INFLUENCE OF ATTACHMENT COLOR ON THE ESTHETIC PERCEPTION OF CLEAR ALIGNERS: AN EYE-TRACKING STUDY

Gil Guilherme **Gasparello**[1,2]; Fabio **Acciaris**[3]; Sergio Luiz **Mota-Júnior**[4]; Henrique Brunetti **Semaan**[2]; Mohamad Jamal **Bark**[2]; Orlando Motohiro **Tanaka**[2*]

[1] University of Oulu, Oulu, Finland; [2] Pontifícia Universidade Católica do Paraná, Curitiba, PR Brazil; [3] Private Practice, São Paulo, Brazil; [4] Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil.

Palavras-chave: Aparelhos ortodônticos removíveis; Maloclusão; Estética dentária; Rastreamento ocular.

RESUMO

Objetivo: Investigar como diferentes tonalidades de compósitos utilizados em *attachments* afetam a percepção estética entre leigos e estudantes de Odontologia, por meio da tecnologia de rastreamento ocular (*eye-tracking*). **Materiais e métodos:** Estudo transversal conduzido com 106 participantes (leigos e estudantes de Odontologia). Foram avaliadas imagens digitais de sorrisos com alinhadores e *attachments* nas tonalidades A1, A2 e A3. O *eye-tracking* foi utilizado para registrar padrões de fixação e a distribuição da atenção em regiões de interesse previamente definidas. **Resultados:** *Attachments* na tonalidade A3 atraíram maior atenção visual, especialmente entre leigos. Estudantes de Odontologia focaram principalmente nos incisivos centrais e apresentaram menor sensibilidade aos *attachments*, exceto quando utilizada a tonalidade A3. Foram identificados padrões de fixação distintos: leigos enfatizaram a estética global do sorriso, enquanto os estudantes direcionaram maior atenção aos *attachments*. **Conclusão:** O *eye-tracking* revelou diferenças significativas na percepção estética entre leigos e estudantes de Odontologia em resposta às variações de cor dos *attachments*. O conhecimento profissional modula a atenção visual, ressaltando a importância de considerar tanto o perfil do paciente quanto a seleção do material na tomada de decisão clínica em terapias com alinhadores.

Keywords: Orthodontic appliances, removable; Malocclusion; Esthetics, dental; Eye tracking.

ABSTRACT

Objective: To investigate how different composite shades of attachments affect esthetic perception among laypersons and dental students using eye-tracking technology. **Materials and Methods**: A cross-sectional study was conducted with 106 participants (laypersons and dental students). Digital images of smiles with aligners and attachments in shades A1, A2, and A3 were evaluated. Eye-tracking was employed to record fixation patterns and attention distribution across predefined regions of interest. **Results**: Attachments in shade A3 attracted greater visual attention, particularly among laypersons. Dental students primarily focused on central incisors and demonstrated reduced sensitivity to attachments, except when A3 shade was used. Revised fixation patterns indicated that laypersons emphasized overall smile esthetics, whereas dental students showed more localized attention. **Conclusion**: Eye-tracking revealed significant differences in esthetic perception between laypersons and dental students in response to variations in attachment color. The present evidence supports the clinical relevance of matching attachment shade and placement to patients' esthetic expectations in order to maintain the discrete appearance characteristic of clear aligners.

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***Correspondence to**:
Orlando Motohiro Tanaka. R. Imaculada Conceição, 1155, Curitiba, PR 80215-901, Brazil. E-mail: tanakaom@gmail.com
Telefone: 41999759852

INTRODUCTION

The relationship between patients and orthodontists has evolved from a profession-centered model to a patient-centered approach, prioritizing satisfaction, quality of life, and excellence in dental services.[1] The increasing demand for esthetic orthodontic treatments has driven the adoption of clear aligners, which have emerged as a viable alternative to conventional appliances by offering greater discretion during treatment.[2]

Advances in orthodontic materials have enabled the development of devices that meet both biomechanical requirements and patients' esthetic expectations.[3] Clear aligner therapy is associated with high expectations of comfort, esthetics, and performance, strongly influenced by brand-driven marketing.[1] However, clinical outcomes still remain controversial, as current evidence supporting their functional and esthetic effectiveness is limited and of low quality.[4,5]

Attachments bonded to teeth are essential for certain dental movements but may compromise smile esthetics during aligner therapy.[5] Attachment color directly influences patients' esthetic perception, which is modulated by factors such as natural tooth shade, aligner translucency, and color changes associated with dietary habits.[6]

With technological advances, eye-tracking has become an objective tool for evaluating visual attention in response to different aligner configurations. The presence of lips may divert visual focus from attachments, reducing their esthetic impact, whereas their absence may highlight these elements.[7]

Biomechanical alternatives, such as *divots* (small depressions incorporated into the aligner) or varying aligner thickness, have also been explored to reduce the need for visible attachments without compromising the efficiency of tooth movements.[8]

Thus, the individualization of orthodontic treatment, taking into account patients' esthetic perception, is essential for clinical success and treatment adherence. Investigating esthetic aspects of aligners may contribute to design improvements, promoting a more comfortable and satisfactory orthodontic experience.

Therefore, the objective of this study was to evaluate the esthetic perception of laypersons and dental students regarding different attachment colors in clear aligners using eye-tracking methodology, and to analyze whether differences exist between groups through qualitative assessment of heat maps. The null hypothesis was that there would be no difference in esthetic perception between laypersons and dental students regarding attachment color.

MATERIALS AND METHODS

This cross-sectional observational study employed eye-tracking technology to explore visual attention patterns. Given the exploratory and descriptive nature of the research, no inferential statistical tests were conducted; only descriptive statistics (means, standard deviations, and frequency distributions) were calculated to characterize the sample. The primary objective was to qualitatively illustrate visual attention patterns through heat map visualization rather than quantitative comparisons.

Sample size calculation

Sample size estimation was based on data from a previous study,[9] considering a statistical power of 80% (= 0.20) and a significance level of 5% (= 0.05). The minimum sample size required was 90 participants.

Inclusion criteria comprised individuals aged 18 years or older, with no academic training in dentistry, adequate visual acuity (with optical correction if necessary), no prior knowledge of the study objectives, and no previous participation in eye-tracking research. Exclusion criteria included a history of neurological disorders, use of psychoactive substances (including alcohol and illicit drugs), or current use of medications with potential effects on cognitive function, to ensure data reliability and consistency.

Clear aligner fabrication – in-office digital workflow

Clear orthodontic aligners were fabricated using an in-office digital workflow with the participation of postgraduate students from PPGO-PUCPR maintain fabrication consistency. Intraoral scanning was performed with an iTero 3.0 scanner (Align Technology, USA), and STL files were exported to ArchForm software (ArchForm Ltd., San Jose, CA, USA) for attachment planning.

Models were printed using a 3D printer (Anycubic Photon Mono 2, Shenzhen Anycubic Technology Co., Ltd., China) with Anycubic ABS-Like Resin Pro 2. STL files were prepared using the Anycubic Photon Workshop software. After printing, the models were washed in isopropyl alcohol and post-cured to guarantee dimensional stability and surface integrity.

Aligners were thermoformed with 0.76 mm Claris acetate sheets (Claris, Morelli, Sorocaba, Brazil) over the printed models, followed by manual trimming and polishing of the borders.

Attachment position and design

For standardization, attachments were strategically positioned on the maxillary teeth. Horizontal triangular

attachments were bonded to the maxillary canines, centered on the labial surface, to provide anchorage and three-dimensional control. On the maxillary lateral incisors, round-edge attachments were positioned incisally with a mesial orientation to facilitate rotation. On the maxillary left central incisor, two round-edge attachments were applied: one oriented incisally toward the mesial and the other cervically toward the distal, to optimize root torque. No attachments were planned for the mandibular arch. The distribution of attachments is illustrated in Figure 1.

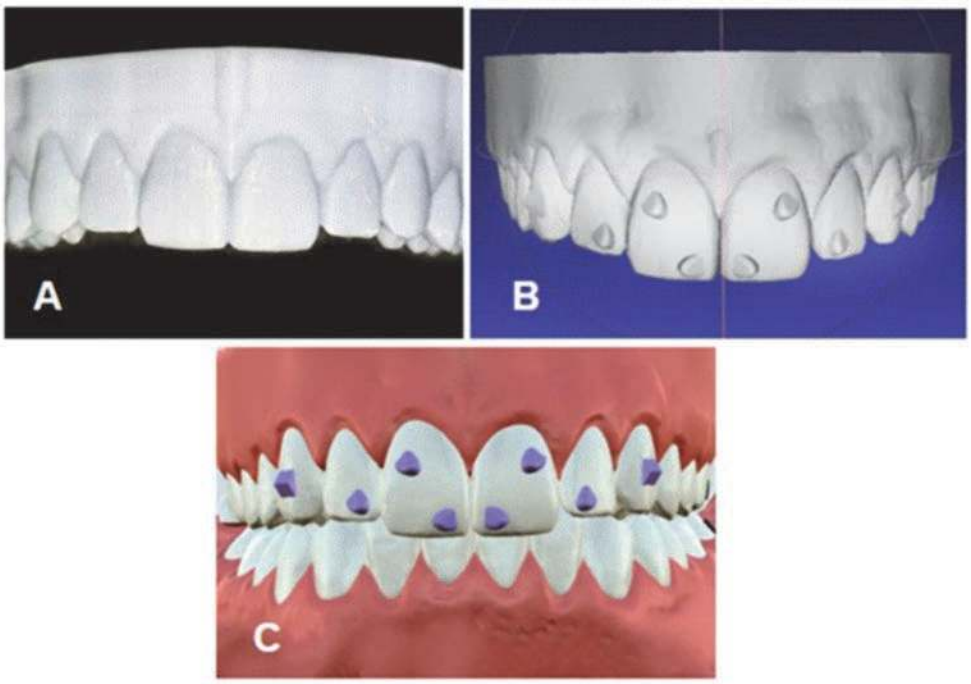

Figure 1. *A) Frontal view of the 3D-printed physical model of the maxillary arch without attachments; (B) digital treatment plan showing a frontal view of the maxillary arch with the designated sites for attachment placement; (C) digital simulation of attachments on the anterior maxillary teeth, including horizontal triangular attachments on the canines, rotational attachments on the lateral incisors, and optimized root-control attachment on the left maxillary central incisor.*

Photography and image manipulation

Aligner images were captured against a black background, with attachments fabricated using composite resins in shades A1, A2, and A3 according to the VITA shade guide (VITA Zahnfabrik, Bad Säckingen, Germany). Images were processed in Adobe Photoshop CC (Creative Cloud, version 25.x) exclusively for standardization of size and removal of visual artifacts, without structural alterations (Figure 2).

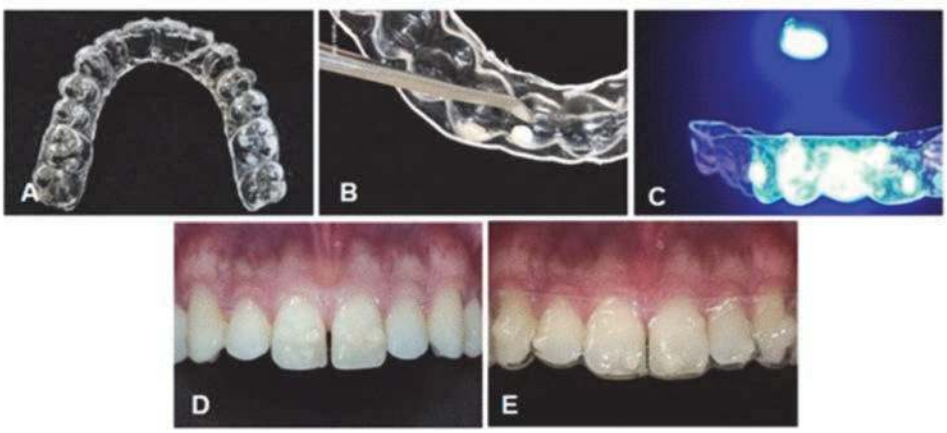

Figure 2*. (A) Thermoformed clear aligner; (B) placement of composite attachments into the aligner using a spatula; (C) light-curing of the composites within the aligner; (D) close-up view of the maxillary incisors with composites of different shades applied directly onto the enamel surface, without the aligner; (E) intraoral frontal view with the aligner in place, demonstrating esthetic adaptation.*

Eye-tracking evaluation

Eye-tracking was performed using the TheEyeTribe device (The Eye Tribe ApS, Copenhagen, Denmark). Data collection and analysis were conducted with OGAMA software (Open Gaze and Mouse Analyzer, Freie Universität Berlin), which enabled the definition of areas of interest (AOIs) in the maxillary and mandibular arches of each image.

The evaluation was carried out in a quiet room, with participants positioned individually 60 cm from a Dell P2317 monitor (resolution: 1366 × 768 pixels; vertical orientation), with the eye-tracker mounted below the screen. A nine-point calibration was performed, and only perfect calibrations were accepted.

Each participant viewed five images for five seconds each: one image without aligners and four images with aligners containing attachments in shades A1, A2, and A3 (Figure 3). Captured data (fixation time and number of visits to the AOIs) were organized for qualitative analysis through heat maps and gaze plots generated by OGAMA software. These outputs provided detailed information on the areas of greatest visual fixation and eye-movement trajectories, enabling a better understanding of the visual impact of attachments and supporting the optimization of their placement in clear aligner therapy.

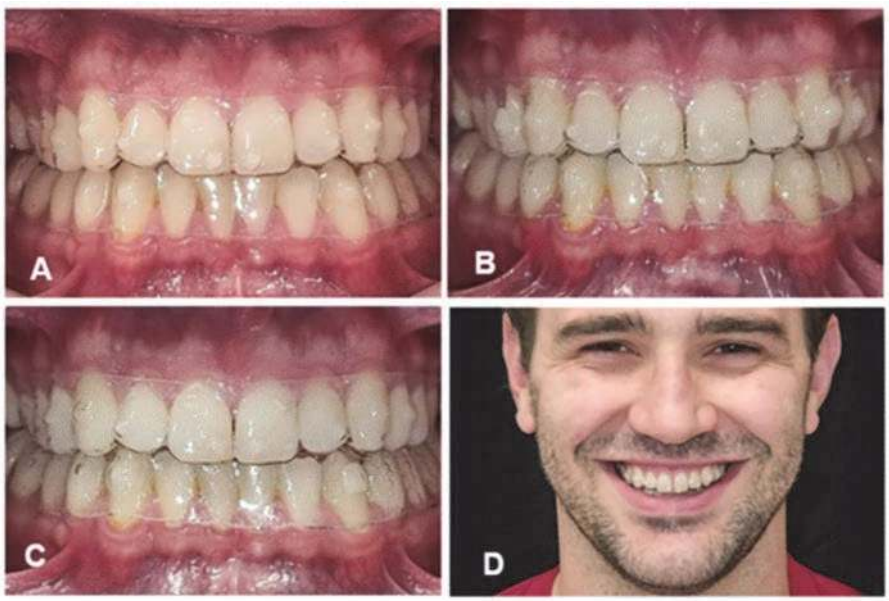

Figure 3. *Intraoral views of aligners with attachments in different composite shades: (A) shade A1; (B) shade A2; (C) shade A3; (D) frontal facial view with spontaneous smile while wearing the aligner.*

RESULTS

Sample characterization

A total of 106 individuals accessed the questionnaire, of which 97 participants (16.7%) provided complete and valid responses. Among the valid cases, 42.3% (n = 41) identified as male and 57.7% (n = 56) as female. The age of respondents ranged from 18 to 89 years, with a mean age of 27.88 years (SD = 12.21).

Overall heat maps (laypersons and dental students)

The global analysis of heat maps generated by eye-tracking (Fig 4) revealed perceptible differences in visual attention depending on the composite shade used for attachments. In intraoral images with shades A1 (Figure 4A) and A2 (Figure 4B), fixation was predominantly concentrated on the maxillary central incisors, with low intensity of attention toward attachment areas. This indicates that lighter shades had minimal visual impact and thus lower esthetic interference.

In contrast, the image with shade A3 (Figure 4C) showed a significant expansion of fixation areas. Although the central incisors remained the main focus, attention was clearly redirected toward attachment sites, suggesting that the darker shade created higher contrast with dental structures and consequently greater visual detectability. This finding was consistent across both laypersons and dental students, indicating a common visual response to stimuli with stronger chromatic salience.

In the facial image (Figure 4D), the pattern of attention shifted, with the primary focus on the mouth, followed by the nose and eyes. The predominance of fixations in the oral region suggests that aligners and attachments, even when discreet, can influence gaze direction in broader facial contexts.

Overall, shade A3 was the most visually detectable among those tested, and was the only shade that significantly redirected gaze toward attachment. Comparisons among shades confirmed that colors closer to natural tooth shade (A1 and A2) exert less esthetic impact, whereas darker or more saturated shades (A3) increase attachment visibility and may compromise the desired esthetic discretion of clear aligner therapy.

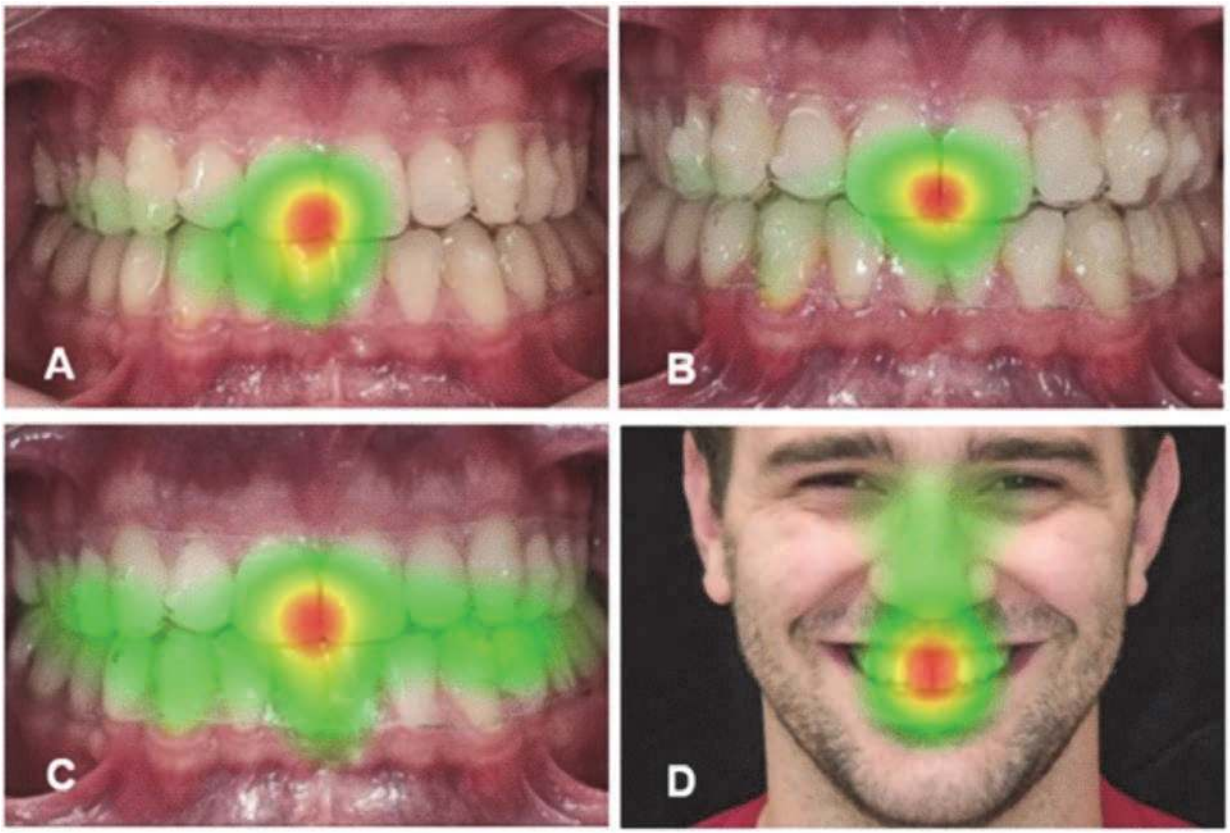

***Figure 4**. Heat maps generated from eye-tracking data of lay participants and dental students, illustrating regions of greatest visual fixation: (A) aligner with shade A1 attachments; (B) shade A2; (C) shade A3; (D) frontal facial view with aligner, highlighting gaze concentration in the smile region. Warmer colors (red/yellow) indicate higher fixation density, whereas cooler colors (green/blue) indicate lower fixation density.*

Laypersons

Heat maps for the layperson group (Figure 5) revealed relevant variations in gaze distribution depending on attachment shade. In images with shades A1 (Figure 5A) and A2 (Figure 5B), attention was mainly directed toward the central incisors, but laypersons exhibited greater gaze dispersion toward lateral areas, including attachment regions, especially on premolars and canines. This suggests higher visual sensitivity of laypersons to subtle volumetric or chromatic changes.

In the image with shade A3 (Figure 5C), the fixation pattern shifted markedly. The highest intensity of visual attention was concentrated on the attachment located on the observer's left side (image right), surpassing even the central incisors. This reinforces that more saturated or contrasting shades are readily detected by non-specialist observers, directly influencing esthetic perception.

In the facial image (Figure 5D), laypersons focused primarily on the smile, with secondary attention to the nose and eyes. This demonstrates that, even in a broader facial view, laypersons remain sensitive to atypical intraoral elements such as attachments, indicating that small esthetic changes are more readily perceived in this group.

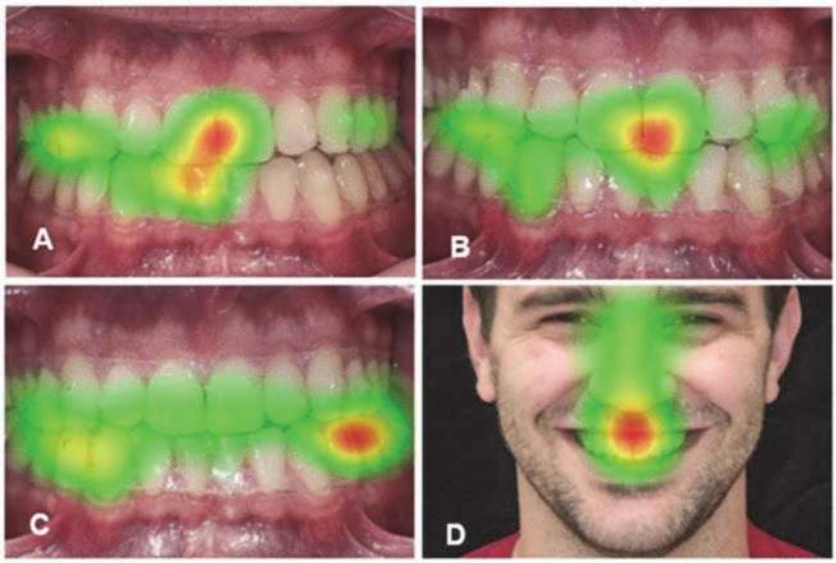

Figure 5. *Heat maps generated from lay participants, showing regions of greatest visual fixation: (A) aligner with shade A1 attachments; (B) shade A2; (C) shade A3; (D) frontal facial view with aligner, emphasizing gaze concentration in the smile region. Warmer colors (red/yellow) indicate higher fixation density, whereas cooler colors (green/blue) indicate lower fixation density.*

Dental students

Analysis of heat maps for dental students (Figure 6) revealed a more concentrated and selective pattern of gaze, with less dispersion compared with laypersons. In intraoral images with shades A1 (Figure 6A) and A2 (Figure 6B), visual attention was strongly concentrated on the central incisors, with almost no fixations on attachment areas. This suggests that students, due to technical familiarity and awareness of their clinical function, do not perceive attachments as esthetically relevant.

In the A3 shade image (Figure 6C), although the central incisors remained the primary focus, a broader distribution of gaze was noted, with increased fixations on attachment sites. This indicates that even among trained observers, the darker shade provided sufficient contrast to influence visual perception, albeit less markedly than in laypersons.

In the facial image (Figure 6D), attention remained centered on the mouth, with residual fixation on the nose and almost none on the eyes. These findings differ from previous study in which the eyes were typically the primary fixation point in facial images, suggesting that intraoral devices can alter gaze patterns, even among trained observers.

Overall, dental students demonstrated lower esthetic sensitivity to chromatic variations in attachments, with more centralized and selective fixation patterns. This supports the hypothesis that esthetic perception is modulated by professional training and prior experience.

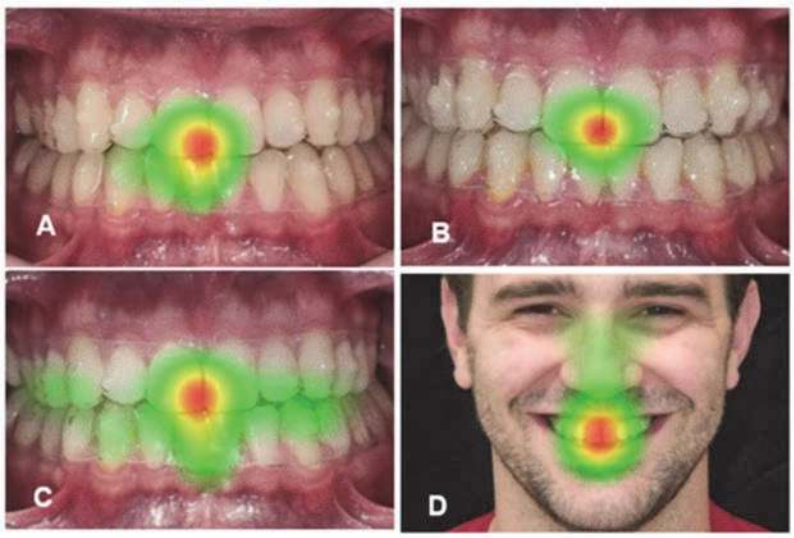

Figure 6. *Heat maps generated from dental students, indicating regions of greatest visual fixation during image evaluation: (A) aligner with shade A1 attachments; (B) shade A2; (C) shade A3; (D) frontal facial view with aligner, emphasizing gaze concentration in the smile region. Warmer colors (red/yellow) indicate higher fixation density, whereas cooler colors (green/blue) indicate lower fixation density.*

DISCUSSION

This study aimed to investigate the influence of attachment shade and shade design on the esthetic perception of dental students and laypersons using eye-tracking methodology.

The null hypothesis, which stated that there would be no difference in esthetic perception between laypersons and dental students regarding attachment color was rejected. The findings demonstrated that attachment shade influenced visual attention, with shade A3 producing the strongest effect, particularly among laypersons.

Esthetic perception in orthodontic treatment plays a crucial role in patients' therapeutic choices, particularly given the growing demand for clear aligners. Although aligners provide significant advantages in terms of comfort and esthetic,[1] the presence of attachments, often essential for achieving specific tooth movements, may compromise smile appearance during treatment.[5,6]

From the layperson's perspective, aligners, with or without attachments, are generally considered more comfortable and more acceptable compared with other orthodontic options, such as aligners with elastics, hybrid treatments involving esthetic or metallic fixed appliances, and mini-implants with or without elastics.[10] Dental students and their instructors also tend to regard aligner therapy as more esthetic and acceptable than conventional fixed appliances.[11]

In this study, intraoral images were selected with cheek retractors and without lips, to minimize peripheral distractions while ensuring full visibility of the attachments. This methodological choice is supported by evidence that the presence of lips can act as a distracting element in the initial direction of gaze.[7]

Here shade A3 attracted the greatest visual attention and was the only color capable of significantly redirecting gaze toward attachment regions, both intraoral and facial images. This effect was more pronounced among laypersons, whereas dental students consistently maintained greater fixation on the central incisors, showing low sensitivity to shades A1 and A2, with only a slight expansion of attention in the A3 image. These findings align with previous studies highlighting the impact of material color on perceived esthetic perception,[6] and support the use of eye-tracking technology to objectively and qualitatively assess such perceptions.[5,7]

Facial images further demonstrated that, for both groups, primary visual attention was directed to the mouth, followed by the nose and lastly the eyes. These results differ with earlier studies evaluating extraoral images with clear aligners, lingual orthodontics, and esthetic fixed appliances, in which participants primarily focused on the eyes before the mouth, except in cases involving esthetic fixed appliances.[12] These results suggest that the presence of visible attachments may alter classical patterns of facial perception, even among trained observers.

Another factor contributing to visual attraction is the number of attachments, as greater quantity has been shown to increase visual attention to aligners.[5] Although the present study did not evaluate different appliance types, differences observed in the literature may be partially attributed to variables such as attachment color, number, and distribution. The suggestion that more posterior attachment positioning may influence gaze should be interpreted with caution, as this factor was not directly assessed and remains speculative.

The differential visual behavior between laypersons and dental students underscores the influence of prior experience and professional training in esthetic evaluation. While laypersons directed greater attention toward attachments, dental students maintained their focus on the central incisors, likely reflecting familiarity with attachments as integral components of aligner therapy. These findings confirm that esthetic perception is both subjective and highly sensitive to the visual context. [7]

Greater visual attention from laypersons to the posterior regions with attachments may be related to increased local volume or to the higher contrast of the resin shade used. Tooth width and irregular incisor morphology attract more attention than asymmetries or inclinations.[13,14] Previous research has shown that laypersons tend to make more critical assessments of smile esthetics compared with professionals.[1]t Among dental students, perception may vary according to the year of study, with early-year students showing patterns more similar to laypersons, particularly regarding the presence of black spaces.[15]

Despite the relevant findings, some limitations should be acknowledged. The student sample was restricted to individuals from a single institution, which may limit the generalizability of the results. In addition, cultural, ethnic, gender-related, and professional training factors must also be taken into account.[16] Furthermore, the absence of quantitative statistical analyses restricts the generalizability of the conclusions, and the present findings should be interpreted as exploratory and descriptive.

Although current evidence regarding the esthetics and biomechanics of clear aligners remains limited,[4] the results of this study indicate that subtle factors, such as composite resin shade, may directly influence visual perception of attachments, reinforcing the importance of individualized

material selection and clinical strategies. Advances such as the incorporation of divots or variations in aligner thickness,[8] represent promising alternatives to preserve esthetics without compromising biomechanical efficiency.

Overall, the findings highlight the complexity of esthetic perception in clear aligner therapy, suggesting that subtle variables such as attachment shade—and possibly attachment location—may influence visual attention, particularly among laypersons. These results reinforce the importance of considering the observer's profile when developing clinical strategies and underscore the potential of eye-tracking as a complementary tool for evaluating orthodontic materials and techniques. Future studies with more diverse samples and broader clinical simulations are warranted to deepen the understanding of esthetic impacts of orthodontic devices and to advance increasingly patient-centered approach.

From a clinical perspective, these findings emphasize the need to individualize attachment shade and placement according to patient expectations, since laypersons are more sensitive to contrast and posterior positioning. Eye-tracking proved to be a valuable tool for objectively assessing esthetic perception and may guide the development of more discreet aligner protocols. Future studies with larger and more diverse samples are needed to strengthen these results and advance patient-centered approaches.

CONCLUSION

Eye-tracking analysis demonstrated differences in esthetic perception between laypersons and dental students when evaluating attachments of different composite resin shades in clear aligner therapy. Heat maps revealed differential fixation patterns: dental students focused more on technical regions associated with attachments, whereas laypersons concentrated on the overall smile appearance. These findings indicated that technical knowledge modulates esthetic perception and emphasize that attachment shade and placement should be tailored to patient expectations to maintain the esthetic benefits of clear aligners.

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