Assessing the feasibility of estimating the age and sex from virtual 3D models: A pilot study into virtual forensic anthropology.

ABSTRACT

Virtual anthropology is an ever-growing sub-field within forensic anthropology that is being applied across a variety of forensic anthropological research areas (Franklin et al, 2016). However, no previous studies have investigated the impact of participant confidence levels in analysing 3D virtual skeletal models. This study explores the feasibility of estimating sex and age from 3D virtual skull and os coxa models, aiming to investigate the feasibility of moving the field of forensic anthropology into virtual lab spaces. A total of 71 participants completed an online survey requiring analysis of published virtual 3D skeletal models. Participants were asked to rate their confidence in the methodology and overall sex/age estimation, as well as preference for assessment method for each skeletal model. Statistical Analysis revealed that level of experience in analysing dry bones was found to not be associated with higher confidence in analysing 3D virtual remains (p=0.360 for sex of skull; p=0.494 for sex of os coxa; p=0.845 for age of os coxa). Confidence ratings for students in analysing skeletal remains in person did not predict perceived difficulty of analysing 3D virtual skeletal models (p=0.717 for sex of skull; p=0.579 for sex of os coxa; p=0.733 for age of os coxa). Prior 3D virtual experience did make a difference in confidence levels in the estimation of skull-sex and os coxa-age models (p=003 and p=0.001). Yet, prior 3D experience did not impact confidence levels with os coxa-sex (p=0.093). To provide insight into the results, the social cognitive concept of the ‘self-efficacy’ theory is discussed.

KEY WORDS: Forensic anthropology; Virtual anthropology; 3D skeletal models; Os coxa; Skull; Self-Efficacy.

HIGHLIGHTS

- Training in virtual anthropology is needed for teaching and research.
- Inability to touch and feel when analysing dry bones may lead to uncertainty when analysing virtually.
- Positive or negative prior experience may influence confidence level and experience in analysing 3D models.
- Increased self-efficacy levels is needed before ‘virtual labs’ can be established.

Introduction

Since the start of the 21st century, the deployment of three-dimensional (3D) digital imaging techniques within forensic research and case analyses has increasingly been reported (Errickson et al., 2014; Garvin et al., 2018; Carew & Errickson, 2019). 3D technologies, such as optical surface scanning, (Sholts et al., 2010) or computer tomography (CT), (Decker et al., 2011) have contributed towards the field of forensic anthropology, due to the utilisation in creating 3D virtual models of skeletal elements (Garvin & Stock, 2016; Uldin, 2017). This application of 3D virtual models within forensic anthropology has led to the new sub-field known as 'virtual anthropology' (Weber, 2001), which has assisted in such research as questions regarding individual biological profiles (Telmon et al., 2005; Grabherr et al., 2009; Ramsthaler et al., 2010; Decker et al., 2011; Lottering et al., 2013; Villa et al., 2013; Belford et al., 2018; Colman., 2019; Kuzminsky et al., 2019).

The advantages of applying 3D virtual skeletal models within forensic anthropology has allowed the creation of virtual skeletal databases and perhaps even a 'virtual lab space' to become more conceivable (Franklin et al., 2016; Simmons-Ehrhardt, 2021). Such an innovation could allow for regular development and testing of forensic anthropological methods in estimating biological profiles, due to having large sample numbers, data from modern individuals, and increased representation of different biological and lifestyle influences than historical skeletal collections (Villa et al., 2019). Moreover, virtual lab spaces may offer the opportunity for enhancing training for students, forensic anthropologists, bioarchaeologists and osteologists, via universal, global data sharing (Kuzminsky et al., 2019).

In addition, researchers have begun to examine the feasibility and reliability of the use of 3D virtual bone models for the estimation of biological profiles (Barrier et al., 2009; Ramsthaler et al., 2010; Villa et al., 2013; Wink, 2014; Kuzminsky et al., 2019). Specifically, studies have focused on 3D visualisation of the skull or pelvis for sex or age estimations, with several publications highlighting the benefits of 3D virtual bone models within forensic anthropology (Telmon et al, 2005; Dedouit et al., 2007; Grabherr et al, 2009; Decker et al, 2011; Lottering et al., 2013; Colman, 2019). Sex and age estimation are two important components in the biological profile as (i) with sex estimations, it is often the first assessment performed when establishing a biological profile, particularly as the application of certain profiling methods are dependent on the sex estimation (Colman, 2019); and (ii) age-at-death estimation may further narrow down the search pool of potential victims among missing individuals (Christensen et al., 2014). Age and sex estimation methods rely heavily on the interpretation of morphological traits from the skull and pelvis, with adult age estimation techniques focused on the assessment of degenerative skeletal changes (Ubelaker & Khosrowshahi, 2019). Whilst there are more recent computational methods for the estimation of biological profiles, such as statistical shape modeling (Mahfouz et al., 2017; Audenaert et al., 2019; Ebert et al., 2022), the traditional methods still hold value in working as existing methods.

While studies have focused on identifying the accurate portrayal of morphological traits on 3D virtual models or examining to what extent existing age and sex estimations could be applied to 3D visualisations of the bones (Telmon et al., 2005; Grabherr et al., 2009; Kuzminsky et al., 2019), previous studies have not analysed how confident observers are in using forensic anthropological methods on 3D virtual skeletal models. More specifically, if level of experience within the methods will result in higher confidence in applying and analysing such methods on 3D virtual skeletal models. Additionally, studies have also not analysed the confidence levels of participants who have had prior experience in analysing 3D virtual skeletal models. Understanding how experience could play a role in the confidence of participants could be vital for examining the social cognitive affects at play during examination of models (Bandura, 1977; Bandura, 2002; Middleton et al., 2019; Schuck & DiBenedetto, 2020). The concept of self-efficacy is a major factor in determining behavior only when sufficient incentives exist to act on one's self-perception of confidence and when possessing the requisite skills (Bandura, 1977; Bandura, 1986; Moritz et al., 2000; Sharma & Nasa, 2014). Research has shown that an important factor in establishing academic outcomes is through self-efficacy (Chemers et al., 2001; Richardson et al., 2012; Eakman et al., 2019). Notably, self-efficacy also has a big role within online education (Pumptow & Brahm 2020), whereby the ever-changing progress of technology and its pedagogical use may require a change in teacher self-efficacy (Bandura 1997). Understanding self-efficacy within an academic setting is essential due to its significant effect on participant aims, effort, motivation and achievement (Kundu, 2020). Additionally, research has not begun to investigate whether-virtual lab spaces could be an appropriate platform for students to enhance biological profile training. Access to virtual lab spaces is important due to our reliance on technology and the advantages virtual models could bring during uncertain times when students and forensic anthropologists are unable to access physical laboratories, or travel to access large physical collections (Thompson et al., 2020).

Although other studies have looked at the feasibility of the use of 3D virtual skeletal models as proxies for real bone (Grabherr et al., 2009; Colman, 2019; Kuzminsky et al., 2019), not many have looked at the observers confidence in skillsets of transferring osteological and forensic anthropological methods to 3D models. Additionally, most published studies have not focused on the aspect in whether establishing a virtual lab space could be applicable as a learning platform for students. Hence, the aim of this initial study was to explore the feasibility of carrying out morphological age-at-death and sex assessments from 3D virtual skull and pelvic models, and determine whether 3D virtual skeletal models can offer a suitable approach to moving the field of forensic anthropology into virtual lab spaces. This study comprised of three research questions:

(i) Will participant experience levels in analysing skeletal remains in person relate to their confidence in estimating the sex and age of virtual skull and os coxa models?
(ii) Will participants who have had prior experience in analysing 3D virtual skeletal elements of the os coxa or skull have a differing level of confidence in analysing the 3D virtual skull and os coxa models in this study?
(iii) Will utilizing 3D virtual skeletal models be feasible for teaching students sex and age estimation methods on the skull and os coxa?

Methods and Materials

Research Design- Online Survey

To explore the feasibility of carrying out age-at-death and sex assessments from 3D models, a qualitative survey was disseminated. This survey was designed using Qualtrics (Qualtrics Provo, UT), an online survey platform, using a sharable web-link sent out to eligible participants through a participation recruitment sheet. The survey incorporated published virtual 3D skeletal models from the online platform ‘Sketchfab’ (Sketchfab.com), which hosts 3D content for reference and sharing, sharable under the Creative Commons License (Panconesi & Guida, 2021). Two links to the ‘Sketchfab’ models were embedded into the survey, one for assessing a 3D os coxa model and one for a 3D cranium with articulated mandible (hereafter referred to as the skull), which, by using open-source data, took the participants directly to the appropriate webpage. All responses were recorded anonymously with no identifiable data collected. Data collection was ongoing over a period of two months.

Material- Sketchfab 3D Virtual Skull and Os Coxa Model

The 3D skull model was derived from a modern known skeletal collection (Terry collection 815 and was logged down as 'female, 32-years of age, of African ancestry' by the owner) (Figure 1) (Modern Human (TC 815) Skull- 3D model by pbeardley [Sketchfab.com]. 2017 [cited 2021 Sep. 5]: Available from: https://sketchfab.com/models/9e8fb082012849ed8bbc990a56df9c57/embed?autostart=1&preload=1&ui_controls=1&ui_infos=1&ui_inspector=1&ui_stop=1&ui_watermark=1&ui_watermark_link=1). This model was chosen based on all morphological features present for conducting sex estimation. Participants were asked to assess the sex and associated morphological features of this skull. The 3D model used for sex and age-at-death estimation of the os coxa was taken from a virtual model produced by the University of Durham Department of Archaeology (Figure 2) (Os Coxa (Pelvis)-3D model by Durham University [Sketchfab.com]. 2019 [cited 2021 Sep. 5] Available from: https://sketchfab.com/models/b040d32aba784d6c837dcbb7c4606479/embed?autostart=1&preload=1&ui_controls=1&ui_infos=1&ui_inspector=1&ui_stop=1&ui_watermark=1&ui_watermark_link=1).The os coxa model did not have any supplementary information about the individual attached but did have all morphological features present on the model to assess sex and age-at-death.

The primary aim of this pilot study was to focus on confidence level of participants when interacting with 3D models. Whilst accuracy is an important aspect when assessing feasibility of a model, as there was no definitive 'ground truth' data for sex and age-at-death for the 3D models, (e.g. DNA result from the skeletal remains for sex estimation), accuracy was not looked at in relation to confidence for this initial study. Other studies, such as Grabherr et al., 2009, have similarly focused on feasibility of 3D virtual remains without considering accuracy. Moreover, studies that have focused on accuracy, such as Bertoglio et al., 2020, have highlighted the difficulties participants had faced, citing caution as some traits were wrongly detected on 3D images. Hence, as the study was looking at the 'feasibility' rather than the 'accuracy', in terms of confidence and assessment, both the os coxa and skull were deemed sufficient for this study for participants to be able to assess all necessary features. Furthermore, both models were rotatable, allowing participants to view the models through 360 degrees and zoom in on features.

(**Figure 1**: Screenshot of anterior view of frontal aspect of skull (cranium and mandible))

(**Figure 2:** Screenshot of anterior view of frontal aspect of Os Coxa (Pelvis))

Participants

An invitation for survey participation was disseminated via internal email, professional organization distribution lists, and several social media platforms. Participants provided valid informed consent, with participants needing to be over 18 years old, and be working and/or studying in fields of forensic anthropology, bio-archaeology and/or osteology. The participant requirements of both students and professionals ensured that the sample size included a variety of experience within sex and age-at-death methods. This was essential to get a deeper understanding of if experience within the methods would have an impact on self-confidence when applied on 3D models of bones. Furthermore, to understand the background of each participant and their level of experience within forensic anthropology more broadly, and the methods specifically, initial questions also gathered information on participant demographics. Finally, this research was deemed exempt from requiring ethical approval as granted by the UCL Department of Security and Crime Science Ethics Committee.

Confidence Level: Likert Scale

Participants were asked to rate their self-identified confidence in applying traditional sex and age-at-death methods, using a five-point Likert scale, with 1 being “Not confident at all” to 5 being “Very confident”. This was followed up with establishing their confidence in each morphological trait observed on the 3D models, and finally in their overall answer for each 3D model. The Likert scale provided a more reliable and effective form of measure than limited ‘yes’ or ‘no’ options (Allen, 2017), with researchers being able to employ more sophisticated statistical techniques due to the Likert scale being of ordinal level (Monette et al., 2007).

Part 1- Sex Estimation on a 3D Virtual Skull

Participants were first asked to estimate the sex of the 3D virtual skull model. The Ubelaker & Buisktra method (1994) was employed, due to it being considered one of the most common methods used in sex estimations of the skull, in addition to its straightforward approach in assessing the five morphological traits through a scoring system utilising illustrations and basic descriptions. Screenshots of the method description were provided for ease of reference. Participants were asked to (i) score each morphological trait, based on the composite scoring from the method, (ii) indicate confidence in their answer to each morphological trait, (iii) estimate the sex of the skull, (iv) indicate confidence in their sex estimation, (v) indicate whether they found assessing the sex of the skull virtually easier or more difficult to assess and (vi) whether they believed their answers would have differed if they could have analysed this skeletal model in person.

Part 2- Sex Estimation on a 3D Virtual Os Coxa

After completing the sex estimation method on the skull, participants were then asked to estimate the sex of the 3D os coxa model. The Klales method (2012) was adopted due to it using traditional morphological traits in combination with an objective five-point ordinal scale, (Klales et al., 2012). Screenshots of the method description were provided for reference. Similar to part 1, participants were asked to follow the same order and steps as previously stated (i-vi).

Part 3- Age Estimation on a 3D Virtual Os Coxa

The final part of the study considered estimating the age of the 3D virtual os coxa model. Participants were instructed to use the Suchey-Brooks method (1990) to analyse the pubic symphysis, due to this method being highly preferred by forensic anthropologists (Garvin & Passalacqua, 2012). Additionally, the Lovejoy et al. (1985) method was utilized to assess the auricular surface, as whilst the Lovejoy method is difficult to apply and results in wide age intervals, forensic anthropologists have favored this method when analysing the auricular surface, retaining its utility and application as a standard method (Garvin & Passaacqua, 2012). Similar to previous section (part 1 and 2), screenshots of the method description were provided for reference and participants were asked to follow the same order and steps with the only difference being assessing the age-at-death instead of sex.

Statistical Analysis

Data analyses were conducted using SPSS Statistics for MacBook (IBM Corp., Armonk, N.Y., USA) Version 26. Normality tests were conducted and showed that all confidence rating data were normally distributed (with Skewness and Kurtosis values being within -1 and 1; (Ghasemi & Zahediasl, 2012)), suggesting that the data was appropriate for parametric testing (Research question 1&2). One-way ANOVA tests were used to explore the general experience and perceived confidence of the participants, with the independent variable being 'general experience in analysing skeletal remains in person' and dependent variable being 'perceived confidence in analysing 3D virtual skeletal remains'. Independent-sample t-tests were used to explore 3D virtual experience and perceived confidence of participants. Sum scores for all outcome measures of confidence ratings for 3D virtual skeletal models were computed; as the number of items to visually analyse for each skeletal element differed, sum scores had difference ranges. Skull-sex confidence ratings consisted of n=6 and possible range was 6-30; os coxa-sex confidence ratings consisted of n=4 and possible range was 4-20; os coxa-age confidence ratings consisted of n=3 and possible range was 3-15. Simple logistic regressions were used to explore student confidence in person and perceived difficulty of 3D virtual skeletal models. All tests were carried out at the 95% significance level. A statistical model to assess *"the relationship between various predictor variables (either categorical or continuous) and an outcome which is binary (dichotomous)"* (Ranganathan et al, 2017: 148), the assumptions were met with the dependent variable being binary and no multicollinearity among the independent variables. The dependent variable, 'perceived difficulty' for the respective 3D virtual skeletal element was coded as a binary variable (due to small cell count): easier/same vs more difficult. The categorical variable included a 5 point likert-scale from 'not confident at all' to 'very confident' with student confidence in person. To assess student confidence in person and perceived difficulty of 3D virtual skeletal models, students were grouped together regardless of level of current study/degree.

Results

A total of 71 participants responded, being either current students studying, or academics working in, the fields of forensic anthropology, bio-archaeology and/or osteology. As certain age groups had low participant samples, some of the age brackets were grouped for analysis (18-20 years with 20-29 years, 40-49, 50-59 and 60+ together), whilst 30-39 stayed the same (Table 1).

Table 1. Participant Demographics

Characteristics	Full sample (N=71) N (%)
Gender	
Male	12 (16.9)
Female	59 (83.1)
Other	0 (0.00)
Prefer not to say	0 (0.00)
Age	
18-29	43 (60.6)
30-39	15 (21.1)
40+	13 (18.3)
Education Level	
Undergraduate degree	2 (2.8)
Master's degree	30 (42.3)
Doctoral degree	17 (23.9)
Working in the field of Forensic Anthropology/ Bioarchaeology/ Osteology	22 (31)
Level of Experience	
Less than a year	19 (26.8)
1-2	12 (16.9)
3-5	16 (22.5)
5-10	15 (21.2)
10+	9 (12.7)
Prior Experience- 3D Assessment Skull Sex	
Yes	14 (19.7)
No	57 (80.3)
Prior Experience- 3D Assessment Os Coxa Sex	
Yes	12 (16.9)
No	59 (83.1)

Prior Experience- 3D Assessment Os Coxa Age	
Yes	11 (15.5)
No	60 (84.5)
Would Answer have Differed if Assessed in Person- 3D Os Coxa Sex	
Yes	45 (63.4)
No	26 (36.6)
Would Answer have Differed if Assessed in Person - 3D Os Coxa Sex	
Yes	47 (66.2)
No	24 (33.8)
Would Answer have Differed if Assessed in Person - 3D Os coxa Sex	
Yes	58 (81.1)
No	13 (18.3)

Part 1- General Experience and Perceived Confidence

One-way ANOVAs were conducted to explore to what extent experience analysing skeletal models in person was related to perceived confidence in analysing 3D virtual skeletal elements. The results indicated that there was no statistically significant difference in confidence in estimating sex from the skull (F(4,66)=1.108, p=0.360), no statistically significant difference in estimating sex from the os coxa (F(4,66)=0.858, p=0.494) and no statistically significant difference in estimating age from the os coxa (F(4,66)=0.347, p=0.845). Please see table 2 for results.

Table. 2

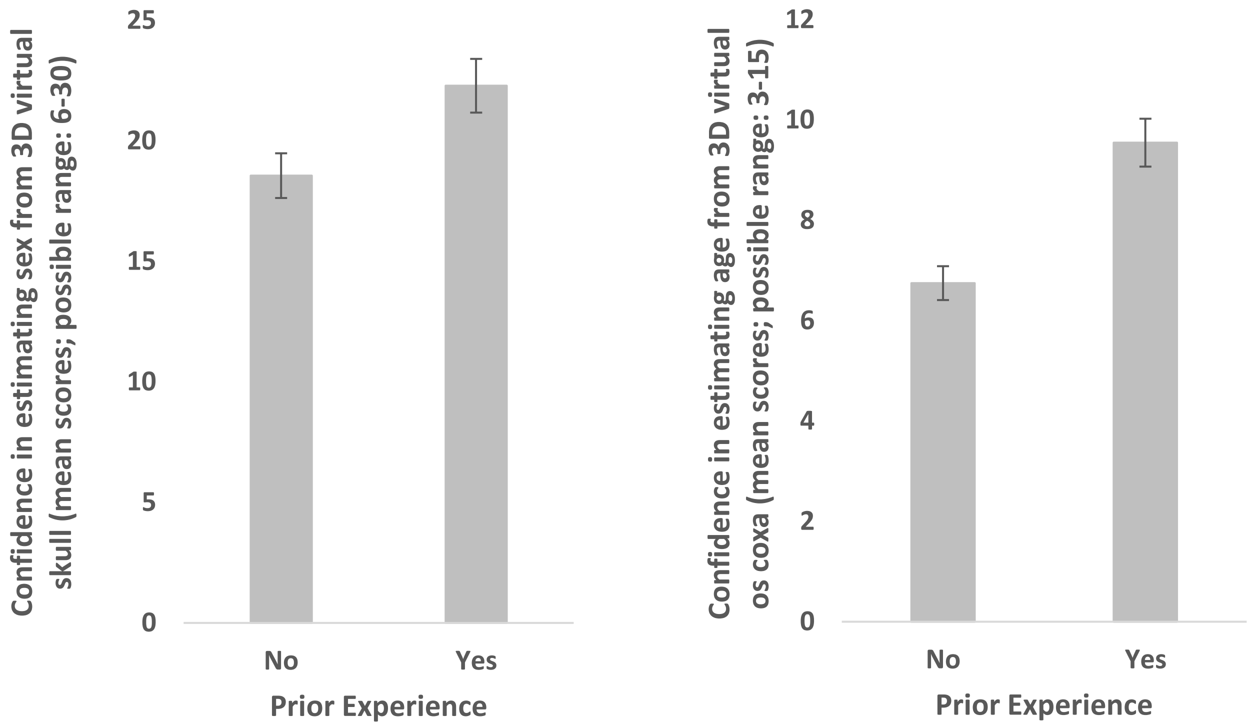
Comparison		Sum of Squares	df	Mean Square	F	Sig
Estimating sex from the skull	Experience	78.686	4	19.671	1.108	0.360
	Confidence	1172.103	66	17.759		
Estimating sex from the os coxa	Experience	45.277	4	11.319	0.858	0.494
	Confidence	870.920	66	13.196		
Estimating age from the os coxa	Experience	10.243	4	2.561	0.347	0.845
	Confidence	486.377	66	7.369		

Part 2- 3D Virtual Experience and Perceived Confidence

Independent-sample t-tests were conducted to explore whether there was a difference in perceived confidence when analysing the respective 3D virtual skeletal elements between participants with and without prior experience analysing such 3D skeletal models. The independent-sample t-tests revealed to be statistically significant, with the p-value of <0.05, in perceived confidence in estimating the sex from a 3D virtual skull model between the prior experience groups ($t(69)=-3.134$, $p=0.003$). Individuals with prior experience of estimating the sex from 3D virtual skull models reported higher levels of confidence in estimating the sex from the 3D virtual skull model (M=22.29, SD=4.14) than individuals without prior experience (M=18.56, SD=3.95). The independent-sample t-tests also revealed to be statistically significant, with the p-value of <0.05, in perceived confidence in estimating the age from a 3D virtual os coxa model between the prior experience groups ($t(69)=-3.438$, $p=0.001$). Individuals with prior experience of estimating the age from 3D virtual os coxa models reported higher levels of confidence in estimating the age from the 3D virtual os coxa model (M=9.55, SD=2.94) than individuals without prior experience (M=6.75, SD=2.39). However, there was no significant difference in perceived confidence in estimating the sex from a 3D virtual os coxa model between the prior experience groups ($t(69)=-1.706$, $p=0.093$). Please see table 3 for results. Figure 3 depicts the significant difference in mean confidence ratings of estimating sex/age from 3D virtual skeletal models by experience.

Table. 3

Comparison	t	df	Sig. (2-tailed)
Estimating sex from 3D virtual skull	-3.134	69	.003
Estimating sex from 3D virtual os coxa	-1.706	69	.093
Estimating age from 3D os coxa	-3.438	69	>.001



(Figure 3. Difference in mean confidence ratings of estimating sex from 3D virtual skeletal skull (left) and age from 3D virtual skeletal os coxa (right) by prior experience of analysing 3D virtual skeletal models (error bars represent standard error of the mean)).

Part 3- Student Confidence In Person and Perceived Difficulty of 3D Virtual Skeletal Models

Simple logistic regression models were conducted to explore whether student confidence ratings in analysing skeletal remains in person will predict perceived difficulty of analysing 3D virtual skeletal models. The results revealed that student confidence ratings in estimating sex from the skull in-person was not significantly predicting perceived difficulty of estimating sex from the 3D virtual equivalent ($B=-0.128$, $SE=0.354$, $p=0.717$) (explaining 0.4% of the variance, Nagelkerke R^2). Student confidence ratings in estimating sex from the os coxa in-person were also not significantly predicting perceived difficulty of estimating sex from a os coxa 3D virtual model, $B=0.198$, $SE=0.357$, $p=0.579$ (explaining 1.0% of the variance, Nagelkerke R^2). Student confidence ratings in estimating age from the os coxa in person were also not significantly predicting perceived difficulty of estimating age from a os coxa 3D virtual model, B=-0.182, SE=0.532, p=0.733 (explaining 0.6% of the variance, Nagelkerke R^2). Please see table 4 for results.

Table. 4

							95% C.I for EXP(B)	
	B	S.E.	Wald	df	Sig.	Exp(B)	Lower	Upper
Student Confidence in estimating sex from 3D virtual skull	.128	.354	.131	1	.717	1.137	.568	2.276
Student Confidence in estimating sex from 3D virtual os coxa	.198	.357	.308	1	.579	1.219	.605	2.457
Student Confidence in estimating age from 3D virtual os coxa	-.182	.532	.117	1	.733	.834	.294	2.365

Discussion

This study aimed to evaluate the feasibility of 3D virtual models within forensic anthropology morphoscopic assessments, with specific focus on looking at the self reported confidence of observers when interacting with 3D models, in order to further understand the feasibility of moving forensic anthropology into virtual lab spaces. A qualitative survey assessed how experience can play a role in the confidence of participants in assessing age and sex from 3D models. The survey also investigated how student confidence levels in analysing dry bones can play a role in the perceived difficulty for participants to assess age-at-death and sex from 3D models. Analysis of the survey results indicated that confidence ratings in estimating the sex and age of 3D virtual skull and os coxa models was not different by level of experience in analysing skeletal remains in person. There was a statistical significance in the estimation of the sex from 3D skull skeletal remains between individuals with and without prior experience of estimating the sex from 3D virtual skull models, with participants reporting higher levels of confidence when they had prior experience. There was also a statistical significance in the estimation of the age from 3D os coxa skeletal remains between participants with and without prior experience of estimating the age from 3D virtual os coxa models with participants reporting higher levels of confidence when they had prior experience. However, this difference was not observed with regards to estimating the sex from 3D virtual os coxa models. Lastly, perceived difficulty of analysing 3D virtual skeletal models could not be predicted by student confidence ratings in analysing skeletal remains in person.

General experience level and Confidence

Exploring the relationship between experience levels of participants for analysing skeletal models in person and their perceived confidence in analysing 3D virtual skull and os coxa models is a novel area. The results showed that participants level of experience in analysing dry bones was found to not be associated with higher confidence in analysing 3D virtual remains. This may be explained through the social cognitive concept of the 'self-efficacy' theory (Bandura 1977; Pajares, 1996; Middleton et al., 2019; Gebauer et al., 2020), referring to what an individual believes they can accomplish using their skills under certain circumstances (Bandura 1977). Bandura's (1977) major self-efficacy belief of 'performance accomplishments' provides the most accurate confidence information, as it is based on the participants prior experience (Druckman & Bjork, 1994). Moreover, the influence of experience on perceived self-confidence can be dependent on the perceived task difficulty (Bandura, 1986). Particularly, the suggestion of perceived difficulty in this task may stem from the inability of being able to apply certain aspects of the methods when analysing elements on virtual bone models. This may be because certain landmarks on the skull and os coxa are only determinable by palpating, or touching, as highlighted within previous findings (Colman et al., 2019; Kuzminsky et al., 2019). This would affect such trait investigations as of the supra-orbital margin, requiring individuals to feel for the 'sharpness', the ischio-pubic ramus requiring a 'pinch' to feel for a sharp ridge of bone below the symphyseal face, and the pubic symphysis, requiring a feel for the presence or absence of lipping on the symphyseal dorsal margin. Participants cannot use touch to assess 3D virtual skeletal models, therefore this traditional approach to touch and palpate certain landmarks is lost. Not having the sense of touch and the physical interaction could explain the loss of confidence, no matter how experienced an individual may be in analysing physical remains.

Experience in 3D models and Confidence

In assessment of prior 3D virtual experience and perceived confidence, the results indicated that having prior 3D virtual experience did make a difference in confidence levels when estimating sex on a 3D virtual skull and age on a 3D virtual os coxa, respectively from two out of three 3D virtual models. However, the assessment in estimating sex from 3D virtual os coxa models revealed that prior experience did not impact confidence levels. This finding may be explained through the perception of prior experiences generally influencing confidence (Lee et al., 2002), impacting cognitive decision-making processes and outcome quality (Egan, 2019). Hence, reverting to Bandura's 'self-efficacy' theory (1977) and considering the source of 'performance accomplishments', the results may be explained through participants having had a 'positive' prior experience, whereby if one performed well previously, self-efficacy will increase. However, with regards to sex estimation on a 3D virtual os coxa model, a possible explanation for this finding could stem from participants having had a 'negative' prior experience, whereby if one did not perform well previously, self-efficacy will decrease (Bandura 1977). Another suggestion may be due to 3D virtual models not providing accurate representation of the original model as virtual 3D models are stereoscopic (in two-dimensions on a screen), implying that 3D virtual models "only give the illusion of depth" (Carew et al., 2019: 342). However, due to the lack of literature considering confidence levels of participants who have had prior experience in analysing 3D virtual skeletal models, this paper is unable to compare the presented results to previous findings.

Feasibility of 3D models in Teaching and Education

The application of 3D virtual models within forensic anthropology has been highlighted for its benefits (Weber, 2014; Garvin & Stock, 2016). However, very few studies exist that have considered how feasible 3D virtual skeletal models may be for teaching students on how to construct the biological profile. Previous research has largely recruited experienced forensic anthropologists, with few examples having recruited students (Leon 2014 and Kuzminsky 2019). Whilst past studies have looked at the suitability in replacing physical skulls with virtual 3D skull models, results suggest that digital renderings may be difficult to utilize effectively for teaching purposes (Khot et al., 2013; Leon, 2014, Azer & Azer, 2016 & Kuzminsky, 2019).

This study revealed that confidence ratings for students in analysing skeletal remains in person did not predict perceived difficulty of analysing 3D virtual skeletal models for all three morphological assessments. It could be suggested that the traditional physical approach utilizing touch for analysing dry bones may lead to uncertainty and unfamiliarity when analyzing virtually. This sense of unfamiliarity could be linked to the difficulty in scoring certain traits virtually, as traditional methods typically involve palpating certain regions of the skull and os coxa, in addition to issues relating to possible feature distortion on the computer monitor (Kuzminsky et al., 2019). Another suggestion may be due to the spatial abilities of the participants, as viewing an unfamiliar object virtually through multiple angles may ‘create extraneous cognitive load by creating unnecessary mental images, and hamper long-term learning’ (Khot et al., 2013: 214).

Without the necessary skills and experience needed to analyze virtually, despite a student possessing high confidence in analyzing skeletal remains in person, these suggested challenges will negatively impact the perceived difficulty of the virtual task. Moreover, perception of perceived difficulty in a task demonstrates expectancies of success and/or failure (Wigfield & Eccles, 2000). Arguably, 3D printed skeletal models should be considered for teaching purposes, as it allows the students to palpate and feel for any ‘sharpness’ or ‘bumps’ on certain regions, allowing student confidence to increase. The use of 3D replicas has been utilized for teaching purposes within other forensic subfields, such as forensic medicine (Rybicki & Grant, 2017). Though the utilisation of 3D printing in forensic anthropology is limited, Carew et al., (2019) have examined the accuracy of 3D printing osteological samples using different 3D printers. However, more research is needed to examine whether 3D printed skeletal models, or 3D virtual skeletal models, are more effective for teaching students on how to assess morphological features.

The overall results based on the statistical analyses demonstrated that possessing the requisite skills must go together with self-confidence in those skills to be used effectively, so that a task can be completed successfully, as obtaining the necessary skills alone cannot fulfill the whole requirements in completing a given task (Bandura, 1997; Kurbanoglu, 2009). Moreover, this suggestion indicates that moving the field of forensic anthropology into virtual lab spaces, has limitations specifically when looking at individuals self-confidence to perform the visual assessments on the 3D models. Arguably, without any practice, the individual’s belief in achieving a confident result is adversely affected, as only after gaining skills and experience over time will self-efficacy develop (Bandura 1986). One suggestion is to provide 3D visualization training before applying anthropological methods to 3D bones.

This study identified a wider implication for forensic anthropologists; that through practice and repetition, the chances of shifting this field into virtual labs could increase. This notion can be linked with the 'growth mindset' theory (Dweck, 2006), a belief that an individual can improve their intelligence and skills through practice and repetition. For this growth mindset to be achieved, individuals must have the desire to learn through embracing challenges, accepting constructive criticism and continuously practicing (Dweck, 2006). Hence, individuals should be continuously trained to visually assess 3D virtual skeletal remains to increase their confidence and skills and thus improve their self-efficacy. Additionally, whilst obtaining prior experience can play an important role in belief in one's capabilities, sometimes 'negative experiences' can occur. Regarding this, when self-efficacy is low despite having been trained, praising the individual's effort, providing positive feedback and critique will allow the individuals to believe that they can accomplish challenging tasks (Dweck, 2009). Thus, this paper does encourage the incorporation of 3D virtual labs into teaching so that students and experienced forensic anthropologists/ bio-archaeologists and osteologists can become more familiar and comfortable with the methods.

4.1 Limitations

The survey responses obtained provided a valuable dataset to begin to assess the confidence of observers when applying morphological assessment methods on 3D virtual models. A participant drop-out rate of 28% was observed, with 72% of participants completing the survey. However, the number of participants (n=71) gathered is, to the knowledge of the author, the biggest data set yet collected in 'virtual anthropology' research investigating 3D virtual skeletal remains. Additionally, the disproportioned participant demographics data introduced certain limitations when conducting statistical tests, due to small cell counts that had to be grouped together. For future studies, a longer time frame for distribution and completion of the survey could enable greater participation. To increase the number of N and minimize participant drop out, this initial study was designed to be time efficient for participants aiding in gathering a larger sample size for a baseline study. Therefore, only a small sample size of 3D models were used. Further, the models used in this study were also selected based on the criteria that they had all the features present for the participants to be able to complete the task, arguably creating a straight forward assessment. Future studies should increase the sample size of the 3D models that are more representative of a variety of morphological features. In addition the selected 3D virtual models from Sketchfab, did not always state their scanning procedures. Future studies could use known models or a greater number of models to further assess feasibility. Further consideration is also needed around the scanning and modelling techniques, as well as the display of 3D models. Whilst various techniques and procedures have been developed and applied in creating reliable 3D virtual models (Freiss, 2012; Karatas & Toy, 2014), errors in scanning and modelling procedures can affect skeletal models and their subsequent interpretation (Bertoglio et al., 2020). Further issues around inappropriate opacity or brightness adjustments of the 3D virtual image can potentially obscure certain traits and features (Pattamapaspong et al., 2019).

This study is the first of its kind looking at feasibility of estimating age and sex from virtual 3D skull and os coxa models that focuses specifically on self-confidence. As a feasibility study, the single virtual skull and os coxae scan were valuable to get an early indication on how conceivable it may be to virtually estimate age and sex. For future studies, assessing the feasibility and accuracy would be beneficial, through utilizing multiple models to fully test the applicability of 3D models across different phases.

Moreover, future research should analyze why, when having prior 3D virtual experience in analysing skeletal remains, the significance of findings varied between different morphological assessments. Another suggestion would be to gain a deeper insight into what participants find challenging when analysing 3D virtual skeletal models, by asking specific questions as to what aspects of the trait analysis were considered challenging. This would provide more granular data into participant perceived confidence levels when carrying out certain analytical tasks. Additionally, understanding how disadvantaged groups may be affected by visual anthropology training needs to be investigated. Issues such as internet accessibility, owning appropriate devices, students with visual impairments, or the subsequent lack of personal interaction between teachers and students should be considered. This would provide valuable insight into how such issues can be evaluated so that virtual teaching can be implemented inclusively. Furthermore, with the possibility of students learning in a purely virtual environment in the near future, it will be beneficial to incorporate an understanding of imaging platforms as well as computational methods for estimating biological profiles, such as statistical shape modelling (Mahfouz et al., 2017; Audenaert et al., 2019; Ebert et al., 2022) in higher education teaching and learning. In future studies, it will be prudent to also explore student confidence with virtual methods, for those who have learnt in entirely virtual/online environments.

Lastly, further research could consider assessing the feasibility and accuracy of estimating the age and sex from virtual 3D skull and os coxa models, through evaluating what specific 3D scanning procedure is the most reliable in accurately representing a skeletal element. As differences in equipment application can affect the reliability of the 3D data collected from the virtual model scans (Garvin et al., 2018), identifying the optimal equipment to create 3D virtual skeletal models may provide higher quality scans and better representation of skeletal characteristics.

Conclusion

This pilot study investigated the self reported confidence of participants when assessing the age and sex from virtual skull and os coxa models, and whether it can offer further insight into the feasibility of moving the field of forensic anthropology into virtual lab spaces. The initial results have demonstrated that without continuous practice, individuals will not develop the necessary skills and confidence in completing the given task. The statistical analysis has presented the implication that before 'virtual anthropology' can be utilized for morphological assessments, training students right from the beginning in virtual labs will increase their self efficacy in using 3d virtual models. This is particularly important when moving forensic anthropological teaching into virtual spaces.

Overall, this study promotes the possibility of transitioning forensic anthropology into the virtual world. Whilst this study has implicated the importance of increased self-efficacy levels before 'virtual labs' can be established, there is a real possibility that this challenge can be eliminated through practice and repetition, increasing the chances of applying forensic anthropological methods in virtual settings.

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