The value of eye-tracking technology in the analysis and interpretations of skeletal remains: A pilot study

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Abstract:

This initial study is the first to use eye-trackers as a tool in order to study gaze pattern strategies and decision making processes involved in the assessment of skeletal remains. Three experienced participants were asked to wear eye-tracking glasses (Tobii Pro Glasses 2) when estimating sex and age-at-death of one set of skeletal remains from a known archaeological sample. The study assessed participants' fixation points (the features of the skeleton focused on), fixation duration (the total time spent on each assessment and feature) as well as visit count and duration (the total number of visits and the duration of visits to particular areas). The preliminary results of this study identified differences in gaze "strategies" with regards to fixation points, visit duration, and visit counts between the participants. The data generated provide a starting point for assessing how such technologies could be used in order to more fully understand the decision making processes involved in forensic anthropological interpretations and their role in forensic reconstructions.

Keywords: Forensic science, forensic anthropology, eye tracking, decision making, sex estimation, age at death estimation,

1. Introduction

The study of human factors and their implications on forensic science reconstruction have gained increasing levels of interest within recent years. The growing recognition that expert decision-making is influenced by cognitive processes has led to an increase in research studies specifically focused on applying different judgment and decision making theories to increasing our understanding of the how scientific evidence is interpreted in forensic reconstruction approaches [1,2]. This has led to research within the expertise, decision making and situation awareness literature shifting its focus to not only concern human judgments in the social, psychological, and behavioral economics domains, but also within, law enforcement agencies, and forensic science disciplines [3–10].

To address the specific issue of reproducibility and accuracy of measurement taking, some of the published research conducted within forensic science has highlighted the use of modern technology in forensic investigations in order to create new approaches for robust scientific measurements [11]. Such techniques have included the use of eye-trackers to further understand how experts go about visual tasks particularly in terms of the reliability and reproducibility of methods. Within forensic science this has specifically focused on handwriting documentation [12] finger mark comparison tasks [13], criminal line-up identification [14] crime scene investigator practice [15,16], and blood pattern analyses [17].

In a similar manner to other forensic domains, the methods used in the creation of a biological profile and positive identification of skeletal remains are based on visual tasks. Therefore, some of the recent published studies that have been carried out within forensic anthropology have focused on gaining a better understanding of the underlying processes of the decisions being made, and the potential cognitive influences that may impact the routinely employed visual methods [10,18]. However, no published research to date has used eye tracking as a research tool in order to further understand the decision-making strategies associated with the way information is visually extracted when conducting analysis on skeletal remains.

The aim of this paper is to provide insight into the application of eye tracking technology in forensic anthropology. First, an overview of key research that has been conducted within forensic science and the use of eye tracking technology in other fields is presented. Then the findings of an initial pilot study in which eye-tracking technology was deployed to assess the potential of this form of technology to be used to study visual tasks in forensic anthropology. The study used wearable eye-trackers, Tobii Pro Glasses 2 (https://www.tobiipro.com/product-listing/tobii-pro-glasses-2/) where participants were asked to conduct a biological profile/osteobiography focusing on sex and age-at-death assessments. Therefore, the purpose of this pilot study is to explore how such technologies may be used in visual skeletal assessments and how future studies within forensic anthropology could use eye tracking technology as a tool to help understand human decision making in method applications, in addition to how to improve method development and training, rather than to explain decision-making in forensic anthropology *per se*.

1.1 Eye-tracking technology and Forensic Science

Eye tracking is an advanced behavioral research technology that makes it possible to capture the visual experience of a person in any professional context. The use of eye-trackers as a research tool has increased in recent years, with a growing interest from a number of different disciplines [19]. Eye-trackers are measurement devices used to capture eye-movements and have been applied to assess tacit knowledge from human experts and their performance [20]. Groundbreaking research has shown that the human eye movement focuses on parts of a scene that offer relevant information [21,22].

The technology specifically enables the collection of data related to the visual and attention processes involved in a specific task, looking at certain areas of interest (AOI), which allows a measurement to be taken of how long the attention of the participant is captured on a specific attribute [23] . Traditional usability methods (e.g. interviews, thinking out loud) depend very much on explicit data and the ability of the subjects to assess, remember and verbalise what they have done and why. Although these techniques can provide helpful insights, there are however limitations when trying to study decision making strategies in these ways. In comparison, with eye-tracking technology the data collected has significant potential to further our understanding of the visual attention of a participant, ultimately revealing information about human perception, cognition and the decision-making process that are based on gaze behavior [20].

Much of the research being conducted using eye-trackers has been within the areas of psychology [20], performance sports [24] , psycholinguistics [25], marketing [26] , aviation [27], engineering [28], gaming and entertainment [29], as well as medicine and medical technology [30]. Although eye-tracking technology has been applied within these fields for various reasons, many of the studies have focused on proficiency testing of experts and how experts (compared to novices) undertake a task [31]. For example, research within the medical domain has shown that experienced surgeons spend more time fixating on task relevant areas than novices [32]. Equally, in studies related to mammograms, eye-tracking technology revealed not only what features radiologists rely upon when inspecting the image, but also provided insights into the holistic processing and cognitive mechanisms involved when experts are viewing mammograms and reaching conclusions [31].

Within forensic science however, the use of eye-tracking technology as a tool to study forensic decision making has been largely underutilised, with only a few published studies conducted to date. For example, in handwriting documentation, studies have shown that forensic document examiners (FDE) perform significantly better on the task given compared to lay people when analysing signatures for authenticity [12,33]. Although both groups had similar mean fixations on different areas of interest (showing a similar amount of time making decisions when calling the different types of signature) the expert group still performed higher [12]. Similarly, studies within consistency and variability amongst latent print examiners also found that under time controlled circumstances, experts were more consistent as a group than novices when inspecting latent prints, having a higher accuracy, as well as spending a greater proportion of time in search patterns under certain conditions [13].

Eye-tracking technology has also been used in order to further understand volume crime scene investigator practices. One study explored the differences in searching strategies between expert and novice crime scene examiners, showing that experienced crime scene examiners (compared to the novice group), targeted fewer items within the crime scene but did however spend a longer time on the item being viewed [15]. Furthermore, a recent study in evidence recognition and crime scene investigation showcased the use of mobile eye-trackers, and identified differences in search duration and search sequence approaches between experts and inexperienced novices when processing a mock crime scene [16]. The study observed that experts had greater similarities in search sequences compared to the novice group. Conversely, this was not the case when it came to search duration where the expert group showed a greater dissimilarity compared to the novice group.

In addition, eye-trackers have also been used as a tool for gaining access to the gaze patterns and decision-making strategies involved in blood pattern analyses [17]. In this study eye-tracking technology was used to collect data from 24 blood pattern analysts whilst inspecting bloodstain patterns from a laboratory generated task. The result of the study gave further insight into experts gaze fixations and areas of interest when analysing bloodstain patterns [17].

1.2 Eye tracking technology and Forensic Anthropology

In a similar manner to forensic comparative examinations, forensic anthropologists rely heavily on well established visual methods when conducting the task of creating a biological profile. Some of the most common methods used are based on visual assessments of skeletal remains where information from the skeleton can aid in answering questions regarding sex, age at death, ancestry, stature and circumstances around and after time of death [34,35]. To some extent, this practice takes full advantage of the human perceptual system. Although there is a growing body of research addressing the application of technological advances to study bones [36] currently however, there is a limited understanding of how technology could be used to study the visual patterns and processing involved in the human interpretations of skeletal remains. Understanding the underlying processes of the decisions being made and potential cognitive influences on the decision-making critical to the application of the visual methods currently in place is therefore, important.

This initial pilot study explored the utilisation of eye-trackers as a means to study visual attention among experienced practitioners within the field, and how this might have an impact upon which traits are focused on when making interpretations of skeletal remains, using Tobii Pro Glasses 2. This study sought to assess the capabilities of using eye-trackers as a tool in studying visual strategies involved in the assessment of skeletal remains, and to ascertain how eye-movements and visual processing of information could potentially be used in order to study evaluations of skeletal remains. There was a specific focus on visual (non-metric) sex and age-at-death assessment approaches used within the field of forensic anthropology and specifically addressed:

- Fixation points (what features experts focuses on),
- Fixation duration (how much total time they spend on each assessment and features)
- Visit count and duration (the number of total visits and duration to particular areas)

By addressing the fixation points, fixation duration and visit count it was possible to gain more insight and detail into where participants look during an assessment, based on the visual methods used in sex estimation and age at death, and whether they spend more time on certain methods and morphological traits, in addition to understanding whether participants have certain areas of interest that they go back to during their assessments. This was particularly important for establishing a starting point (baseline) of how such technologies could be applied when looking at some of the most common visual assessments used when creating a biological profile. This is particularly pertinent since the biological profiling traits used here are very popular ones, and are often applied from memory, based on experience, sometimes even without reference to a reference text.

2. Methodology

2.1 Research design and Materials

Participants in this study were asked to analyse one set of skeletal remains taken from a known archeological sample. Participants were asked to establish a biological profile/osteobiography with a special focus on sex, and age-at-death. In addition to this, participants were also told that they could make any further observations about possible ancestry, stature, trauma, pathology, and taphonomy. The remains were in fairly good condition, with the majority of the skeletal elements present. For example, the skull (and mandible), and the left os coxa were complete, which made it possible for participants to conduct sex, and age at death estimations using non-metric methods. Participants were asked to wear the Tobii pro eye-glasses whilst conducting the analysis on the skeletal remains. The Tobii Pro eye-tracking camera recorded the eyes of participants during the task and the pattern of visual attention, with the illuminator in the eye-tracking glasses creating a pattern of near infrared light on the eyes. In this way it was possible to identify the focus points on the skeletal remains of each participant.

2.2 Participants and Procedures

A total number of three participants took part in this pilot study wearing the eye-tracker. All three participants had extensive experience within forensic anthropological/osteological methods as well as casework experience in archeology/osteology in addition to forensic casework (for two of the participants), albeit from a European perspective (see table 1).

In order to minimise any potential influence on the decision making process, participants in this study were not asked to follow a specific biological profile form, stating what methods to use and in what order to conduct the assessments. Instead, participants were asked to establish an osteobiography by applying whatever widely accepted methods they felt most comfortable to apply. Participants were also told to not undertake any analysis or apply any methods that they were not trained in. In this way the study sought to address real world practice as closely possible. Participants were asked to log their decision making process and the methods they used in a notebook. This not only allowed for a more detailed understanding of the decision-making process of the participants and their initial hypothesis (in addition to the eye-tracker), but also revealed the specific methods within the biological profile to focus on (for the purpose of this study) when comparing the data between the participants. This resulted in comparisons only being made on the methods that all three participants applied, resulting in only focusing on areas of interest on visual non metric tasks in sex assessments on the skull, and the os coxa, as well as age at death using the pubic symphysis [37–39]

Each participant conducted the analysis separately in a laboratory with all the necessary equipment and reference materials provided with no specific time limitations.

2.3 Analysis

Tobii™ offer state of the art eye tracking technology and lightweight hardware, which are widely applied in many different domains and international settings. The software program Tobii Pro Lab was used in order to analyse initial gaze patterns of the participants separately, as well as a group, in order to look at the fixation points, fixation duration, and visit count and duration of each participant.

3. Results

Table 1.

Participant Summary

	P1	P2	P3
Highest degree of education	PhD	MSc	PhD
Educational Background	Biological anthropology/archeology forensic anthropology	Biological anthropology/archeology	Biological anthropology/archeology forensic anthropology
Forensic case work experience	Yes	No	Yes
Archaeological case work experience	Yes	Yes	Yes
Member of a professional body	Yes	Yes	Yes
Method preference	Non-metric	Both metric and non-metric	Metric

3.1 Time spent on Biological profile (sex assessment on skull and os coxa)

Table 2 shows the breakdown for the total time each participant spent on completing the full task of the biological profile, as well as the total time spent on sex assessment for skull and os coxa. In addition, participant examination points (and average time spent on each examination point) are also shown.

Participant	Total time of full inspection	SKULL	Amount of examination points	Average time per examination points
Rec P1	125 min	5,3 min	22	14,4 sec
Rec P2	69 min	6,6 min	35	10,9 sec
Rec P3	83 min	3,7 min	17	13 sec

Participant	Total time of full inspection	OS COXA	Amount of examination points	Average time per examination points
Rec P1	125 min	10,7 min	35	17,4 sec
Rec P2	69 min	2,7 min	22	7,6 sec
Rec P3	83 min	6 min	10	36 sec

3.2 Number of examination points sex assessment skull and os coxa

Figures 1 and 2 show the examination points of the participants when making sex assessments on the skull (fig 1) and the os coxa (fig 2), the number of examination points for each participant, in addition to average time spent across all participants per occasion for each point. The results show that the average time per occasion spent on each trait (across all participants) for the skull (12.76 sec) was lower than average time spent per occasion on each trait for the os coxa (20.3 sec). In addition, the results also show variations in the number of examination points for each participant, and how often they go back to a certain trait. This is especially notable for participant number 2 on the majority of the skull traits, and participant number 1 on the os coxa examination.

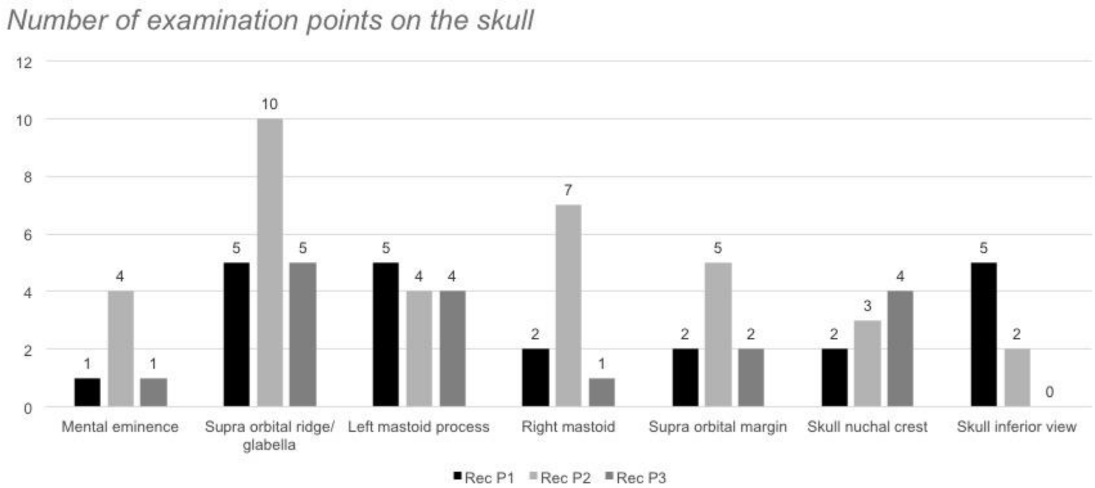

Fig. 1 showing the number of examination points of the participants when making sex assessments on the skull

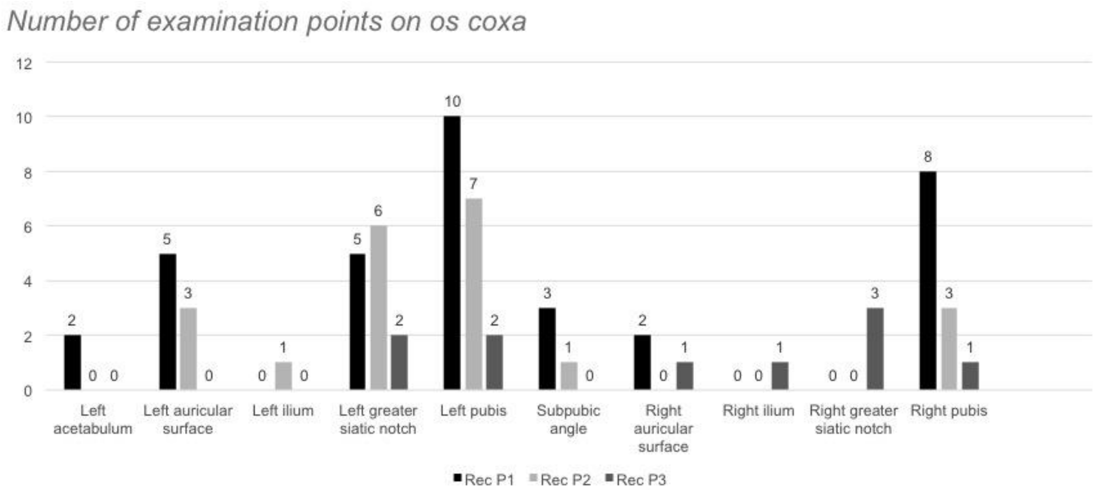

Fig. 2 showing the number of examination points of the participants when making sex assessments on the os coxa

3.3 Time spent on Age at death assessment os pubis

Table 3 shows the breakdown for the total time each participant spent on completing the full task of the biological profile, as well as the total time spent on age at death.

Participant	Total time of full inspection	Age at death	Amount of examination points	Average time per examination points
Rec P1	125 min	4 min	20	12 sec
Rec P2	69 min	4 min	27	12 sec
Rec P3	83 min	2.5 min	25	6 sec

Number of examination points age at death assessment pubis symphysis

Figure 3 shows the examination points for each participant when undertaking the age-at-death assessment on the pubis symphysis area, including the number of examination points for each participant, in addition to the average time spent by all participants per occasion for each point. The results show that the average time spent on each examination point was 10 sec with some variation in number of examination points across all three participants. For example, participant number 2 looked at the inferior extremity almost twice as much as participant number 1 and 3 whilst participant number 1 only looked at the ventral border once compared to participant number 2 and 3, who both looked at the same feature multiple times (5 and 6 times respectively).

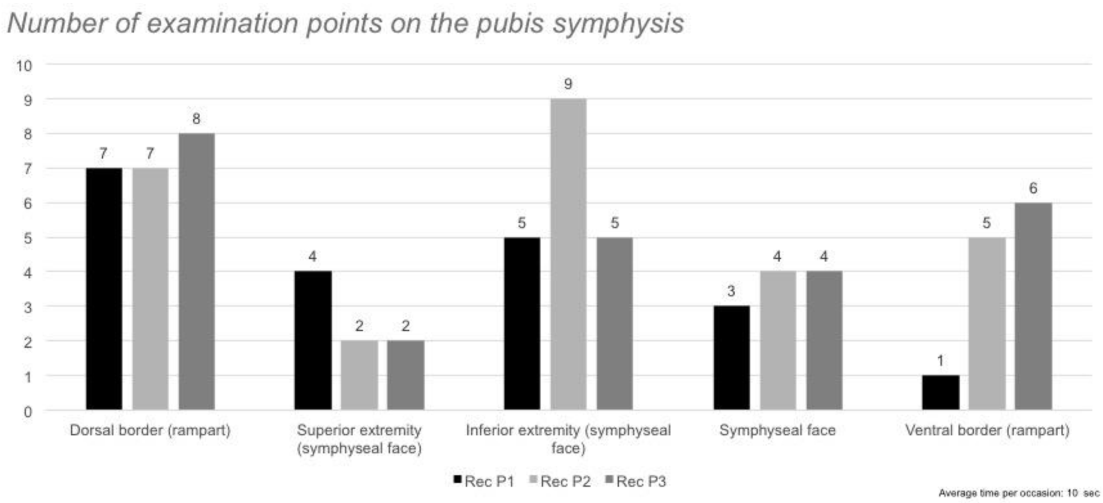

Fig. 3 showing the number of examination points of the participants when making age at death examinations on the os pubis

4. Discussion

This initial pilot study was designed to assess the potential application of eye tracking technology in forensic anthropology, in the hope of creating an initial baseline of how such technology could be applied in visual methods used in sex and age-at-death estimation. A small dataset was collected for this initial study and therefore the study was limited in terms of statistical analysis, and hence it was not feasible to generalize to a broader sample from this dataset. In addition to this, the dataset only focused on visual methods used on the skull and the os coxa, added to one visual method used in age at death, with no metric methods studied. Nonetheless, the fact that results were successfully collected and that differences across the participants were identifiable demonstrates the feasibility of this approach at a larger scale. The fixation points, fixation duration and visit count will therefore only be discussed from an 'applied' point of view, in terms of showing what data could be collected, and how forensic anthropologists could use eye tracking technology in order to study the interpretation of skeletal remains. There is clearly scope for collecting larger datasets that could be used to explore other avenues within this field in the future.

4.1 Fixation points

The eye-tracking data show that there were differences in gaze "strategies" with regards to fixation points, visit duration, and visit counts across participants. The initial results suggest there are variations in how participants within the field go about the same task, and possibly also what features they focus on more (or less) when making interpretations in sex and age at death estimations.

For example, in sex estimation of the skull, participant 2 spent more time going back to certain AOI (such as, mental eminence, supra orbital ridge/glabella, right mastoid, and supra orbital margin) compared to participants 1 and 3. Similarly, variation on the number of examination points were also observed in sex estimation of the os coxa, showing for example participant 1 going back to certain AOI to a greater degree compared to participant 2 and 3 (e.g. left auricular surface, left pubic angle, right pubis). Equally, in age at death estimation, the ventral border (rampart) was only looked at once by participant 1, compared to that of participants 2 and 3 who looked at the same feature multiple times. In addition to this, the results from the fixation points also indicate that certain AOI are not looked at by all participants. For example, in sex estimation of the skull, participant 3 didn't once look at the skull from an inferior view, compared to participants 1 and 2. Likewise, similar results were observed for sex estimation of the os coxa, where certain AOI were being 'ignored' by participants.

The variation in number of examination points, time spent on each feature, and which features are being processed identified in this pilot study opens up avenues for future studies in forensic anthropology, exploring how such technology could be used in order to study gaze pattern variations, and hopefully their meaning in the interpretation of skeletal remains. For example, all three participants from this study reached the same final conclusion on sex estimation and age-at-death for the skeletal remains, (despite the observed variations in gaze strategies and certain AOI being ignored) arguably meaning that the preliminary results in task variation, (in terms of what areas analysts were mostly interested in, how long they spent on each feature, as well as how many times they went back to certain areas of interest in order to draw inferences) did not necessarily impact the final conclusions of sex and age-at-death of the skeletal remains. This could be due to a variety of reasons, and further research is necessary to explore these in greater detail. For example, the skeleton used in this pilot study was from a known archeological sample, with the majority of the skeletal elements being intact and in good condition, arguably creating a straightforward, analysis for the experienced participants, where the variation in time spent on each morphological feature within the method and when not ignoring certain features did not 'impact' their interpretations. Future studies could look into more complex scenarios (e.g. fragmented, partial and ambiguous skeletal remains) in order to study if, and under what conditions, gaze pattern variations may impact interpretations and final conclusions. Furthermore, participants in this pilot study were experienced practitioners. Similar to other studies within consistency and variability [12-13, 15, 33) future research could build upon this baseline to compare the gaze pattern strategy differences between experienced practitioners and novices, in order to study to what extent expertise plays a role in where experts are looking, against what information is available.

4.2 Fixation duration, and visit count

When looking at fixation duration, it not only showed that participants were spending differing amounts of time individually completing sex and age at death estimation, but also that there was a difference in the average time across sex and age-at death estimation. For example, participants spent more time on average on examination points of the os coxa (20.3 sec) compared to the skull (12.7 sec). This may not be surprising as the os coxa is known for having a higher accuracy in visual sex estimation compared to the skull [40], hence why participants may have spent longer on average looking at the os coxa. In addition, when making interpretations, participants were spending only seconds on each feature across sex and age at death, perhaps showing a fast and frugal decision making process. It has been argued that with experience and expertise, comes automaticity, where experts use schemas, selective attention, as well as chunking information, to allow them to perform quickly and efficiently [41]. All three participants in this study had experience with the methods used, (as they specifically chose methods they were familiarised with) which could arguably be the reason for spending a short amount of time on each feature.

Eye-tracker approaches have the potential to be utilised to empirically measure the extent of visual attention used in complex tasks in order to further our understanding of the cognitive mechanisms involved in forensic interpretations. However this is a complex phenomenon and it is difficult to relate the observations made during these tasks to the cognitive processes involved in the eye movement, especially when dealing with a limited sample size. In forensic anthropology, challenging interpretations of skeletal remains could reasonably depend on the experience of the observer, the nature of the observer's training, the ambiguity level of given characteristics being interpreted (e.g. what features of the skeleton is present for analysis), difficulty of the judgment (e.g. burnt, fragmented, or comingled remains) as well as the context in which the judgment is being made. Therefore, there are many variables involved in how inferences are made. However, the findings from this initial study indicate that there are some interesting trends, and future studies incorporating a larger number of participants and different levels of experience have significant potential to offer valuable insights. Eye tracking technology therefore has promise as an additional tool to study decision making strategies involved in the assessment of skeletal remains, particularly given that the participants in this study did not find the eye-tracker kit distracting or intrusive, thereby enabling 'normal performance' during the tasks to be observed.

This initial study only focused on visual (non-metric) analysis of sex and age at death. In future studies it will be possible to assess how this technology could be used in the interpretation processes in both metric and non-metric assessments, (in addition to new method development). It appears to be possible to target potentially confusing or problematic aspects of a particular method, and develop valuable training approaches. More importantly, undertaking further empirical research that builds on this approach and these findings will generate data that will aid a greater understanding of which factors lead to and influence the interpretations reached in the assessment of skeletal remains. Developing a greater understanding of the how different actions are incorporated into decision making and reaching final conclusions, offers significant potential for greater clarity in the communication of the evaluative interpretations of experts that have been derived from their observations, analyses, and reconstruction conclusions These future developments also offer value in terms of the potential to apply these findings beyond forensic anthropology to other forensic science domains where expert decision making is (and will remain) integral to forensic reconstruction approaches.

5. Conclusion

This initial pilot study is the first to use eye-trackers as a tool in order to study gaze pattern strategies involved in the assessment of skeletal remains. Notwithstanding the limitations of an initial study, the preliminary results of this study show how eye-tracking data could be used successfully to further understand how experienced practitioners within the field of forensic anthropology go about the same task and the attributes of expert decision making that can be identified to inform training and continuing personal development. The study offers insights into the empirical variations observed in fixation points, fixation duration and visit counts of the analysts when making interpretations of the skull and the os coxa for sex and age at death estimation.

The data generated here offer a starting point for establishing how such technology may be used in order to develop our understanding of the decision-making processes involved in forensic anthropological interpretations more fully and inform the analysis, interpretation and communication of forensic science intelligence and evidence in anthropology and other forensic science domains. Further studies with larger sample sizes and different levels of expertise are needed in order to fully assess the visual attention processes involved in skeletal assessments, to ultimately reveal valuable insights and information about human perception, and the decision-making process that are based on gaze behavior. To date, eye-tracking technology has been highly under-utilised within forensic science. However, this study demonstrates that engaging with eye-tracking technology has the potential to be used further as a research tool in order to help the forensic anthropology community (in addition to other fields within forensic science) to study how inferences have been reached and the basis for the conclusions made [42,43].

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