

Esthetic perception of clear aligner therapy attachments using eye-tracking technology

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Introduction: The purpose of this research was to assess and compare esthetic perceptions of clear aligner therapy with attachments and esthetic brackets by measuring differences in eye fixations using eye-tracking technology. **Methods:** The sample involved 250 adult subjects. The subjects gave verbal consent, then viewed photographs showing 4 variations of orthodontic appliances: clear aligner control with minimal attachments, clear aligner with anterior and posterior attachments, esthetic brackets, and clear aligner with posterior attachments. Images were displayed for 6 seconds each on a computer monitor. Location and time to first fixation, total fixation duration, and total visit count and duration for each type of appliance were measured. Subjects were then asked to complete an online survey. **Results:** Participants spent the least amount of time looking at the photograph of the control, followed by those of the ceramic brackets, posterior attachments, and anterior and/or posterior attachments. The anterior and/or posterior image had the least number of visits but garnered the longest visit duration (1.32 visits averaging 0.74 seconds per visit). This was followed by the images of the posterior attachments (1.40 visits, 0.70 seconds per visit), ceramic brackets (1.43 visits, 0.65 seconds per visit), and minimal attachments control (1.45 visits, 0.61 seconds per visit). The hierarchy of most preferred appliances across all 250 respondents was as follows: minimal attachments control, ceramic brackets, posterior attachments, and anterior and/or posterior attachments. Overall, 88.4% of subjects would compromise appliance esthetics during treatment for a better outcome ($n = 221$). **Conclusions:** Eye-tracking data show that time to the first fixation was negatively correlated with its survey ranking and that an increase in attachments led to an increase in total fixation duration. There is a general desire for clear aligners without attachments and ceramic brackets over clear aligners with multiple attachments. Survey data suggest that although respondents viewed appliance esthetics as highly important, nearly all would compromise appliance esthetics during treatment if it resulted in a better outcome. (*Am J Orthod Dentofacial Orthop* 2020;158:400-9)

In recent years, orthodontic clinicians have seen an increase in adults seeking orthodontic care, resulting in a record high of nearly 1.5 million adult patients in the United States and Canada.¹ This shift in the market has resulted in orthodontic treatment that has continually evolved in response to available technology to meet the desires of the adult consumer.¹⁻³ Patient demands for esthetic

treatment outcomes have grown to include esthetic appliances during treatment. This demand has driven manufacturers to develop systems designed to appeal to the patient, with an underlying goal of reducing appliance visibility.²⁻⁵

Orthodontic patients and practitioners currently have a slew of esthetic alternatives to traditional braces that reduce the visibility of appliances, including options such as ceramic brackets, lingual appliances, and clear aligners.⁶

Previous studies had shown that nearly two-thirds of young adults would reject orthodontic treatment if it involved being treated with visible appliances.⁷ Visible options were not only seen as being less attractive but also led to the assumption of the wearer as having less favorable traits, including decreased intellectual ability.⁸ In this way, clear aligners have quickly become synonymous with esthetics for most patients, and this is how the product is marketed nowadays.

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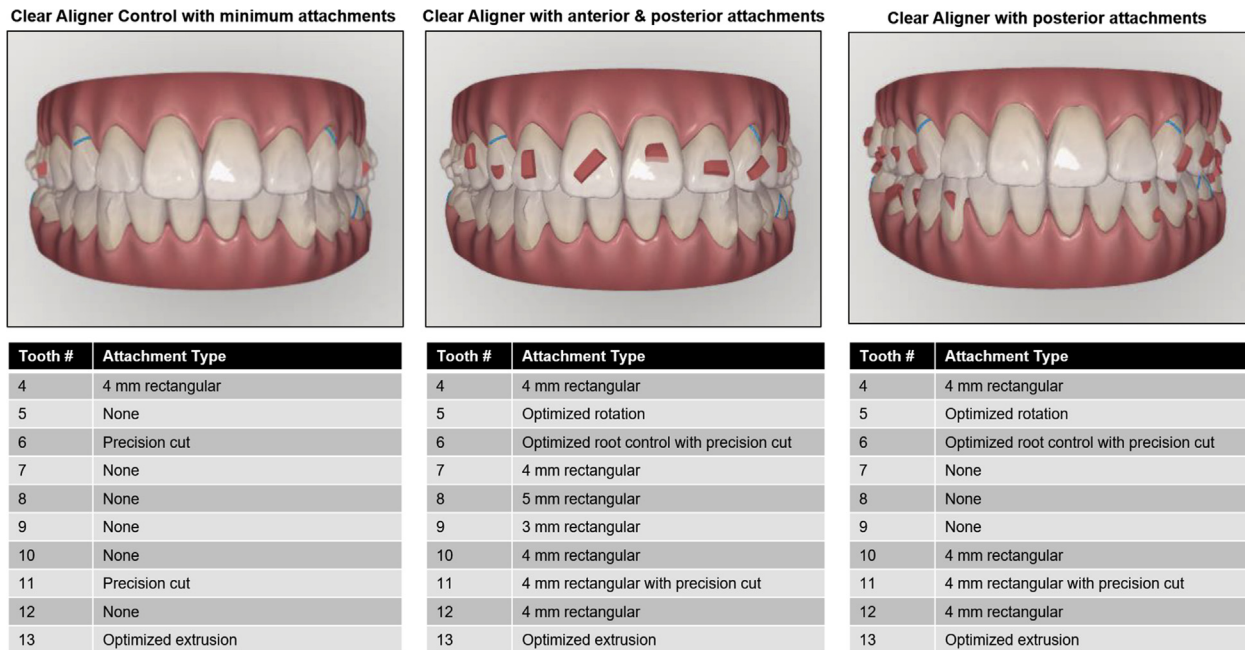


Fig 1. Lists of visible attachments used per photograph as displayed on Invisalign ClinCheck software.

Although aligners assumed to be the most esthetic treatment among the choices, it has not been fully studied, and its attractive aspects are still controversial. To date, little research has been done to assess the patients’ perception of how they view the appearance of esthetic appliance systems, such as clear aligners with auxiliaries attached and their desired treatment preferences. The question remains how one objectively and subjectively perceives even the most esthetic appliances on the market.

MATERIAL AND METHODS

For the present study, 250 subjects over the age of 18 years were randomly recruited from the Saint Louis University campus in St Louis, Missouri. The sample consisted of 158 females and 92 males. The only exclusion criteria were subjects with visual or cognitive impairments. Participants were not required to be in orthodontic treatment, nor were they required to have ever had any treatment in the past.

Images of the clear aligner and esthetic appliances were taken with a Canon EOS Rebel T5 EF-S camera (Canon, Huntington, NY) by a single photographer in the same location to ensure for analogous lighting conditions and positioning of each photograph.

One photograph of each of the following was taken on a live model: clear aligner control with minimal attachments (on maxillary second premolars) (Align

Technology Inc, San Jose, Calif), clear aligner with anterior and posterior attachments, ceramic brackets with 0.016-in nickel-titanium wire and clear ligature ties (AO Radiance Plus; American Orthodontics, Sheboygan, Wis), and clear aligner with posterior attachments (from maxillary canines to second premolars). For the images depicting clear aligners with attachments, aligners containing attachments were fabricated, filled with shade A2 Filtek Supreme Ultra by 3M (St. Paul, Minn), and worn by the model. Attachments were not bonded to the model. See Figure 1 for a list of visible attachment types per photograph.

The photographs were merged into two 2 × 2 composite images. The first photograph consisted of the following: (1) clear aligner control with minimal attachments, (2) clear aligner with anterior and posterior attachments, (3) ceramic esthetic brackets, and (4) clear aligner with posterior attachments (Fig 2).

The 2 composite images were imported into Tobii Lab Pro eye-tracking software (Tobii Pro Lab, version 1.4; Tobii Technology AB, Danderyd, Sweden) installed on a 21.5-in iMac (Apple, Cupertino, CA) running Windows 10 Education (version 1803; Microsoft Corporation, Redmond, Wash). The desktop was equipped with Tobii eye-tracking hardware (Tobii X2-60, Danderyd, Sweden). Each appliance was given its area of interest (AOI) to allow the software to isolate data for later analysis (Fig 3). The demarcated areas were grouped into a single AOI per appliance type.



Fig 2. Composite image of appliances. **A**, Clear aligner control with minimal attachments; **B**, clear aligner with anterior and posterior attachments; **C**, ceramic brackets; **D**, clear aligner with posterior attachments.

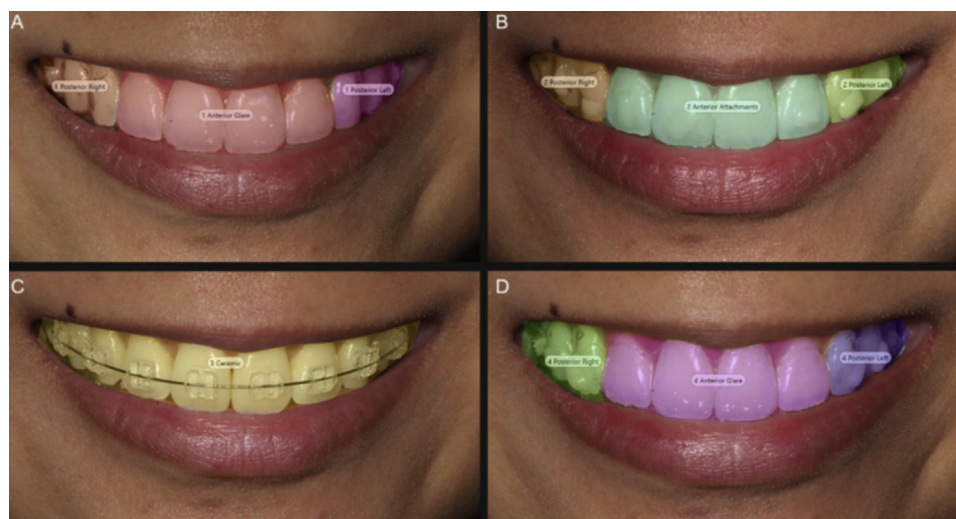


Fig 3. Tobii Pro Lab AOI. AOIs were demarcated, and anterior and posterior AOIs were grouped. Each appliance type had one total AOI.

The study protocol, recruiting statement, participant consent, appliance photographs, and study survey were approved by the Saint Louis University Institutional Review Board (IRB protocol no. 29146) before initiation of the study.

Potential adult subjects were randomly recruited from the Saint Louis University campus and given a brief description of the study, stating that the purpose was to assess esthetic orthodontic appliances. All subjects were seated at eye-level, approximately 60–65 cm (23–26-in) in front of a computer equipped with a Tobii X2-60

eye-tracking device and calibrated to the eye-tracking device by following a moving ball across the screen. Calibration was repeated until satisfactory, aiming for estimated accuracy and precision below 1°. On successful calibration, the composite image showing the 4 appliance variations was displayed on the screen for 6 seconds, according to a previous eye-tracking study.⁹ Data including location and time of first fixation, total fixation duration, total visit count, and total duration were collected for each AOI. Fixations were measured as any instance; the eye remained stagnant for 80 milliseconds or greater.¹⁰ After

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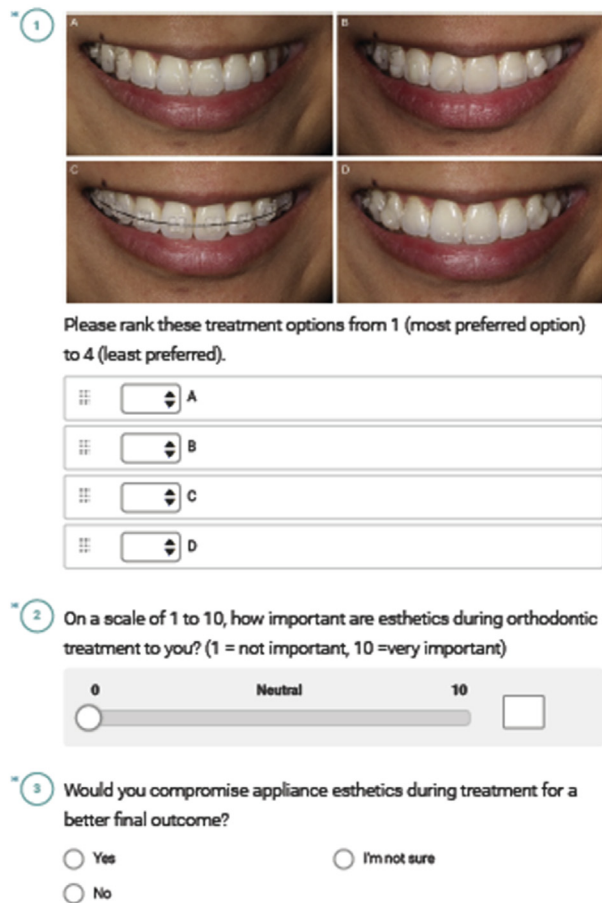


Fig 4. Sample survey as viewed online.

viewing the image, the participant was asked to complete an online survey (Fig 4).

Statistical analysis

Statistical analysis was performed using SPSS software (version 24.0; SPSS, Chicago, IL). Descriptive statistics were calculated for each appliance variation. Descriptive statistics and 1-way ANOVAs between age, gender, and ethnicities were used to analyze data. In variables in which the same distribution was nonparametric, the independent sample Kruskal-Wallis tests or 1-way ANOVA on ranks was used. The null hypothesis is that there is no significant difference in how clear aligner therapy attachments and esthetic brackets are

viewed using eye-tracking. The alternative hypothesis is that there is a significant difference in how clear aligner therapy attachments and esthetic brackets are viewed using eye-tracking.

RESULTS

When analyzing the location of the first AOI fixation, participants tended to look at the photograph in the top left corner first and continued in a clockwise pattern. When averaging the 2 photographs to offset this tendency, it took participants 1.55 seconds to fixate on the minimal attachment control after the initial composite image was shown on the screen. This image was the first that participants fixated on the screen.

Table I. Descriptive statistics for eye-tracking metrics for all participants

Metric	Average	SD
Time to first fixation, s		
Control	1.55	1.40
Ant and/or Post attachments	2.09	1.30
Ceramic brackets	1.84	1.46
Post attachments	2.22	1.45
Time to first duration, s		
Control	0.73	0.68
Ant and/or Post attachments	0.81	0.70
Ceramic brackets	0.80	0.62
Post attachments	0.81	0.65
Time to first duration, s		
Control	1.45	0.88
Ant and/or Post attachments	1.32	0.85
Ceramic brackets	1.43	0.88
Post attachments	1.40	0.81
Time to visit duration, s		
Control	0.61	0.48
Ant and/or Post attachments	0.74	0.49
Ceramic brackets	0.65	0.45
Post attachments	0.70	0.46

SD, standard deviation; *Ant*, anterior; *Post*, posterior.

Participants looked at the ceramic brackets second, taking an average of 1.84 seconds before fixating on this image (Table I). Participants looked at the anterior and/or posterior attachments third, spending an average of 2.09 seconds before fixating on this image, and lastly, posterior attachments (2.22 seconds to the first fixation). Although there were no group differences by gender or ethnicity in terms of what they looked at first and the time it took to the first fixation, there was a group

difference by age. The viewing patterns of participants differed depending on their age group ($P = 0.019$) for the image with posterior attachments (Table II). Post-hoc tests did not reveal any significant difference between age groups.

When analyzing the total fixation duration for each AOI, participants spent the least amount of time fixating on the control photograph (0.73 seconds total fixation duration). This was followed by the images of the ceramic brackets (0.80 seconds), and posterior attachments and anterior and/or posterior attachments (0.81 seconds for each). Figure 5 displays the total fixation duration heat map for all participants. In analyzing participant demographics and total fixation duration, there were differences by ethnicity for the anterior and/or posterior image ($P = 0.002$) and minimal attachments control ($P = 0.047$) (Table III). Post-hoc tests revealed that white participants looked longer (0.922 seconds) at the anterior and/or posterior image than black participants (0.688 seconds) ($P = 0.029$).

Throughout the entire recording, participants visited the anterior and/or posterior attachments image the least amount of times but spent the longest duration at that location compared with the other appliance types (1.32 visits for an average of 0.74 seconds per visit). This was followed by the images of the posterior attachments (1.40 visits for an average of 0.70 seconds per visit), ceramic brackets (1.43 visits for 0.65 seconds per visit), and minimal attachments control (1.45 visits averaging 0.61 seconds per visit).

No significant differences were found between the different areas of interest in terms of total visit count. There were no group differences by ethnicity or gender.

Table II. ANOVA comparing time to the first fixation across age groups

Metric	Sum of squares	df	Mean square	F	P
Control					
Between groups	16,291,964.158	6	2,715,327.360	1.383	0.220
Within groups	814,523,717.150	415	1,962,707.752		
Total	830,815,681.308	421			
Ant and/or Post attachments					
Between groups	10,780,181.860	6	1,796,696.977	1.051	0.392
Within groups	665,122,451.867	389	1,709,826.354		
Total	675,902,633.727	395			
Ceramic brackets					
Between groups	8,161,267.777	6	1,360,211.296	0.634	0.703
Within groups	860,814,612.495	401	2,146,669.857		
Total	868,975,880.272	407			
Post attachments					
Between groups	31,781,012.863	6	5,296,835.477	2.559	0.019
Within groups	850,653,825.319	411	2,069,717.337		
Total	882,434,838.182	417			

Note. Statistically significant at $P < 0.05$

df, degrees of freedom; *Ant*, anterior; *Post*, posterior.

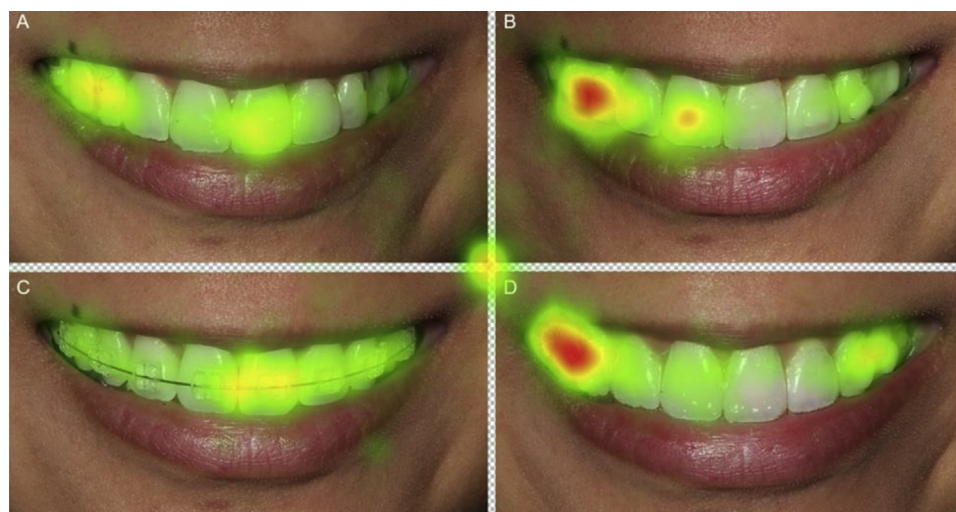


Fig 5. Total fixation duration heat map for all participants. **A**, Clear aligner control with minimal attachments; **B**, clear aligner with anterior and posterior attachments; **C**, ceramic brackets; **D**, clear aligner with posterior attachments.

In analyzing the means of both images together, there was a significant effect of age on visit count for the posterior attachments image ($P = 0.020$) (Table IV). Follow up Bonferroni post-hoc tests did not reveal significant findings between age groups.

The time to the first fixation was negatively correlated with its ranking for the minimal attachments control ($r = -0.180, P = 0.008$). The lower the time to fixate, the higher the ranking. No other correlations were found to be significant for eye-tracking data.

Comparing the overall ranking score between appliance types showed that participants chose the minimal attachments control as their preferred treatment option with a mean score of 1.77 out of 4.00. Overall, 84.40% of participants chose it as their most preferred choice ($n = 106, 42.4\%$) or second choice ($n = 105, 42.0\%$). Although ceramic brackets ranked second overall with a mean score of 2.18, most participants chose it as their preferred option ($n = 111, 44.4\%$). Posterior attachments ranked third overall with a

Table III. ANOVA comparing time to the first fixation across age groups

Metric	Sum of squares	df	Mean square	F	P
Control					
Between groups	16,291,964.158	6	2,715,327.360	1.383	0.220
Within groups	814,523,717.150	415	1,962,707.752		
Total	830,815,681.308	421			
Ant and/or Post attachments					
Between groups	10,780,181.860	6	1,796,696.977	1.051	0.392
Within groups	665,122,451.867	389	1,709,826.354		
Total	675,902,633.727	395			
Ceramic brackets					
Between groups	8,161,267.777	6	1,360,211.296	0.634	0.703
Within groups	860,814,612.495	401	2,146,669.857		
Total	868,975,880.272	407			
Post attachments					
Between groups	31,781,012.863	6	5,296,835.477	2.559	0.019
Within groups	850,653,825.319	411	2,069,717.337		
Total	882,434,838.182	417			

Note. Statistically significant at $P < 0.05$.
df, degrees of freedom; Ant, anterior; Post, posterior.

Table IV. ANOVA comparing visit count across age groups

Metric	Sum of squares	df	Mean square	F	P
Control					
Between groups	6.026	6	1.004	1.211	0.299
Within groups	377.335	455	0.829		
Total	383.361	461			
Ant and/or post attachments					
Between groups	4.059	6	0.676	0.967	0.447
Within groups	318.168	455	0.699		
Total	322.227	461			
Ceramic brackets					
Between groups	4.466	6	0.744	0.966	0.448
Within groups	350.676	455	0.771		
Total	355.143	461			
Post attachments					
Between groups	9.953	6	1.659	2.538	0.020
Within groups	297.357	455	0.654		
Total	307.310	461			

Note. Statistically significant at $P < 0.05$.

df, degrees of freedom; Ant, anterior; Post, posterior.

mean score of 2.58, and anterior and/or posterior was the least preferred option with a mean score of 3.47 out of 4.00 (Table V).

No significant differences were found between age groups; however, descriptive data trended toward the age group subjects who were 18–24 years old choosing the minimal attachments control as their most desirable option, whereas the age group of subjects who were 45–54 years old most preferred ceramic brackets. There was a significant difference in the distribution for preference choices, minimal attachments control, ceramic brackets, and posterior attachments across categories of ethnicities ($P = 0.014$, $P < 0.001$, and $P < 0.001$, respectively). The differences in the distribution for African Americans and Asians for these answer choices were $P = 0.001$, $P < 0.001$, and $P = 0.025$, respectively. The distribution of posterior attachments was different between white people and Hispanics ($P < 0.001$), African Americans and Hispanics ($P = 0.020$), and Asians and Hispanics ($P = 0.004$).

African Americans tended to prefer ceramic brackets, with 72.92% selecting it as their first option (mean score, 1.50), followed by minimal attachments (1.98), posterior (2.92), and lastly, anterior and/or posterior (3.60). In contrast, 66.7% of Asians mostly preferred the minimal attachments control (mean score, 1.47), followed by posterior attachments (2.50), ceramic brackets (2.60), and lastly, anterior and/or posterior attachments (3.43). White people favored minimal attachments (mean score, 1.75), followed by ceramic brackets (2.39), posterior attachments (2.42), and anterior and/or posterior attachments (3.45). Hispanics most preferred ceramic brackets (mean score, 1.60), followed by minimal attachments (1.80), anterior and/or posterior attachments (3.10), and posterior attachments (3.50).

When asked about the importance of appliance esthetics during treatment on a scale of 1 (not important) to 10 (very important), the mean score was 7.16 ± 2.52 . No significant differences were found regarding the importance of esthetics across age groups and gender; however, there was a difference in distribution across categories of ethnicity ($P = 0.013$). Statistical analysis showed that there was a significant difference in the distribution of esthetic importance between African Americans and Hispanics ($P = 0.020$), and Asians and Hispanics ($P = 0.046$). Hispanics tended to find appliance esthetics of lesser importance (5.50 ± 2.94) than African Americans (7.77 ± 2.90), and Asians (7.67 ± 2.12).

Overall, 88.4% of subjects would compromise appliance esthetics during treatment for a better outcome ($n = 221$). Only 6% of participants answered no ($n = 15$), with the remaining 5.6% being unsure ($n = 14$).

DISCUSSION

A comparison of eye-tracking data for location and time to the first fixation suggests that subjects tended to look at the photograph in the upper left corner first continued in a clockwise pattern. According to literature, left-to-right directionality is engrained through the English language, and research shows that for a wide range of visuospatial tasks, a majority of people

Table V. Preference data for all participants

Metric	First choice		Second choice		Third choice		Fourth choice		Mean
	n	%	n	%	n	%	n	%	
Control	106	42.40	105	42.00	30	12.00	9	3.60	1.77
Ant and/or post attachments	4	1.60	19	7.60	83	33.20	144	57.60	3.47
Ceramic brackets	111	44.40	41	16.40	39	15.60	59	23.60	2.18
Post attachments	29	11.60	85	34.00	98	39.20	38	15.20	2.58

Ant, anterior; Post, posterior.

demonstrate a preference for left-to-right and clockwise perceptual directionality.¹¹ However, averaging the 2 photographs for this metric to help offset this perceptual directionality, participants tended to fixate on the minimal attachments control first, followed by ceramic brackets, anterior and/or posterior attachments, and lastly, posterior attachments.

Participants spent the least amount of time on the photograph of the minimal attachments control, followed by those of the ceramic brackets, posterior attachments, and lastly, anterior and/or posterior attachments (as measured by total fixation duration and total visit duration). When considering how the subjects ranked the treatment options, the results followed the same pattern. Preference data showed that when asked to rank the 4 treatment options, participants preferred the minimal attachments control, followed by ceramic brackets. This finding supports previous literature stating that adults rated clear aligners without attachments the most attractive, followed by esthetic brackets.^{4,5,8,11,12} Two clear aligner options ranked below ceramic brackets. Clear aligners with posterior attachments ranked third, and clear aligners with anterior and posterior attachments was the least desired option.

Participants tended to spend the least amount of time on the image they ranked the highest, whereas their least preferred choice garnered the most attention for the longest duration. It is important to note that these are trends purely based on descriptive statistics and are not of statistical significance. The only significant finding correlating eye-tracking data and preference data was with the minimal attachment image. The time to the first fixation was negatively associated with its ranking for this image. The faster subjects fixated on this image, the higher it was ranked as their most preferred option. In other words, participants fixated on the image they preferred first and spent the longest time on the image they ranked the lowest.

This finding corresponds to the results from previous studies that showed focus became more relevant as the level of attractiveness decreased,¹³ so it can be inferred that participants spent more time on the image that drew their attention negatively. As described in previous studies,¹³⁻¹⁵ the level of attractiveness is inversely related to attention. As levels of attractiveness decreased (eg, more attachments), participants paid more focus to those areas.

When considering the total visit count, the results followed a similar pattern. Although the anterior and/or posterior image yielded the lowest number of visits, subjects spent the most amount of time looking at this image. This finding is also true for total visit duration and total

fixation duration. A possible explanation is that the increase of attachments required participants to spend more time processing and analyzing the image to fully comprehend what is being seen, therefore delaying them from moving on to the next image. When multiple objects (ie, attachments) are being tracked, more visual attention is being allocated to these areas. Even in infants, complex visual stimuli lead to more attention and longer fixation times, compared with simple stimuli.¹⁶

The minimal attachments control yielded the highest number of visits; however, subjects spent the least amount of time on this image. A probable explanation could be that their natural gaze path brought them to this particular image but quickly moved to the next image because they did not note anything out of the ordinary on which to spend more time. The lack of attachments allowed for quicker processing and consequently allowed them to move to the next image faster. According to Sokolov's comparator model, if a stimulus is not novel, then further looking or encoding is unnecessary, and the fixation will shift to a different stimulus.¹⁷

Although the control image ranked highest in overall preference data, it is important to note that a higher percentage of participants chose ceramic brackets as their most preferred option ($n = 111$, 44.4%) over the control ($n = 106$, 42.4%). When asked the reasoning behind ranking choices during data collection, many reported that the ceramic braces looked *intentional*, *symmetric*, and *clean* compared with the aligners with attachments. Although most subjects recognized the Invisalign name and clear aligner therapy options for orthodontic treatment, many have never seen the appliance up close and could not identify the attachments. Many reported that they believed the attachments were cavities or that the teeth were simply dirty. It should be clarified that there was not a specific question that prompted participants to justify their answer choices. The surveys were completed through an online web-based survey with the principal investigator, and many participants freely rationalized the reason behind their answer choices during the process.

Delving deeper into the survey data showed that the age group of subjects who were 18-24 years old chose the minimal attachment control as their primary treatment choice. On the contrary, the ceramic treatment option was more heavily weighted toward the age group of subjects who were 45-54 years old. This finding gives us some insight into how a potential patient's demographic plays a role in how they view esthetics and its importance. There were no significant differences across age groups for the importance of esthetics during treatment, leading us to infer that the idea of esthetics may not differ depending on patient demographics.

Descriptive data trended toward African Americans and Hispanics favoring ceramic, whereas white people and Asians desired clear aligners with minimal attachments.

The goal was to determine whether any differences exist between esthetic appliance types using eye-tracking and subjective survey data. Data collected provided valuable insight into how laypersons visually assess appliance types and their desired treatment preferences. Information from eye-tracking supports the notion that clear aligners with attachments garner more visual attention, and survey data show that many still prefer ceramic brackets over clear aligner therapy options. These findings indicate that although adult patients desire esthetic appliances, the idea of what is considered esthetic varies among demographics, and many prefer the look of minimal attachments and ceramic brackets over clear aligners with multiple attachments. Therefore, patients with complex movements that require many attachments may be better suited for ceramic brackets; they will find this more esthetic.

For the current study, photographs of the 4 treatment options were taken and compiled into a 2 × 2 composite image. Although the images were taken by the same photographer in the same room and lighting conditions, some inconsistencies still exist between the photographs. Our study objective was to assess clear aligner therapy auxiliaries; however, subjects may be drawn to other aspects of the photographs. Qualities that may distract and take away from attachments such as dental to facial midline, the shape and alignment of teeth, and skin irregularities within the photographs may exist, although a summary of gaze plots for all participants show that focus remained mostly on the teeth.

The goal of this study was to gauge the initial reaction to viewing photographs with attachments and therefore limited the time each participant had to view the image to 6 seconds. More time may have been needed for subjects to fully assess and process what was being seen as participants may not be accustomed to viewing teeth up close. Although research shows that in an everyday scenario, many look at the eyes first, this study elected to focus solely on the mouth and teeth to prevent distraction from the entire face.

A major shortcoming of the Tobii Pro Lab eye-tracking software is its lack of ability to randomize photographs. All participants viewed the images in the same order; therefore, we can only infer the pattern in which these photographs were viewed are due to random chance from the different appliance types. To help offset the inability to fully randomize the photographs between participants, a second image of the 4 appliance

types rotated in a clockwise position was placed and analyzed in all 250 participants, and eye-tracking metrics were taken using a combination of the 2 recordings.

CONCLUSIONS

Eye-tracking data indicate that subjects tended to spend the least amount of time on the photograph of the minimal attachments control, followed by those of the ceramic brackets, posterior attachments, and anterior and/or posterior attachments. Appliance preference data mirror eye-tracking data. There is a general desire for clear aligners with minimal attachments and ceramic brackets over clear aligners with multiple attachments. Survey data suggest that although respondents viewed appliance esthetics as highly important, nearly all would compromise appliance esthetics during treatment if it resulted in a better outcome.

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