit to that area (as opposed to the number that indicates “attention getting” and not “attention keeping”). There was no significant difference between expertise levels ($F(1, 371) = 0.01$, $p > 0.05$) but there were AOIs that differed significantly ($F(50, 371) = 1.97$, $p < 0.05$). Post hoc tests indicated that the visit durations on the top left most AOI on the orthomosaic map were significantly longer than some of the lower AOIs. This is reflected on the heat maps in Figure 10 that show a markedly longer visit duration on the top AOIs. Hence, there are individual areas on the map, regardless of map type, that attract the attention of the viewer repeatedly.

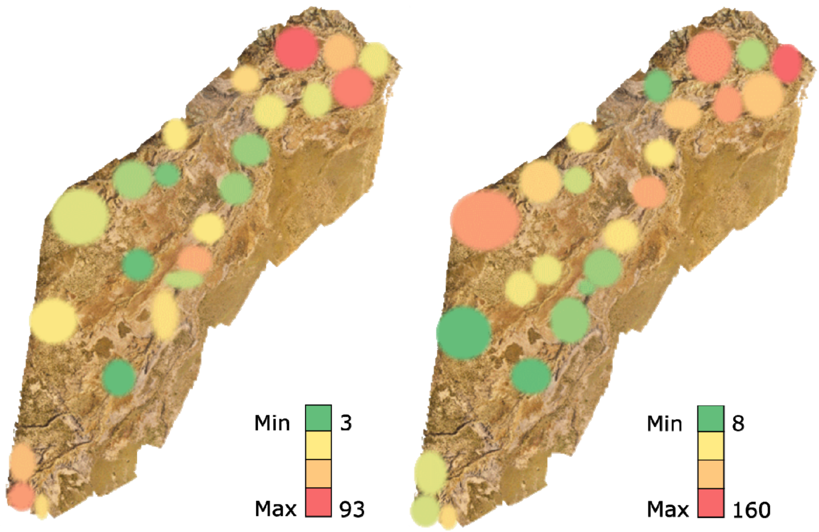

Figure 10. Heat map for visit duration in milliseconds for novices (**left**) and experts (**right**) on the othomosaic map.

For the satellite maps (Figure 11) the center AOI that had higher fixations did not show an increased number of visits, but rather a more average number of visits, as opposed to the bottom left AOI that had a high number of revisits. This lower AOI had only an average number of fixations and fixation duration; hence, there were many short visits to this AOI. This confirms the prior assertion that the center of the map was not looked at longer or more due to its position on the map.

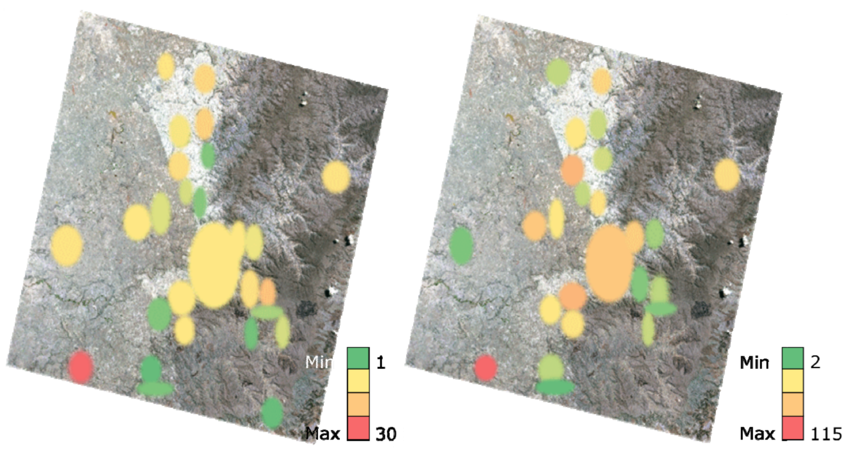

Figure 11. Heat map for visit duration in milliseconds for novices (**left**) and experts (**right**) on the satellite map.

As can be seen in Figure 12, the average visit durations are also longer on the orthomosaic map than on the satellite map, indicating that participants stayed within an AOI for longer. Coupled with the higher number of visits, this shows that the areas on the orthomosaic map kept drawing and keeping the attention of the participants, more so than the satellite map. Therefore, the features of the map do influence gaze behavior.

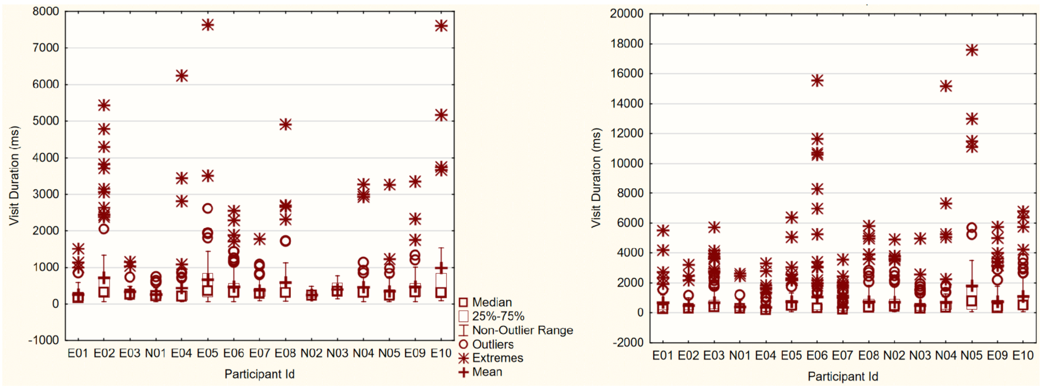

Figure 12. Average visit durations for each participant on the satellite (**left**) and the orthomosaic (**right**) map.

3.5. Sequence Charts

Sequence charts (refer to Appendix A for AOI identification numbers) were drawn for the best participant—this participant is an expert and was chosen based on his performance observation. In the same manner, a sequence chart was drawn for a randomly chosen expert and a randomly chosen novice. Each chart shows only the first 50 visits to AOIs for the sake of brevity and simplicity. Only AOIs that were fixated on are shown for the sake of clarity. Each vertical line represents a single fixation, and where successive fixations in an AOI were too many, the number of successive fixations is shown in brackets instead.

The sequence charts for, respectively, the satellite (Figure 13) and orthomosaic (Figure 14) map for the best participant (blue), the random expert (green), and the random novice (red) are shown below. The "other" AOI indicates fixations on areas outside the marked AOIs, and very long visits are indicated by the number of subsequent fixations in brackets instead of graphically.

In the satellite map, the novice had much fewer visits in total and, as can be seen, much shorter visits than both experts. The experts also concentrated on isolated AOIs, namely those labeled 9–14, whereas the novice looked at many more AOIs. As reflected on the heat maps, the experts were particularly interested in the center AOI, numbered 13, whereas the novices only glanced at it a few times. Likely, the experts extrapolated the geology of the area and focused on areas that were suitable. For example, avoiding built-up urban areas or high vegetation zones such as forests.

As with the satellite map, the best participant stayed within a few AOIs, but in this instance, the random expert and the random novice both looked at a wide range of AOIs, always with short visits—contrary to the longer visits of the best participant.

As evidenced on Figures 13 and 14, the orthomosaic maps had, on average, longer and more visits than the satellite map. Interestingly, only the best participant showed evidence of this behavior in terms of the number of subsequent fixations. The two randomly selected participants had very few fixations per visit and were more inclined to prospect widely and within shorter timeframes, although it is possible that their single fixations were longer on the orthomosaic map and bearing in mind that the sequence chart only shows the first 50 visits.

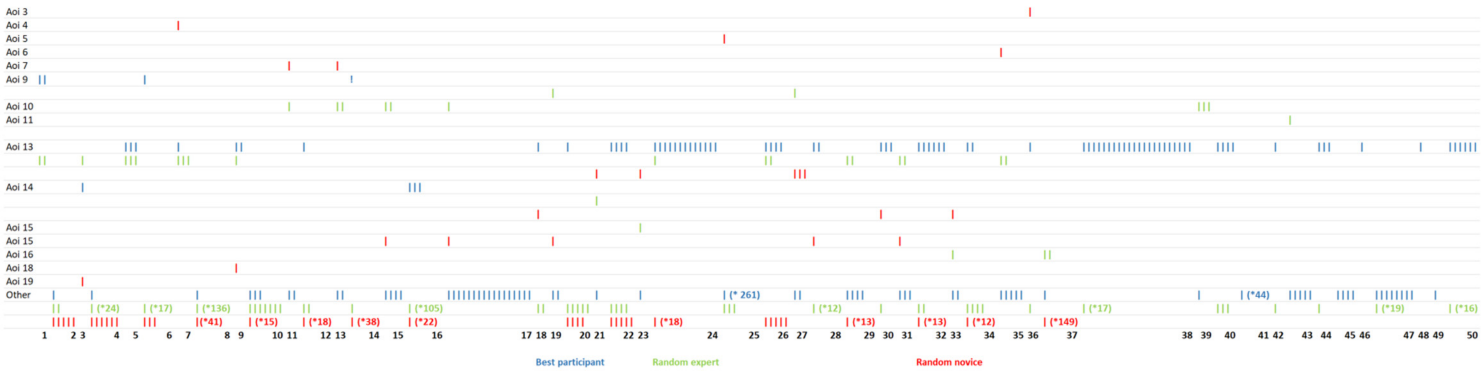

Figure 13. Sequence chart for first 50 visits on satellite map of randomly selected participants.

Figure 14. Sequence chart for first 50 visits on orthomosaic map of randomly selected participants.

3.6. Number of Transitions

In total, there were 71 transitions (defined as the participant switching between the satellite and the reference map) made by eight participants, two novices, and six experts. The experts were responsible for 67 of these transitions. The average fixation durations were in line with those on the satellite map and did not show a significant increase in length, hence indicating that the site maps and the reference map required comparable cognitive processing. For illustration purposes, Figure 15 shows the mean fixation duration (for each medium, namely orthomosaic, satellite, and reference map) for each participant who looked at the reference map—the minor differences preclude any heightened cognitive load between the various map mediums.

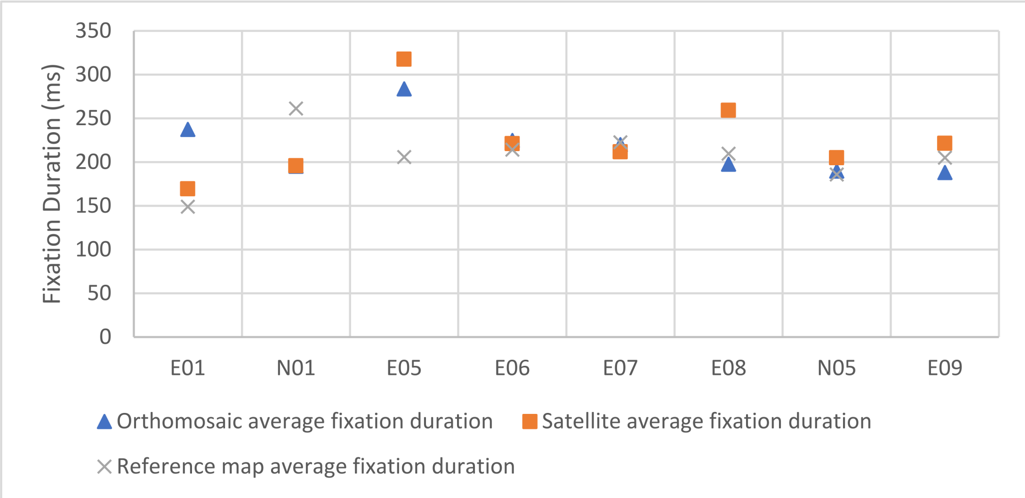

Figure 15. Average fixation duration between orthomosaic, satellite map, and the reference map.

3.7. Participant Performance

Performance was measured as the number of sites correctly identified by the participants. Figure 16 shows the number of experts (blue) and novices (orange) who correctly identified the AOIs or fossil sites. The darker shades on the lower part of the bar shows the number of participants who correctly identified the sire, while the faded upper part shows the remainder of the participants in that group who were unable to identify the fossil sites.

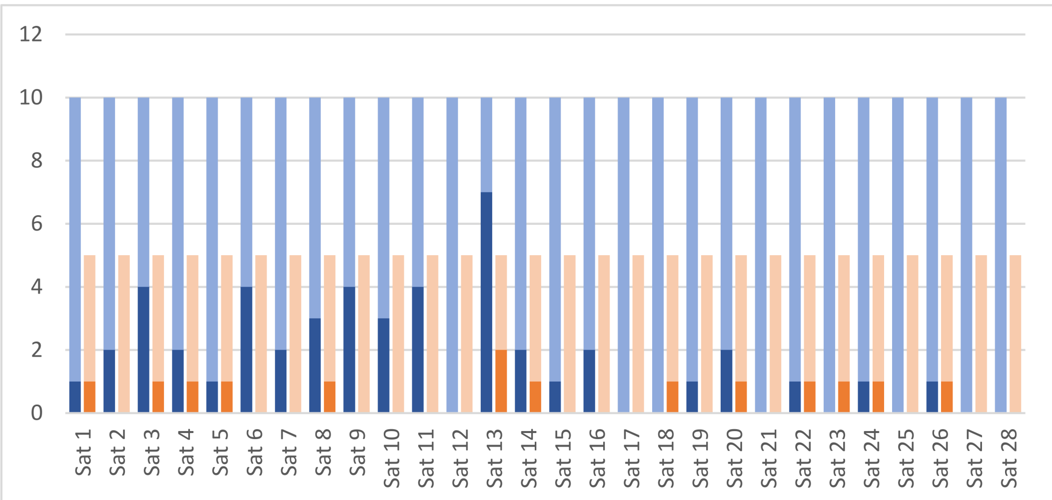

Figure 16. Site identifiers for satellite map.

There were five sites on the satellite map that were not identified by any of the participants (Sat 12, 17, 21, 27, and 28), and a further 12 sites that the novices were not able to identify (Sat 2, 6, 7, 9–12, 15–16, 19, 21, 25). It appears that the novices struggled to identify prospectable sites on the satellite map compared to the experts, even though these were clearly high erosion areas. While the experts performed much better at site identification on this map, even the majority of the sites (Sat 12, 17, 18, 21, 25) here were identified by less than 50% of the experts (apart from site 13). It is particularly interesting that sites Sat 12, 17, 21, and 25 are common between both groups and were never identified as sites that could be prospected. Sat 12 and 25 are unusual sites, located near a river system and on eroded slopes. However, the sites are located near built-up rural areas, which could have resulted in the areas being overlooked. Sat 17 and 21 are suitable locations with all the features required, perhaps because Sat 18 is the end of the mountain range of the area that drew attention and appeared better for prospecting.

On the orthomosaic map (Figure 17), there were only two sites (Drone 21 and Drone 23) that none of the participants were able to identify, one of which was site Drone 21 that no one looked at for the entire duration of the test. Drone 21 and 23 have clearly visible dongas and evidence of heavy erosion—ideal for prospecting. Perhaps because the sites are right on a jagged edge of the drone map, they were overlooked. Site identification was once again much better for the experts than for the novices. The site demarcated Drone 1 was identified by the most participants, and this correlates well with the heat maps, which showed heightened attention in this AOI.

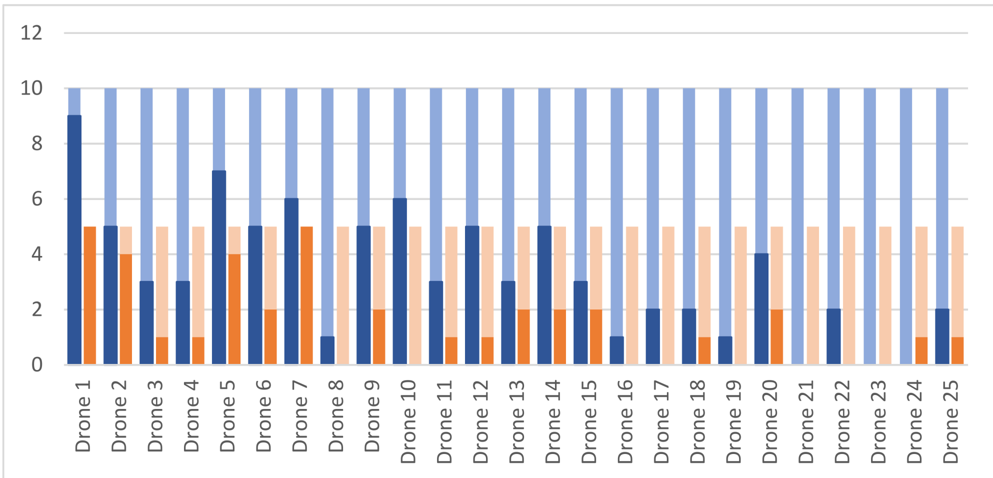

Figure 17. Site identifiers for orthomosaic map.

Overall, it would seem that site identification was improved on the orthomosaic map.

3.8. Subjective Satisfaction

Participants were asked to complete a small questionnaire pertaining to the use of the orthomosaic map. Overall, the reaction to the map was very positive, and participants were enthusiastic about the possibility of using a map such as this in future. Most participants commented on the fact that the detail of the map was high and that it made it easier to find details and features they were looking for.

4. Limitations

As mentioned, the sample size does impact the results of the study, and it would be preferable to extend the study to include more participants. Additionally, no saliency measures were extrapolated for the given maps, based on the assumption that the task would dictate visual selection. Therefore, it would be interesting to generate saliency measures on the map and analyze the attention based on saliency to determine whether it played a significant role in visual selection.

5. Discussion

With fixation durations, it was seen that the longest and shortest average durations were both experts, which suggests that experts will either know exactly what they are looking for and add a point or spend time analyzing features looking for what they want. The orthomosaic and the satellite map had mean fixation durations in the same order; hence, neither of the maps elicited more cognition or concentration to interpret for either novices or experts.

Both expertise levels measured many more fixations on the orthomosaic map compared to the satellite map. Since the fixation durations are no longer for the orthomosaic map, participants had many more fixations of comparable length on the orthomosaic map. The lack of significant difference between expertise levels means that the first hypothesis is not rejected and also confirms the results of prior studies [24]. The features of the map could contribute to differences as seen in [23], but a further more detailed study is required in order to absolutely investigate this possibility.

For both novices and experts, the orthomosaic map had far more returning visits and longer visit durations. Hence, the features on this map both kept the attention of the participants and kept attracting their attention as well. This could be attributed to the increased detail on this map that caused participants to revisit an area (as well as stay within an area for longer) and look for more features. Since results were not significant, the second hypothesis cannot be rejected, but it is cautiously suggested that the different maps do lead to different gaze behaviors. According to [23], the design of a map has a significant effect on map interpretation, but the expertise of the user has little to no effect. The exceptional detail available within the drone orthomosaic map results in a change of gaze behavior, regardless of expertise.

Subjectively, participants reported preferring the orthomosaic map to the satellite map for the increased detail and clear image.

Although no significant differences were found, other than isolated AOIs, virtual prospecting for a fossil site is preferable with the orthomosaic map compared to a satellite map for both experts and novices as evidenced by the increased attention and prospecting behavior exhibited on the orthomosaic map. As mentioned in a prior section, top–down versus bottom–up processing can significantly influence gaze behavior. However, it is asserted here that the almost monotonous tones of the individual map precludes saliency features attracting attention significantly. Hence, the processing would most likely be top–down processing as participants searched for features to complete the task at hand.

However, this research does not want to suggest that the use of drone surveys and orthomosaic maps is a replacement for virtual prospecting using satellite imagery but rather another tool to help paleontologists prospect for fossils. The proposed workflow would assist the paleontologist in virtual prospecting using a satellite map, identifying good prospectable areas and then having a drone survey completed. Then, the resulting orthomosaic map would be analyzed and prospected, and areas identified long before the first paleontologist reaches the site. This process will utilize far less resources than current manual prospecting approaches.

6. Conclusions

Neither expertise nor map type significantly influenced gaze behavior. However, differences between the maps were observed, and some areas showed a tendency to both attract and keep the attention of the viewer. Therefore, map features appear to lead the behavior of the map reader to some degree. Participant performance was better on the orthomosaic map than on the satellite map, with more sites being identified and more participants being able to correctly identify sites. Thus, the increased resolution and clearer image could mean that features are more easily identified and recognized. An orthomosaic-based drone map used in conjunction with a satellite map is a useful tool for high spatial density virtual prospecting for novices and experts. The ability to drone survey an area and then analyze the map for fossil sites to prospect within a lab environment has the potential to open far more sites.

Future work would be determining not only where a participant fixated but the context as well. This could answer questions such as where they are looking and why.

This research provides an understanding of what a paleontologist looks for, and how, when prospecting for fossils using a satellite or drone map. The next step would be to extract these features and create an algorithm to determine prospectable fossil sites automatically. The approach is usable by both novices and experts; therefore, the tool could be considered for training purposes.

Author Contributions: Conceptualization, Tanya Beelders and Gavin Dollman; methodology, Tanya Beelders and Gavin Dollman; formal analysis, Tanya Beelders; data curation, Tanya Beelders; writing—original draft preparation, Tanya Beelders; writing—review and editing, Tanya Beelders and Gavin Dollman; visualization. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of University of the Free State UFS-HSD2018/1490/2020 October 2018.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to intellectual property rights.

Acknowledgments: The authors would like to thank Jonah Choiniere and he's laboratory of the Evolutionary Studies Institute at the University of the Witwatersrand for the assistance and mentorship during the composition of the orthomosaic map.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Figure A1. AOIs on the satellite map.

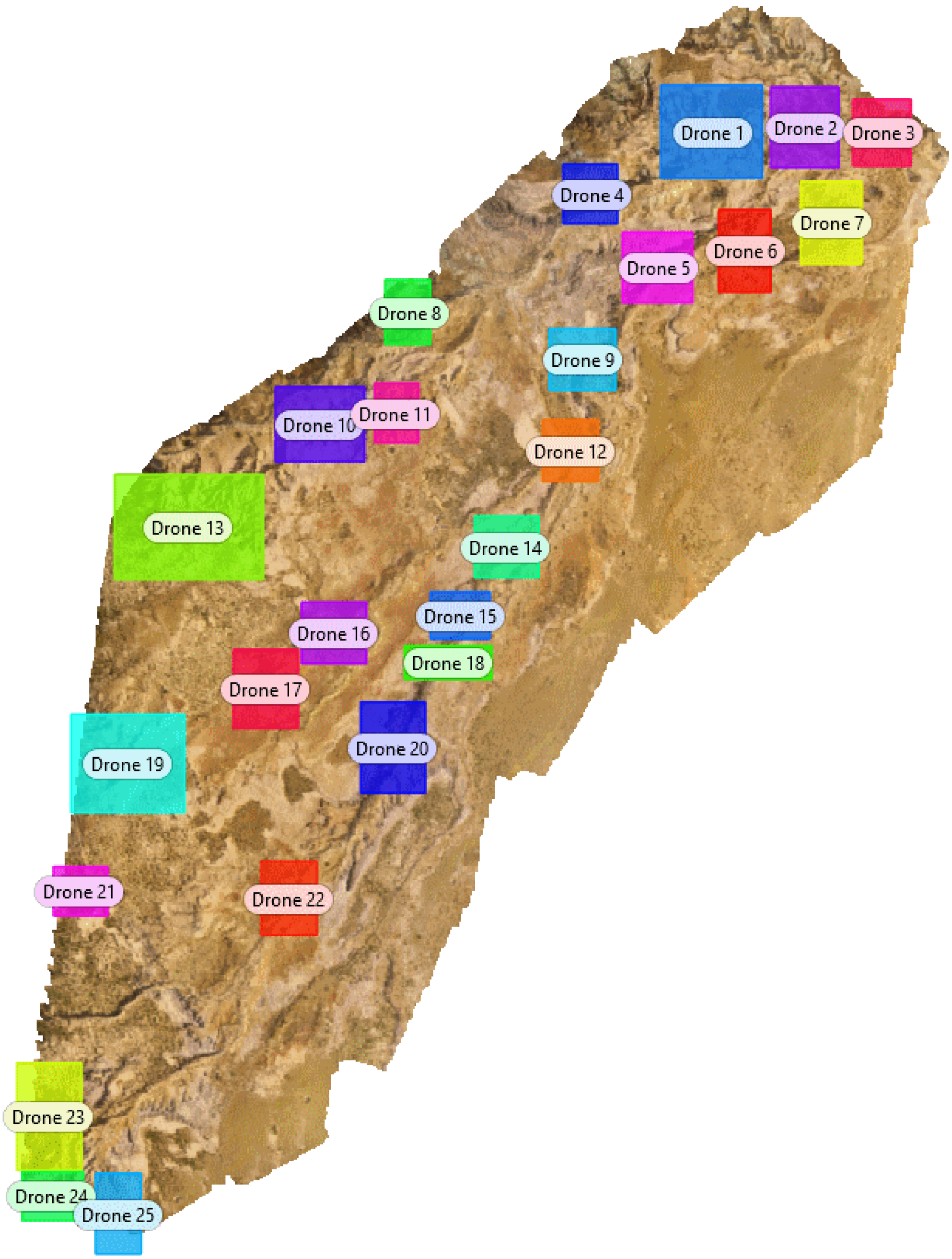

Figure A2. AOIs on the orthomosaic map.

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