Augmented-reality-assisted intraoral scanning: An andragogical study

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ORIGINAL ARTICLE

Augmented-reality-assisted intraoral scanning: An andragogical study

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Abstract

Purpose: The aims of the present study were to (a) compare the scanning time and image count to complete optical scans of a typodont between augmented-reality-assisted intraoral scanning (ARIOS) and intraoral scanning (IOS), (b) compare the precision of the scan data derived from ARIOS and IOS, (c) compare participant-related outcomes between ARIOS and IOS, and (d) evaluate the effect of andragogical training in enhancing operator proficiency.

Materials and Methods: A multisession within-subject experiment was conducted to compare ARIOS and IOS. Twenty-five dental students participated in the study. A training session was done to procure familiarity with both experimental conditions. The trial session consisted of each participant performing three sets of optical scans of a typodont under ARIOS and IOS. The time required to complete the scan and the number of images taken were recorded. Participant feedback was collected by means of entry, exit, and NASA-Task Load Index surveys. Precision of the scanned data was measured in root mean square (RMS).

Results: The present study observed a 7:3 preference for ARIOS at the exit survey. Scanning efficacy from ARIOS to IOS found an 8.5% decrease in mandibular scanning time, a 10.5% decrease in maxillary scanning time, an 8.6% decrease in mandibular scanning image count, and a 9.3% decrease in maxillary image count in favor of ARIOS. Precision of the scan data between ARIOS and IOS was comparable in RMS.

Conclusion: Andragogical practice of training enhanced participants' proficiency with ARIOS. ARIOS was advantageous compared to IOS in scanning efficacy, ergonomics, ease of use, and overall workload.

KEYWORDS
augmented reality, data accuracy, dental education, dental impression technique, ergonomics, mixed reality glasses, optical-see-through head-worn-display (ost-hwd), prosthodontics

Virtual reality (VR) immerses users in a synthetic three-dimensional (3D) environment through wearable screens, such as VR headsets. In contrast, augmented reality (AR) integrates elements of VR by superimposing digital content onto the real world, displaying it in real time through an electronic device's screen.[1,2] Advantages of adopting AR into surgical and reconstructive procedures in the dental field include the ability for real-time alignment of the physical field of operation and corresponding virtual information and to maintain visual contact with other team members while viewing the displayed information. In this case, the clinician is not required to alternate their attention between the field of operation and a stationary monitor, which will prevent the potential hand-eye coordination issue[3,4] while retaining access to the "real-life" clinical presentation. AR promises to be useful for various procedures in dentistry, such as intraoral optical impression, surgical navigation and many others.

An optical impression derived from intraoral scanning (IOS) is convenient and efficient by directly generating a digital reproduction of the patient's intraoral anatomy. IOS is an additional asset for patient communication, providing an intraoral surface dataset immediately visible on a display. In addition, IOS enhances clinical efficacy by enabling selective rescanning of impressions and real-time visualization of preparations utilizing analysis tools.[5] A recent systematic review reported IOS is faster than conventional impression, independent of whether a quadrant or complete arch scan is conducted.[6] IOS can improve the patient experience measured by overall preference and comfort and is able to provide reliable outcomes.[6,7] The current technology mandates a stationary monitor in which the scanning data is displayed. Inevitably the operator will have to focus their sight on the monitor rather than the target site of interest, the patient and respective clinical site, which leads to a lack of direct visual oversight. Clinician's monitoring is necessary partially due to the limitations of the technology, such as difficulty scanning reflective and/or wet surfaces, undercut regions, interproximal regions, and during patients' sudden movements.[8] Such necessity inevitably diverts the clinician's attention between the patient and the stationary monitor, rendering the process ergonomically suboptimal and unintuitive.[9]

As dental care is an interactive activity, and given that the patient experience with IOS has been proven to be positive,[6] the authors have focused on enhancing the operator experience. The NASA Task Load Index (NASA-TLX) is a multidimensional tool for assessing subjective workload during or after task performance.[10] It quantifies workload across six subscales: "Mental Demand," "Physical Demand," "Temporal Demand," "Performance," "Effort," and "Frustration." By focusing on human-centered workload perception, NASA-TLX accounts for variability through calibrated raters, reference tasks, and bias recognition. Its sensitivity to experimental manipulations enables detailed diagnostic insights, distinguishing workload components not captured by other assessments.[10,11] NASA-TLX was originally developed by NASA for aviation and spaceflight workload evaluation; since then, the application has been broadened to various domains, including education and training.

However, adoption of new/newer technology often warrants adequate training.[12,13] Thus, the authors sought to investigate the influence of andragogical training on the efficacy of IOS in conjunction with an optical-see-through head-worn display (OST-HWD) application. To date, the learning effect of utilizing AR in conjunction with IOS has not been extensively investigated.

The purpose of this study was to investigate the impact of andragogical training on the feasibility of ARIOS (Augmented-Reality-Assisted Intraoral Scanning) as an alternative[14] to conventional IOS performed with a stationary display, which currently represents the standard of care. Specifically, the study sought to compare ARIOS and IOS across several domains of performance and user experience. These included the time and number of images required to complete mandibular and maxillary typodont scans, as well as the precision of the resulting scan data. In addition, participant-reported experience outcomes were evaluated to determine differences in usability and workflow perception between the two modalities. The study also examined the influence of operator-related factors such as loss of tracking, deviation from recommended scan strategies, and deviation from line of vision, and assessed how these factors correlated with scanning time. Finally, the role of andragogical training in enhancing operator proficiency was evaluated, with the aim of determining whether adult learning-based strategies could mitigate challenges inherent in adopting new digital technologies. The null hypothesis was that ARIOS, compared to IOS, would not significantly improve efficiency in the optical scanning protocol and would not yield significant differences in operator experience.

MATERIALS AND METHODS

The study protocol was approved by the Institutional Review Board of Columbia University Irving Medical Center (IRB-AAAU2648). The study was conducted in accordance with the Helsinki Declaration of 1975, as revised in 2013. All participants were informed in detail about the study aims and procedures and provided written informed consent before their inclusion in the trial.

Trial design

The present study was designed as a single-session within-subject experiment conducted to compare IOS and ARIOS using an intraoral scanner (TRIOS 3 Basic, 3Shape, Copenhagen, Denmark) with and without an OST-HWD (SCOPEYE EUD, MediThinQ, Seongnam-si, South Korea) for the scanning of a typodont (Frasaco Articulated Typodont, Frasaco USA, Greenville, NC).

AR setup configuration

A binocular OST-HWD with a 40° diagonal field of view and transparent high-definition display (SCOPEYE EUD, MediThinQ, Seongnam-si, South Korea) was included in this study. During the session, the headset was connected to the intraoral scanner (TRIOS 3 Basic, 3Shape, Copenhagen, Denmark). IOS data was mirrored and visualized using the OST-HWD as a heads-up display. The mirrored data is displayed directly in front of the operator, attenuating the need to deviate line of vision from the field of interest.

Pre-procedure

Participants practiced optical impressions in both experimental conditions until consistent image counts of less than 2500 images for complete arch scanning were obtained. Participants were asked to complete an entry survey

(Supporting Information) prior to the study procedure. The entry survey obtained information regarding each participant's pre-trial perception of ARIOS, IOS, and ergonomic posture.

Procedure

Twenty-five dental students (mean age: 25.6; R:[23, 36]) were recruited to participate in the study. Sample size calculation was based on previous study[14] results. R (4.4.2, R Core Team) was used to detect a 12% difference in scanning time at 95% confidence level with a power of 80%. Sample size of 21 was required to detect the difference, whereas 44 would have been required to detect a similar difference in image counts. Scanning time was deemed as the most clinically relevant outcome and selected for sample size computation. Twenty-five participants were planned in anticipation of 15% drop out.

Among 25 participants, 14 were female and 11 were male. Each participant was designated a computer-generated randomized number. The sequence of ARIOS (test) and IOS (control) was counterbalanced as each experimental condition was recorded in alternating order. The participants used an intraoral scanner (TRIOS 3 Basic, 3Shape, Copenhagen, Denmark) to obtain an optical impression of a typodont (Frasaco Articulated Typodont, Frasaco USA, Greenville, NC) mounted in a phantom head to simulate clinical conditions. To obtain an optical impression of a predetermined quality, the scanning time and image count were measured after the impression was satisfactory with reference to the standard quality. The quality of the scan was determined to be unsatisfactory if the scan included overlapping artifacts or large voids that could not be compensated by the device software. When the impression was unsatisfactory, scanning was reinforced until it met the standard requirements. Each participant completed a trial consisting of three impressions of the mandible and maxilla for each experimental condition.

"Loss of tracking," "deviation from scan strategy," and "deviation from line-of-vision" were recorded by the investigators as counts per scan (e.g., each arch scan per trial per experimental condition was treated as one scan). Loss of tracking was defined as the failure of the scanner's software to recognize its current position in relation to the previously recorded oral anatomy. The scan strategy followed the Trios (3Shape, Copenhagen, Denmark) scan strategy recommendation. The bite registration was not recorded. Deviation from the line of vision was defined as looking away from the stationary monitor in the IOS experimental condition.

Optical impression with augmented-reality-assistance (ARIOS)

For the ARIOS (test) condition, the stationary monitor was mirrored by an OST-HWD (SCOPEYE EUD, MediThinQ, Seongnam-si, South Korea), enabling a heads-up display (Figure 1a). The time required to complete the scan, the number of images taken, and participant feedback were recorded.

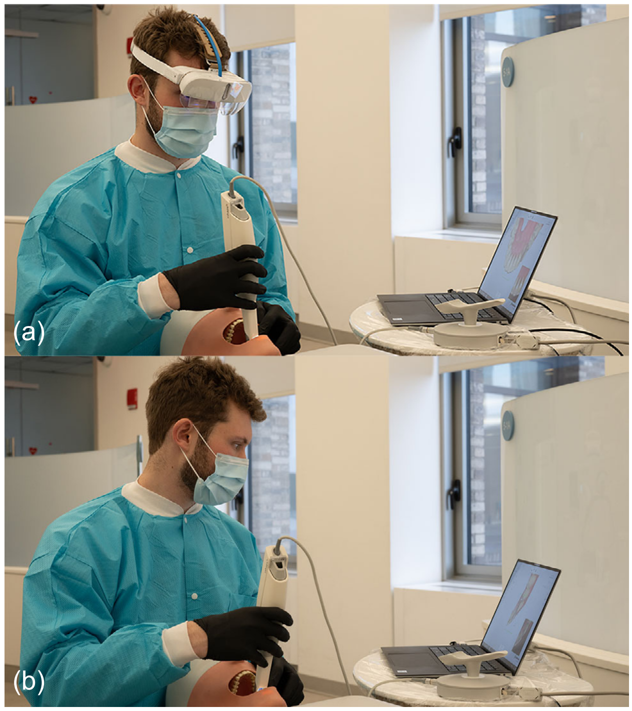

FIGURE 1 (a) ARIOS set-up with OST-HWD, (b) IOS set-up with stationary monitor. ARIOS, augmented-reality-assisted intraoral scanning; IOS intraoral scanning; OST-HWD, optical-see-through head-worn display.

Optical impression without augmented-reality-assistance (IOS)

For the IOS (control) condition, participants used a stationary monitor to view scanning status (Figure 1b). For right-handed participants, the stationary monitor was positioned on the left side of the phantom head at the 5 o'clock direction approximately 50 cm away. For left-handed participants, the stationary monitor was in the mirror position of the right-handed participants. Participants were allowed to adjust the position of the monitor within the platform of the base table. The time required to complete the scan, the number of images taken, and participant feedback were recorded.

Post-procedure

Participants were asked to complete an exit survey (Supporting Information) and a post-trial unweighted NASA-TLX[10] (Table S1), which gauged their perceived cognitive workload for both ARIOS and IOS conditions. Scan data was exported in stereolithography (STL) format for evaluation.

Scan data analysis

Scan data alignment and analysis was performed using a 3D inspection software (Geomagic Control X 2024.2, 3D Systems, Rock Hill, SC). Trials were independently analyzed for each arch (mandible, maxilla) and test and control conditions (ARIOS, IOS). For each arch, one scan (t1) was designated as a reference point cloud for alignment and statistical analysis independently with the other two trials (t2, t3) of the corresponding experimental condition. First, an initial alignment was obtained between the reference (t1) scan and the target (t2, t3) scans. Second, the dentition digitally segmented from gingival anatomy as the region-of-interest (ROI) for iterative closest point alignment was limited to tooth structures utilizing the "best-fit mathematical algorithm"[15] command. Third, reference scan alignment was redefined and repeated for each respective experimental condition and arch. Dimensional analysis was performed utilizing the previously defined dentition-only ROI. The root mean square (RMS), standard deviation, and variance were collected for each trial pair (eight pairs total for each participant). RMS is a standard method to measure the square root of the average of the squares of a set of values.[16] The formula for RMS is $\sqrt{\frac{1}{n}\sum_{i=1}^{n} x_i^2}$ whereas n is the number of samples, and x is observed values.

Statistical analysis

Statistical analyses were performed using a statistical software suite (IBM SPSS Statistics, v28; IBM Corp), and p-value ≤ 0.05 was considered significant. Distribution of the data was tested with a Kolmogorov–Smirnov test to show that distributions were not normally distributed for "loss of tracking" and "line of vision." Data on the questionnaire were mainly normally distributed except for a few questions. Statistical analysis of non-normal distribution data consisted of: Related-Samples Wilcoxon signed-rank test and Spearman's rho correlation. For normally distributed data, the paired t-test and Pearson correlation coefficient were used. For the "preference question," participants were asked to score their preference on a scale from 0 to 100, where 0 meant total preference for IOS and 100 total preference for ARIOS. To test if the mean value was statistically different from the no preference value (i.e., 50), a one-sample t-test was used. For NASA-TLX, the family-wise error rate was addressed by Bonferroni correction. A general linear model, repeated measure, was used to compare ARIOS and IOS time with the "arch" variable as a covariate. For precision analysis, a general linear model was used to compare RMS standard deviation, considering the experimental condition, the three repetitions, and the respective arch as a covariant.

RESULTS

Participant information

Among the participating dental students (n = 25), self-reported prior optical impression experience was the following: 12 had less than 10, 15 had 10–500, and only one had more than 500 optical impression experiences. None of the participants had previous experience with an OST-HWD. Participant-reported IOS expertise was 41.20 ± 26.98 on a scale of 0 to 100, with 100 representing very experienced.

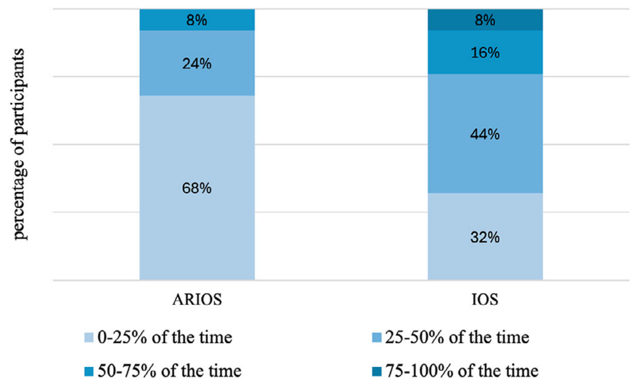

FIGURE 2 Ergonomic posture deviation in ARIOS and IOS conditions. ARIOS, augmented-reality-assisted intraoral scanning; IOS intraoral scanning.

Entry and exit survey

The present study found there was no preference at the beginning of the study, whereas a 7:3 preference towards ARIOS compared to IOS was reported at the exit survey. Participants reported perceived proficiency in ARIOS as 75.8 ± 18.12 on a scale of 0 to 100, with 100 indicating complete proficiency. Sufficiency of training was 89.00 ± 13.99 on the same scale, with 100 representing sufficient training. During the IOS condition, 17 participants reported needing to adjust their posture more than 25% of the time, compared to only 8 participants in the ARIOS condition (Figure 2). Participants deviated from an ergonomic posture more frequently with IOS than with ARIOS, a difference that was statistically significant (p < 0.01).

NASA-TLX

For the subscales of "mental demand," "physical demand," "temporal demand," "effort," and "frustration," ARIOS was less demanding. For the subscale "performance," there was a tendency for ARIOS to be more successful. After Bonferroni correction was applied, "temporal demand" and "effort" were significantly less demanding, and "frustration" was borderline significantly less with ARIOS (Figure 3).

Scanning time and image count

There was a difference in scanning time and image count for the maxilla and the mandible (Tables 1 and 2), with ARIOS requiring less time (ARIOS mandible time: 111.4 ± 29.3 (s) R:[57, 227], ARIOS maxilla time: 123.3 ± 27.3 (s) R:[64, 215]; IOS mandible time: 121.7 ± 29.3 (s) R:[62, 179], IOS

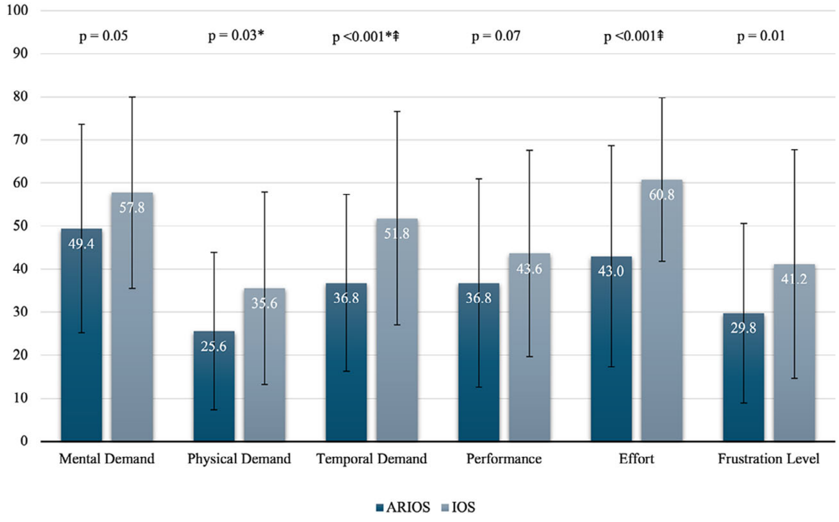

FIGURE 3 NASA-TLX subscales were analyzed with paired *t*-test. Family-wise error rate was addressed by Bonferroni correction. ‡Statistically significant reduction in workload for ARIOS compared to IOS. *Confirmed by nonparametric Wilcoxon signed-rank test. ARIOS, augmented-reality-assisted intraoral scanning; IOS, intraoral scanning; NASA-TLX, NASA Task Load Index.

TABLE 1 ARIOS and IOS mean scanning time.

	ARIOS mean ± SD	IOS mean ± SD
Mandible	111.4 ± 29.3	121.7 ± 29.3
Maxilla	123.3 ± 27.3	137.7 ± 30.9

Abbreviations: ARIOS, augmented-reality-assisted intraoral scanning; IOS, intraoral scanning; SD, standard deviation.

TABLE 2 ARIOS and IOS mean image count.

	ARIOS Mean ± SD	IOS Mean ± SD
Mandible	2040.07 ± 539.86	2208.71 ± 505.97
Maxilla	2294.77 ± 461.43	2531.19 ± 508.70

Abbreviations: ARIOS, augmented-reality-assisted intraoral scanning; IOS, intraoral scanning; SD, standard deviation.

maxilla time: 137.7 ± 30.9 (s) R:[66, 215]), and lower image counts (ARIOS mandible image count: 2040.07 ± 539.86 R:[822, 4341], ARIOS maxilla image count: 2294.77 ± 461.43 R:[1634, 3377]; IOS mandible image count: 2208.71 ± 505.97 R:[1162, 3859], IOS maxilla image count: 2531.19 ± 508.70 R:[1216, 3751]) on average. Pearson correlation coefficient analysis indicated a strong correlation of 0.93 (95% confidence interval: 0.91–0.94) between scanning time and image counts (Figure 4, Figure S1 and S2). As scanning time is clinically more relevant, further analyses utilized scanning time as a variable. There was no difference between the repetitions (t1, t2, and t3) (Figures 5 and 6); however, the maxilla required more time to scan than the mandible. ARIOS required less time regardless of the repetition and scanned arch; however, statistical significance was not achieved.

Loss of tracking, deviation from scan strategy, and deviation from line of vision in IOS

Loss of tracking occurred both in ARIOS and IOS conditions (ARIOS mandible: 2.57 ± 2.31 R:[0, 11], ARIOS maxilla: 2.27 ± 2.11 R:[0, 9]; IOS mandible: 3.73 ± 3.35 R:[0, 13], IOS maxilla: 3.43 ± 2.90 R:[0, 14]) (Supporting Information). For both methods, the loss of tracking increased the time to complete the scan ($p < 0.01$).

For IOS, there was no difference in the time required to complete the scan, whether the scan strategy was followed or not. However, for ARIOS, deviation from the scan strategy increased the time required to complete the scan ($p = 0.015$) (Supporting Information). The deviation from line of vision reduced the time required to complete the scan in IOS; however, it was not statistically significant ($p = 0.240$) (Supporting Information).

Scan data precision

Scan data precision was tested with RMS. The first repetition (t1) was compared against the second (t2) and third (t3) repetitions in each respective experimental condition (ARIOS, IOS) and arches (mandible, maxilla). Reported precision, measured in a general linear model using RMS standard deviation, was comparable for both arches in both experimental conditions (ARIOS mandible: 0.085 ± 0.019, ARIOS maxilla: 0.088 ± 0.016; IOS mandible: 0.089 ± 0.017, IOS maxilla: 0.084 ± 0.016; unit in millimeters). Trueness was not measured in the present study.

DISCUSSION

The results of the present study support the first null hypothesis, indicating that optical impression proficiency in both ARIOS and IOS test conditions is comparable. Although scanning time and image counts were lower for both the mandible and maxilla in ARIOS compared to IOS, the differences were not statistically significant. Operator perception, on the other hand, indicated a general preference towards ARIOS, rejecting the second null hypothesis ($p < 0.05$).

The authors previously published a preliminary study[14] on a related topic, albeit with a different experimental setup. The

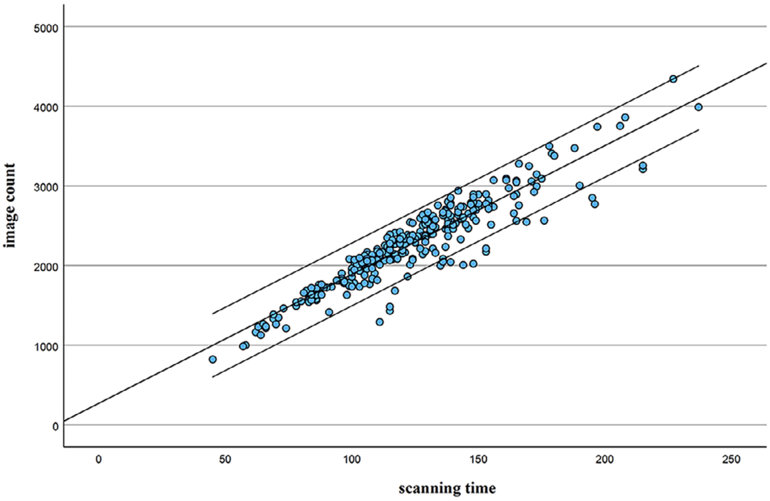

FIGURE 4 Correlation of scanning time and image count correlation depicted in a scatter plot.

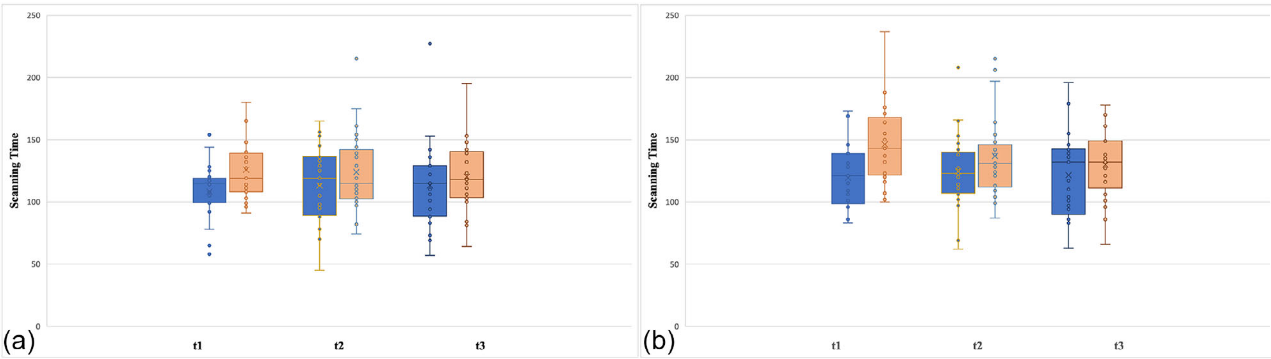

FIGURE 5 (a) ARIOS t1, t2, t3 mandibular and maxillary scanning time; (b) IOS t1, t2, t3 mandibular and maxillary scanning time. ARIOS, augmented-reality-assisted intraoral scanning; IOS intraoral scanning.

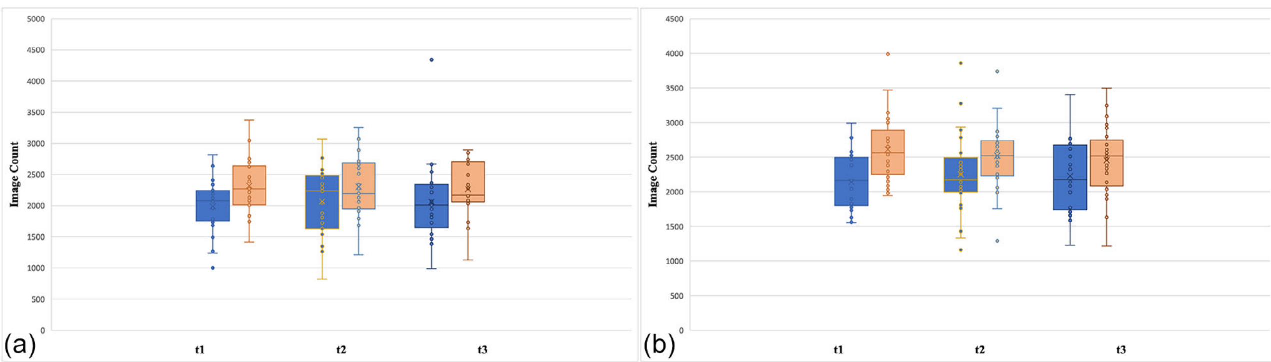

FIGURE 6 (a) ARIOS t1, t2, t3 mandibular and maxillary image count; (b) IOS t1, t2, t3 mandibular and maxillary image count. ARIOS, augmented-reality-assisted intraoral scanning; IOS intraoral scanning.

main difference in the present study is the amount of pre-trial training and number of repetitions in the trial design. We have identified the importance of andragogical practice of training by repetition as a means to consolidate two different layers of technological sophistication.[17] Using Knowles' 6 Principles of adult education theory[12] (need to know, self-concept, prior experience, readiness to learn, orientation to learning, and motivation to learn), the training sessions were designed to provide (1) basic information regarding IOS and AR technology, (2) adequate repetition until participants achieved standardized scanning goals, (3) input regarding adherence to scanning strategies, and (4) input regarding ergonomics. The duration of the training varied from one to three hours and one to two sessions depending on the participants self-direction. New technology such as IOS requires adequate training to reinforce learner experience and proficiency.[18–21] Since AR is an underutilized technology in dentistry, it is reasonable to assume that the provided training contributed to the differences observed between our previous study and the present study.

A comparison of scanning efficacy from ARIOS to IOS revealed an 8.5% decrease in mandibular scanning time, a 10.5% decrease in maxillary scanning time, an 8.6% decrease in mandibular scanning image count, and a 9.3% decrease in maxillary image count in favor of ARIOS. These results contrast sharply with a previous investigation,[14] where scanning time and image count increased from IOS to ARIOS by 19.84% (mandible scanning time), 18.05% (maxilla scanning time), 13.73% (mandible image count), and 12.07% (maxilla image count). While the results did not achieve statistical significance, this discrepancy may be attributed to andragogical training[17] while utilizing an OST-HWD, which likely improved scanning efficiency in ARIOS by enhancing users' ability to adapt and optimize their scanning techniques.

AR has been extensively investigated for its utility in medicine. Applications include but are not limited to intubation,[22] central line placement,[23] laryngoscopy,[24] fluoroscopy,[25] and laparoscopy.[26,27] Although these studies did not show a difference in procedure time, they reported higher participant adherence to the evidence-based practice and the procedure protocol. In an in vitro investigation, Heiliger et al. reported SURG-TLX[28] survey results indicating higher "Mental Demands" and "Physical Demands" scores in the control compared to the experimental conditions.[26] Similarly, the present study found reinforced results in the NASA-TLX survey.

In the present study, participants reported significantly lower scores for the subscales "Mental Demand," "Physical Demand," "Temporal Demand," "Effort," and "Frustration" in ARIOS compared to IOS conditions, indicating a substantially lower perceived task load in ARIOS. The subscale "Performance" was slightly lower for ARIOS (with lower scores indicating better performance), reflecting participants' perceived successful task completion.

Loss of tracking occurred both in ARIOS and IOS conditions, with slightly lower frequency observed in ARIOS than IOS. In both conditions, loss of tracking led to increased scanning time ($p < 0.01$); however, the differences between the two modalities were not statistically significant. The findings of deviation from the scan strategy indicate that adherence to a proper scanning strategy did not significantly impact the completion time for IOS. However, in the ARIOS condition, deviations from the recommended scan strategy resulted in a significant increase in the time required to complete the scan ($p = 0.015$) (Supporting Information). This discrepancy can be interpreted through the lens of Cognitive Load Theory (CLT),[29] which postulates that the finite capacity of working memory limits learning ability. CLT categorizes cognitive load into three distinct types: intrinsic cognitive load (ICL), which is inherent to the complexity of the task; extraneous cognitive load (ECL), which arises from suboptimal instructional design or interface complexity; and germane cognitive load (GCL), which facilitates schema construction and meaningful learning.[29] Well-designed AR tasks should mitigate ECL while enhancing GCL to optimize learning and performance outcomes. However, if the AR task is overly complex or poorly matched to participants' prior training, ICL may overwhelm working memory, thereby impeding task efficiency.[30] The observed increase in completion time for ARIOS under a sub-optimal scanning strategy suggests that the cognitive demands imposed by the AR interface may have introduced additional ECL or amplified ICL beyond the learners' cognitive capacity. This underscores the importance of designing AR training environments that effectively manage cognitive load to enhance procedural efficiency and learning retention.

During the IOS condition, 17 participants reported needing to adjust their posture more than 25% of the time, compared to only eight participants in the ARIOS condition. Six participants stated they had to adjust their posture more than 50% of the time in the IOS condition compared to two participants in the ARIOS condition. Participants deviated from an ergonomic posture significantly more with IOS than with ARIOS ($p < 0.01$). Such merits are largely due to the position of the display. Utilizing OST-HWD enables the operator to avoid looking away from the field of interest (i.e., the patient). The posture described in "IOS Standard 11226 Ergonomics-evaluations of static operating postures" is recommended for dental professionals and is referred to as balanced or neutral posture.[31] This is a seated posture—natural, unforced, stress-free, and symmetrical—that takes into account the locomotor physiology of the human body.[31] A recent systematic review reported 64%–93% of dental professionals experience musculoskeletal disorder (MSD) throughout their careers.[32] MSD etiology includes cervical torsion, prolonged body flexion, and suboptimal posture. Kinematic data indicates high ergonomic risk for dental students, highlighting the need for ergonomics training and equipment.[33]

Among 25 participants, 24 expressed that ARIOS was easier to use than IOS. Feedback comments from the participants indicated the weight of the headset, and the clarity of display as the desired areas for improvement. One participant expressed lightheadedness during the trial. This side effect may be derived from vergence–accommodation conflict (VAC),[34] which is a well-known phenomenon related to stereoscopic displays in which content is focused at a different distance than its geometric depth: it forces the user's brain to unnaturally adapt to conflicting cues and increases fusion time of binocular imagery while decreasing fusion accuracy.[35] VAC is a major factor contributing to discomfort in current VR and AR, especially for near-field tasks. Displays that can correctly set the distance at which virtual content is focused could eliminate VAC in future headsets.

Accuracy refers to a combination of trueness and precision, as described in ISO standard 5725. In the present study, a comparison was done between each repetition; therefore, trueness was not evaluated. RMS[16] was chosen to evaluate precision and to quantify the ROI's surface error, as it incorporates elements of both bias and dispersion in one metric. Despite the 8%–10% difference in scanning time and image counts, RMS was comparable between the ARIOS and IOS scan data sets. These results may indicate that a slight difference in scanning time and image count may not lead to significant changes in precision in an in vitro setting. However, caution should be taken to apply the same logic in vivo.

The present study had several limitations. The participants were inexperienced dental students, the sample size was small, and a single OST-HWD was tested. Moreover, due to the absence of tracking and alignment of IOS data to the field of interest, the overlayed information was projected within the frontal direction of the operator's line of vision. Additionally, a typodont lacks the representation of a clinical situation such as saliva, patient movement, and musculature. Future investigations should focus on an in vivo investigation to validate the presented results, identifying technological applications of AR in the dental field, and comparing different headsets for various dental applications.

CONCLUSION

ARIOS was advantageous compared to IOS in operator perception, ergonomic posture maintenance, improved scanner tracking, and ease of scanner orientation. Additionally, scanning efficacy was found to be superior in the ARIOS condition. Such results are attributable to the single line of vision enabled by the OST-HWD and andragogical training that enabled participants' adaptability to a new métier. Further development of OST-HWD technology and relevant software, improved user-friendliness, and systematic operator preparation via curricular implementation are required to increase utilization of AR in dentistry.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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