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**How to cite**

ZARAUZ YANEZ, Cristina et al. Influence of age and scanning system on the learning curve of experienced and novel intraoral scanner operators: a multi-centric clinical trial. In: Journal of dentistry, 2021, vol. 115, p. 103860. doi: 10.1016/j.jdent.2021.103860

This publication URL: https://archive-ouverte.unige.ch//unige:161597

Publication DOI: 10.1016/j.jdent.2021.103860

Journal of Dentistry 115 (2021) 103860

Contents lists available at ScienceDirect

Journal of Dentistry

journal homepage: www.elsevier.com/locate/jdent

# Influence of age and scanning system on the learning curve of experienced and novel intraoral scanner operators: A multi-centric clinical trial.

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ARTICLE INFO

*Keywords:*
Intraoral scanner
Performance
Learning curve
Experience
Age

ABSTRACT

*Objectives:* To evaluate the effect of age and intra-oral scanner (IOS) on the learning curve of inexperienced operators.
*Methods:* Thirty-four operators pertaining to 1 of 3 groups: (G1) students ≤ 25 years (y), (G2) dentists ≥ 40y, and (G3) a control group of experienced IOS operators (no age limitation), were included. All participants performed baseline and final quadrant scans on a volunteer subject, before and after a training program of 3 sessions, with two different IOS: TRIOS 3 (S1) and True Definition (S2). Baseline and final scanning times were registered in seconds.
A Pearson correlation was applied to evaluate the correlation between age and scanning time.
An ANOVA of repeated measures test was applied to evaluate inter-group (G1, G2, G3) and inter-system performance.
Significance level was set at $a = 0.05$.
*Results:* Age and scanning time for inexperienced operators showed a weak positive correlation for final scanning time ($r = 0.29$, $p < 0.05$). When comparing groups and filtering by IOS, S1 failed to show differences between groups ($p > 0.05$). With S2, the control group demonstrated a better performance than G2 ($p < 0.05$), while G1 only demonstrated a better performance than G2 at final scanning time ($p = 0.005$). Overall, the type of IOS had a significant impact on the scanning time ($p < 0.001$).
*Conclusion:* Results from this study indicate that age and type of IOS have an impact on the performance and learning curve of inexperienced IOS operators.
*Clinical significance:* Gaining knowledge on how different aspects, such as age, experience or IOS system, influence the learning curve to IOSs is relevant due to the financial and strategical impact associated with the acquisition of an IOS.

## 1. Introduction

Nowadays, many workflows in dentistry begin with an initial impression, a registration of the required teeth, implants, and neighboring tissues. The accuracy of this step is key for the final success of the treatment [1,2].

Traditionally, impressions were made using conventional trays and elastomeric materials. This approach is reliable and provides clinically acceptable outcomes [3]. However, conventional impressions remain technique sensitive [3,4].

Intra-oral Scanners (IOS) were introduced in the early 80 s to counteract the disadvantages of conventional impressions, such as avoidance of uncomfortable trays and impression materials in the oral cavity that were frequently associated with gagging, or logistical challenges such as storage, transportation and handling of impressions and master models [4,5]. The initial idea was to improve efficiency by avoiding the inconveniences of the analog processes [4]. For years, the accuracy of IOS remained inferior to conventional impression methods [6]. Over the last decade, technological developments have allowed a significant improvement in the accuracy of IOS to comparable levels of conventional impressions on single-unit and short-span fixed dental prostheses (FDP) on teeth [7,8] and implants [9–11].

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https://doi.org/10.1016/j.jdent.2021.103860
Received 19 August 2021; Received in revised form 16 October 2021; Accepted 19 October 2021
Available online 26 October 2021

Once the accuracy of conventional and digital impressions is no longer an issue, other aspects gain relevance in the choice of the impression method. Factors such as the costs (initial purchase, consumables, and regular maintenance) [12], the patient's [13] and operator's perception [6,14], the time required to perform an impression [13,15], or the learning curve [16] may play a decisive role. Purchasing costs and maintenance fees are high for IOS systems, although they require fewer consumable materials and storage space than conventional impressions using elastomers [17].

Several studies have shown a patient preference towards IOS in comparison to conventional impressions [13,18,19], while operator preference might depend on the age of the operator [20]. It has been shown that dental students preferred IOS, whereas experienced clinicians tended to prefer conventional over digital impressions [20].

Multiple factors influence the required time to perform conventional or digital impressions. For conventional impressions, factors such as material setting time, tray preparation including screw-access perforation, and adhesive application contribute to the duration of the procedure. In contrast, digital impressions are affected by extension of the impression area (full-arch vs. quadrant impressions), IOS system used, software version, lighting conditions, and patient-related factors (cheek flexibility, tongue interference, salivary rate, breath, preparation margin depth) [4].

Learning curve is defined as the acquisition of a skill over time until plateau performance is achieved [21]. Time has been used to evaluate the learning curve of IOS [12,16,22]. Roth et al. used a hybrid model to evaluate learning curve, by measuring *in vivo* scanning time and image number (count of images created by IOS during the scanning process) [12]. Kim et al. compared model scanning times before and after 4 training sessions (*in vivo*) [12], and Waldecker et al. evaluated the effect of amount of training sessions (1–3) on model scanning times of dental students [16]. It was shown that repeated practice (1–4 sessions) reduced scanning time, yet as no control group was used, it was not possible to determine if proficiency had been reached [12,16,22]. Age was not controlled in any of these investigations.

Evaluating whether factors such as age, previous intraoral scanning experience or the scanning system itself influence the performance and learning curve of IOS operators in a clinical setting needs further clarification.

For this purpose, the objectives of this multicenter clinical trial were to evaluate if the operator age (≤ 25 years, ≥ 40 years) and the type of IOS influence the performance and the learning curve of inexperienced IOS users compared with experienced users. Therefore, the null hypotheses were established as: (1) operator age does not influence the performance and learning curve of IOS operators, and (2) the intraoral scanning system does not influence the performance and learning curve of IOS operators.

## 2. Materials and methods

### 2.1. Study design

This multi-centric clinical trial was performed in the Faculty of Dentistry of University Complutense of Madrid (Center 1) and the University Clinics of Dental Medicine of University of Geneva (Center 2). Consequently, the study protocol was submitted and approved by the local ethical committee of the canton of Geneva (No. 2017–01717) and by the local ethical committee of the Hospital Clínico San Carlos, Madrid (No. 17/367-E).

Two IOS systems, both Conformitè Europëenne (CE) certified, were evaluated in both centers: Trios 3 (3 Shape, Copenhagen, Denmark) and True Definitions (3 M, St. Paul, MN, USA). IOS' characteristics are shown in Table 1.

### 2.2. Study participants

To evaluate if age influences the learning curve of clinicians inexperienced with IOS, two analogous test groups (with marked age difference) and one control group were established in both centers:

- Test Group 1 (≤ 25): dental students aged 25 or younger with no previous experience in the use of IOS.
- Test Group 2 (≥ 40): dentists aged 40 or older with no previous experience in the use of IOS.
- Control Group (control): clinicians with experience in the use of IOS, with no age restriction. Experience was determined by the completion of at least 100 scans [25].

A sample size calculation was performed, including an alpha error of 0.05, a 1-beta error of 0.8 for three groups, and an effect size of 0.3 [26], based on a similar study [22]. In that study, two groups of oral hygienists had shown an improvement in time registrations of 23% and 24%, respectively, after training. The sample size calculation resulted in a minimum of 30 operators. Finally, 36 operators were included in total in both centers (Center 1 and Center 2,) 18 operators per center, to compensate for potential dropouts.

An *in vivo* model was chosen. Ideally, a single patient would be selected to evaluate operators under most standardized study conditions (same cheeks, same mouth opening, etc.). However, as scanning a single patient many times would not be acceptable for ethical reasons, six volunteer study subjects were recruited in each center, 12 in total. Fourth-year dental students, medically healthy, free of active oral inflammation, who were interested in contributing to the advancement of research and becoming acquainted with IOS systems were voluntarily included as study subjects.

### 2.3. Study sessions

All study operators (≤ 25, ≥ 40, and control) completed a 4-session study schedule (Table 2) with each IOS, including three training sessions (one on typodont models and two *in vivo*) and two test scans (baseline and final). Each study session was spaced at least a week apart. Study introduction, training sessions, and time recording were performed in each center by a trained investigator (MRM (Center 1) and AAH (Center 2)).

During the first study session, the study protocol and scan strategy (Fig. 1) were introduced. Participants were requested to complete a partial scan extended from mesial of the canine to distal of the first molar of quadrants 1 and 4, including at least 3 mm of gingiva, and a bite registration (Fig. 1). Study subjects were all in a supine position, and all study scans were performed under the supervision and assistance (retraction and aspiration) of the trained investigator, with dental chair lights turned off [27]. An impression was deemed satisfactory when the requested regions were registered, allowing minimal interproximal

**Table 1**
Intraoral scanner (IOS) characteristics.

| IOS | Software version | Technology | Description |
|---|---|---|---|
| Trios 3 | 1.18.1.2 and 1.18.1.3 | confocal microscopy | The projection of optical slices on the object reflects focused and defocused images. The sharpness of the image determines the distance to the object, correlating to the focal length of the lens [23]. |
| True Definitions | 5.3.1 and 5.4 | active wavefront sampling | Distance and depth information are derived and calculated from the pattern produced by each point formed by the rotating module around the optical axis [24]. |

**Table 2**
Study schedule: task description in each session, time each operator and study subject are required to invest for study participation, per intraoral scanner (IOS).

| Study session | Study task | Time needed by operator / per IOS | Time needed by subject / per IOS |
|---|---|---|---|
| 1 | Introduction to system and scan strategy | 10 min (group) | / |
| 1 | Baseline scan with test patient | 10 min (each) | 30 min |
| 1 | Training with models | 20 min (each) | / |
| 2 | Training with patient | 20 min (each) | / |
| 3 | Training with patient | 20 min (each) | / |
| 4 | Final scan with test patient | 10 min (each) | 30 min |
| Total time needed | | 90 min (1 h, 30 min) | 60 min (1 h) |

gaps. An example case is shown in Fig. 2; a clinical picture (Fig. 2a), and the corresponding complete scans with IOS S1 (Fig. 2b) and S2 (Fig. 2c).

The time each operator spent filling in the laboratory order and scan was recorded in seconds (baseline computer time and baseline scan time). Following the baseline records, each operator performed a 20 min training of specific quadrant scanning on typodont models (Frasaco GmbH, Tettnang, Germany).

The second and third sessions were exclusively training sessions (20 min each), in which each study operator practiced scanning *in vivo* by scanning each other.

In the fourth session, each study operator performed the final scan on their study subject. Again, the time required to complete the laboratory order and the scanning time were recorded in seconds (final computer time and final scan time).

Because completing the study with the first IOS system implied some training for the inexperienced operators, which could potentially have

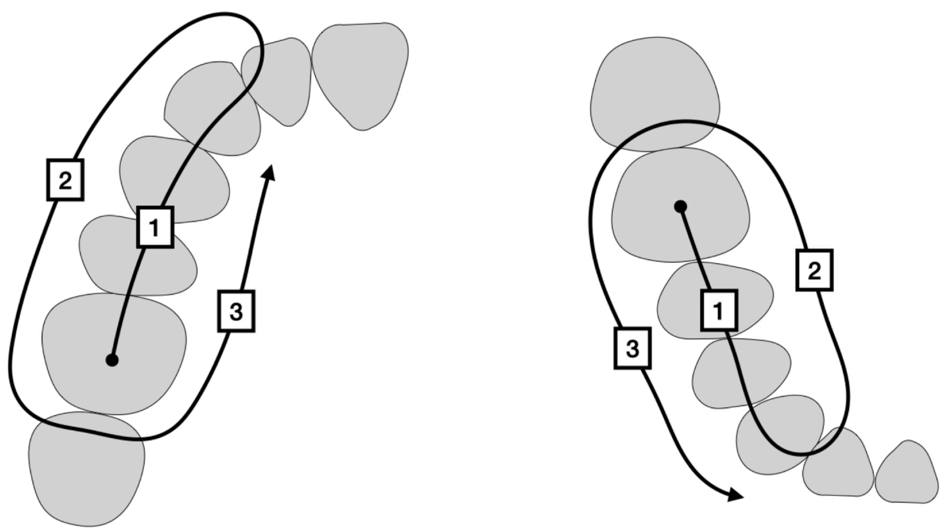


**Fig. 1.** Scan strategy for maxillary (left image) and mandibular (right image) arches, as recommended by the intraoral scanners' manufacturers.

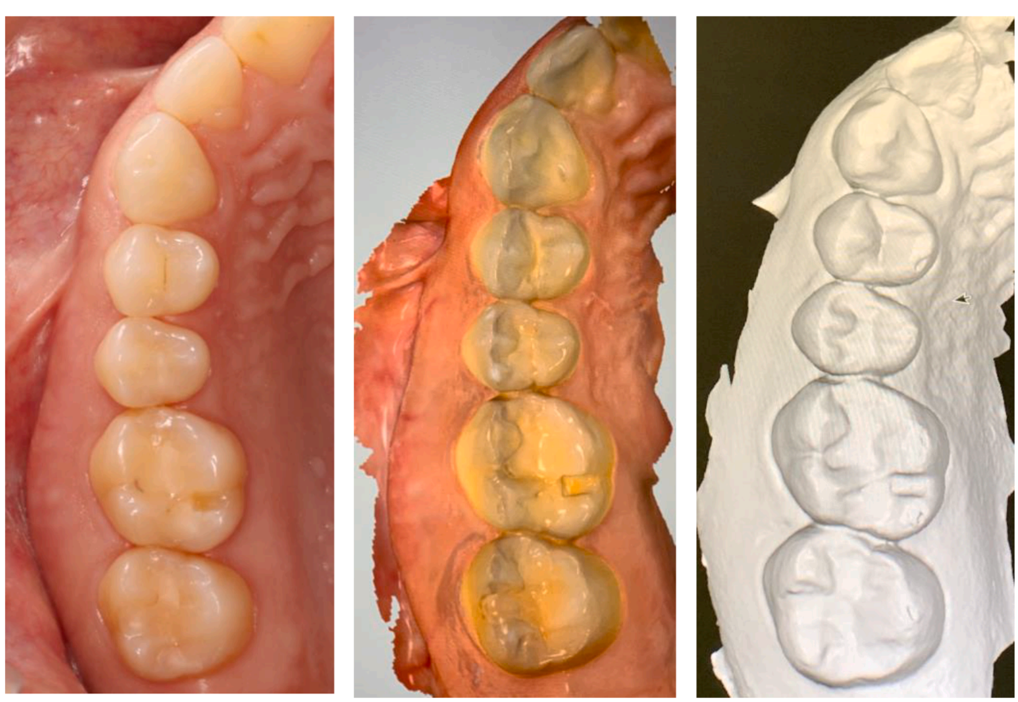

**Fig. 2.** A clinical picture of quadrant 1 is shown (2a), and the corresponding complete scans with S1 (2b) and S2 (2c).

an impact on their performance when completing the study with the second IOS, half of the study participants initiated the study with Scanner 1 (S1) (Trios 3 IOS), based on confocal microscopy technology. The other half began with Scanner 2 (S2) (True Definition IOS), based on active wavefront sampling technology.

### 2.4. Performance and learning curve assessment

The performance was evaluated by comparing the time taken by each study group (≤ 25, ≥ 40, control) to complete the study tasks: (i) filling in the laboratory order (computer time) and (ii) completing a satisfactory quadrant digital impression with each IOS (scanning time), at baseline and final time points.

The learning curve was assessed by comparing the time improvement of each study group before and after training (between baseline and final time points).

### 2.5. Statistical analysis

Independent variables were age (≤ 25 vs. ≥ 40 years old), experience (inexperienced vs. experienced) and IOS system (S1 and S2). Dependent variables were computer time and scanning time at baseline and final time points.

A Kolmogorov–Smirnov test was applied to test the normality of the sample, and the Levene test was applied to evaluate the homogeneity of variances.

A Pearson correlation was applied to evaluate the correlation between age and time performance (baseline and final scanning), excluding the control group.

An ANOVA of repeated measures test, with a Bonferroni correction, was applied to evaluate inter-group (≤ 25, ≥ 40, control) performance (at baseline and final scanning); inter-system (S1 vs. S2) performance (at baseline and final scanning); and experience (inexperienced vs. experienced) performance (at baseline and final scanning).

For the intra-group learning curve evaluation (training effect), the paired-samples *t*-test was applied to evaluate within-group changes (between baseline and final scanning).

The level of significance was set at $a = 0.05$. All results were calculated with SPSS version 26 (SPSS, Chicago, IL, USA).

## 3. Results

A total of 34 operators and 12 study subjects (patients) participated in the two centers of this study. Two operators initially assigned to group ≥ 40 in Center 2 were unable to participate due to agenda incompatibility with the study schedule and were excluded from the study. Mean age of study participants, per center and per group are shown in Table 3.

Computer time ranged between 8 and 170 s (seconds), with a mean (SD) baseline computer time of 62.3 (38.3) s and 57.7 (37.1) s for final computer time. Neither age, scanning system, or training had a significant effect on computer time ($p > 0.05$).

The Kolmogorov test revealed a normal distribution of the data for scanning times 1 and 2 ($p = 0.200$) and the Levene test revealed homogeneous distribution of variances for scanning time 1 ($p = 0.140$) and for scanning time 2 ($p = 0.069$).

Scanning time ranged between 50 s (control/S1/final scan) and 604 s (≥40/S2/baseline scan), with an overall mean (SD) baseline scanning time of 269.4 (124.8) s and an overall final scanning time of 225.2 (103.2) s (Table 4).

**Table 3**
Mean age per center and per group.

| | Mean age | | |
|---|---|---|---|
| Center | Grupo < 25 | Grupo > 40 | Group Control |
| Center 1 | 22 | 59 | 38 |
| Center 2 | 23 | 54 | 34 |

Operators who had better performances (shorter scanning times) at baseline also demonstrated better performances on final scanning after training ($r = 0.8$, $p < 0.01$). Age and scanning time for inexperienced operators showed a weak positive correlation for final scanning time ($r = 0.29$, $p < 0.05$).

Experienced operators demonstrated a better performance than inexperienced operators at both time points ($p = 0.016$). When comparing groups (≤ 25 years (y), ≥ 40y, control), the control group demonstrated a better performance compared with group ≥ 40y at baseline ($p = 0.013$) and final scanning time ($p < 0.001$). However, no differences were found between control and group ≤ 25y and between group ≤ 25y and group ≥ 40y ($p > 0.05$). When comparing groups and filtering by IOS, S1 failed to show differences between groups ($p > 0.05$). With S2, the control group demonstrated a better performance than group ≥ 40y at baseline ($p = 0.010$) and final scanning time ($p = 0.000$), while the group ≤ 25y only demonstrated a better performance than group ≥ 40y at final scanning time ($p = 0.005$).

Overall, the scanning system had a significant influence on the baseline and final scanning times ($p < 0.001$).

With respect to the learning curve, young operators (≤ 25y) revealed a significant improvement in the scanning time between baseline and final scanning for both IOS systems ($p < 0.05$). Older operators (≥ 40y) only showed a significant improvement with S1 ($p < 0.05$). Experienced operators (control) revealed a significant improvement with S2 ($p < 0.05$). A graphical representation of the performance at both time points and time improvement of each group and scanning system is shown in Fig. 3.

## 4. Discussion

The findings of the present clinical study showed that younger operators performed faster scans than older operators with at least one of the IOS (S2). Moreover, improvements in scanning time (learning curve) were seen after training for younger operators with both IOS, while improvements were only seen with one IOS (S1) for older operators. Therefore, as the generation group (age) and the scanning system had an impact on the scanning performance and learning curve of novel IOS operators, both null hypotheses were rejected.

Computer times revealed acceptable performance for all groups and systems even before training. One of the IOS (S2), and the younger operators showed a tendency for shorter computer times. However, no significant differences were found, probably because computer times were generally short.

Studies in the medical field used experienced operators to provide the benchmark for performance and evaluate the learning curve of novel operators [28,29], as was done in the present study. The control group, integrated by IOS expert operators, would be expected to show plateau performance before and after training, or in other words, should not show an improvement in scanning time performance after training, as their learning curve should be flat. In line with this expectation, the control group showed the best performance with both IOS, in agreement with what was reported in a previous study [18], and no improvement with one of the IOS (S1). Unexpectedly, the control group showed a significant improvement with the other tested IOS (S2), which was also the steepest improvement of all groups and IOSs. Participants in the control group were required to have performed at least 100 scans [26] to be included in this study. However, it was not specifically controlled what IOS had been used to acquire experience. In fact, members of the control group were more experienced with S1 than with S2, which is reflected in their flat learning curve with S1 and their steep learning curve with S2. These findings indicate that once an operator is experienced with one IOS, the learning curve for another IOS can be expected to be steep.

The impact of age on scanning time was non-existent before training

**Table 4**
Results table; Mean, standard deviations of Baseline and Final scanning times, including improvement recordings are shown for test and control groups, filtered by intraoral scanner (IOS).

| IOS | Baseline scanning time | | | Final scanning time | | | |
|---|---|---|---|---|---|---|---|
| | Group | Mean (sec) | Standard Deviation | Group | Mean (sec) | Standard Deviation | Improvement (sec) |
| S1 | ≤ 25 years (y) | 208,9 | 91,8 | ≤ 25 y | 163,2 | 63,0 | 45,7 |
| | ≥ 40y | 217,5 | 103,5 | ≥ 40y | 180,7 | 90,3 | 36,8 |
| | Control | 156,8 | 75,6 | Control | 137,9 | 54,3 | 18,9 |
| S2 | ≤ 25 y | 339,3 | 94,8 | ≤ 25 y | 271,1 | 57,0 | 68,2 |
| | ≥ 40y | 414,0 | 104,4 | ≥ 40y | 371,0 | 75,2 | 43,1 |
| | Control | 287,6 | 88,8 | Control | 235,7 | 76,9 | 51,8 |

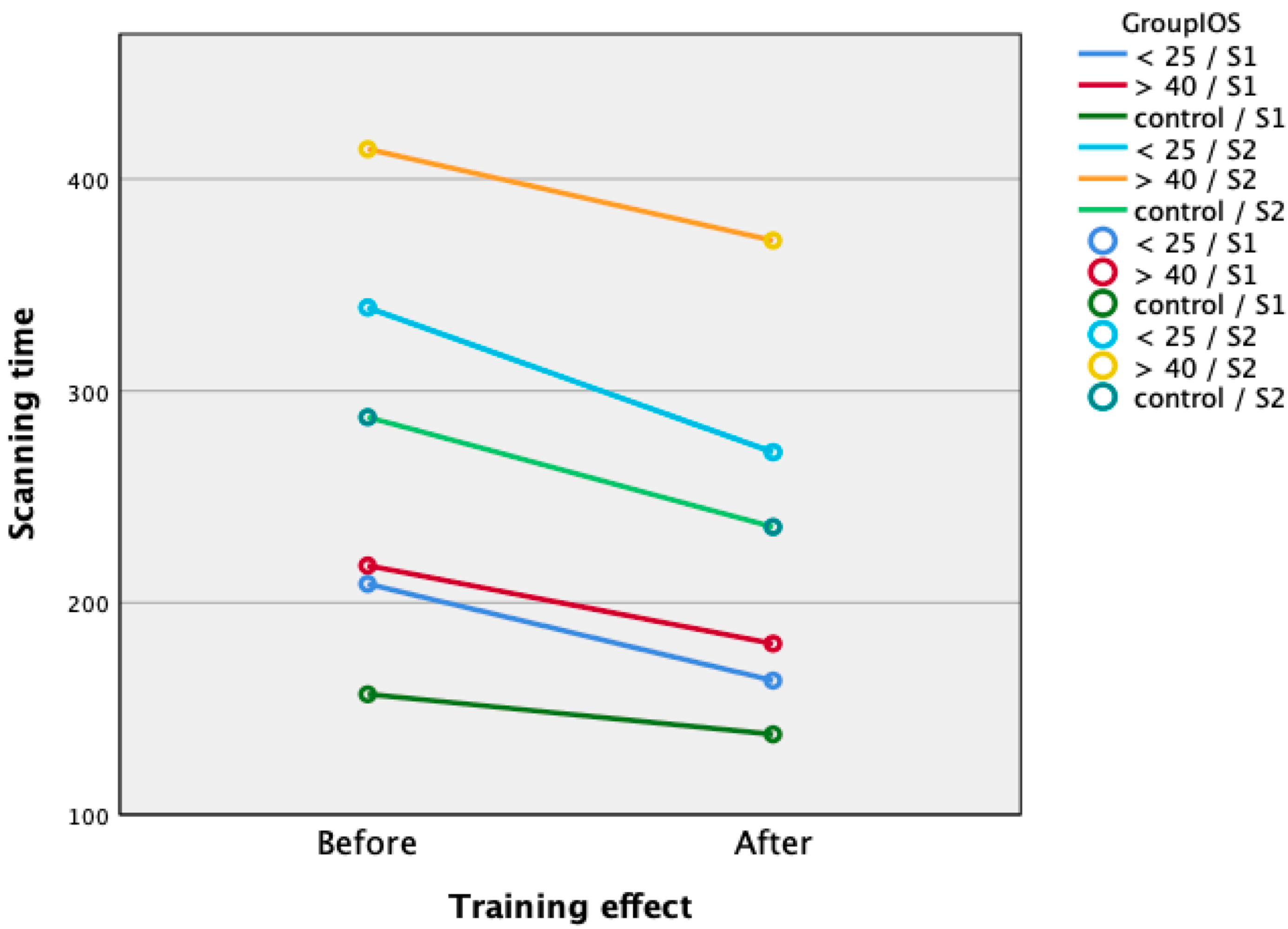


**Fig. 3.** Line graph: Scanning time (seconds) by scanning session (before and after training) filtered by Group (≤ 25 years (y), ≥ 40y, control) and Intraoral scanner (IOS) (S1, S2).

and minor after training, shown by a weak positive correlation between age and final scanning time. This effect was seen specifically for S2, where younger and experienced operators showed a better performance for final scanning times than older operators. Several studies in cognitive psychology have shown that after appropriate training, the benefits of learning plasticity presented by youth are diluted, and older people achieve similar performance and attitude towards computer tasks [30, 31]. Even though older people may reveal slower rates of learning, they maintain their brain plasticity and can retain the benefits of training as much as young adults [32]. The present study's findings may therefore indicate that, while three training sessions are sufficient for novel operators (no matter the age) when S1 is used, older operators might need additional training sessions with S2.

Nevertheless, the strong correlation between each operator's initial and final scanning times indicates that operators who were fast before training were also faster after training. Individual characteristics such as talent or previous experience using other technological devices (such as video games) could be hypothesized as possible factors to influence the performance and learning curve of inexperienced operators [32–34].

The impact of the scanning system was evident, with S1 showing faster performances and strong learning curves for both young and older operators. Experience only had an impact on the scanning times when S2 was used, while with S1, only experienced operators showed a tendency for faster scanning times. The greater differences between groups on the S2 IOS might indicate a higher sensitivity of this device to the operator.

Several software versions were used, as one center performed the study during one academic year (2017–2018) and the other center during the following year (2018–2019), and the software was updated in that time. Additionally, both centers have different temperature, pressure, and humidity conditions. Whether or not these confounding factors played a role in the findings of this investigation is unknown. Ideally, the study should have been performed simultaneously in both centers with the same software versions, under similar conditions.

The included IOS systems were based on different technology, confocal microscopy, and active wavefront sampling. Although both IOSs use light as a light source, they present some differences, such as the need for powder coating (for S2 and not for S1), camera size and weight (S2 has a smaller hand-piece than S1), and distance to the scanning object (S2 requires a specific scanning distance (1 cm), while the S1 hand-piece may be in contact with the occlusal surfaces to be scanned) and image acquisition mode (ultrafast imaging (S1) and continuous video sequencing (S2)). It may be difficult to evaluate how they independently affect scanning time, as systems can only be tested as a whole, and each system has a combination of characteristics. Overall, S1 showed a better performance and steeper learning curve than S2 when evaluating scanning time and additionally reflecting a lower impact of the operator (age or experience) on the scanning time, especially after training. This agrees with a previous study [22], where the same system (S1) reported a low influence of the operator on scanning time. Previous studies evaluating the accuracy of different scanners concluded that active wavefront sampling systems were as accurate as systems using confocal microscopy [1,2,35]. The correlation of scanning time on the accuracy of the resulting scans remains unclear and should be evaluated in future research.

This study was limited to two IOSs, hence the findings may not be applicable to other systems. Further research on multiple systems would be advisable to deepen the understanding of the influence of different aspects related to the operator on the learning curve of IOSs overall.

## 5. Conclusions

Within the limitations of this clinical study, it may be concluded that:

- Age, experience, and operator affected the performance and learning curve of novel intra-oral scanner operators when an active wavefront sampling IOS was used.
- The scanning system affects the performance and learning curve of novel intra-oral scanners operators.

## CRediT authorship contribution statement

**Cristina Zarauz:** Conceptualization, Methodology, Writing – review & editing. **Irena Sailer:** Supervision, Writing – review & editing. **João Pitta:** Writing – review & editing. **Mercedes Robles-Medina:** Investigation, Writing – review & editing. **Abra Abdulahai Hussein:** Investigation, Writing – review & editing. **Guillermo Pradíes:** Supervision, Writing – review & editing.

## Declaration of Competing Interest

The authors declare no conflict of interest with respect to this study. All intraoral scanners used in this multicentric clinical study were the property of the University Complutense of Madrid and the University of Geneva.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgements

We would like to thank Dr. Philippe Mojon for his guidance in statistical analysis, Dr Duygu Narin-Karasan and Dr. Juan Legaz for their valuable support in consulting and discussing digital and logistical technicalities throughout protocol development, and Dr. Andreina Laforì Dr. Ellen Vouters for their support during manuscript finalization.

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