Eye Tracking for Evaluating Esthetics in Treatment of Missing Maxillary Lateral Incisors

by

Caroline Cheung

A thesis submitted in conformity with the requirements for the degree of Masters of Science
Orthodontics
University of Toronto

© Copyright by Caroline Cheung 2015
Abstract

Agenesis of permanent maxillary lateral incisors (MLI) may be addressed by different treatment options including ‘canine substitution’ (CS) or replacement with lateral incisor implants (LII). To determine whether the esthetic outcome differs between CS or LII, forty orthodontists and thirty-five laypersons viewed photographs consisting of three treatment groups: controls with no missing teeth, patients who had bilateral CS, patients with bilateral LII and provided esthetic ratings while undergoing eye tracking. Orthodontists rated the LII more esthetic than CS and spent more time looking at the second and third teeth from the midline for CS photos compared to control photos. There was no significant difference in esthetic ratings given by laypersons between LII and CS and they looked at photos of patients with missing MLI similarly as demonstrated by eye-tracking measures. The esthetics of CS and LII for treatment of missing MLI is comparable as viewed by laypersons.
Acknowledgments

I would like to extend my sincere gratitude to my thesis committee members Dr. John Daskalogiannakis, Dr. Bryan Tompson and Dr. Ernest Lam for your input and advice that guided me along the process of completing this work. Dr. Dask, at times your frequent requests to tweak the project seemed like extra work but in the end I see that it has made this a better project and you pushed me (at the center of resistance) in the right direction.

Dr. Karen Wong, I learned quickly at the lunch meeting that you are a source of great ideas. This eye-tracking project being one of which I hope I did justice.

Some of the photographs used in this study were provided by Dr. Dennis Yokota who is a true artist and perhaps the reason why the implants received such high esthetic ratings. Thanks is also due to Dr. Daskalogiannakis and his orthodontic colleagues who provided photographs of their excellent camouflage work. Graduate orthodontic residents of the University of Toronto contributed their talents as well, by providing the control photographs.

I owe many thanks to the DDS Class of 2018 at U of T, and orthodontists across Canada who generously offered their eyes and time to complete the study. To the graduate students who offered to be the guinea pigs for the pilot study, thank you for kicking off this project.

My colleagues Dr. Fatima Ebrahim, Dr. John Scalia, Dr. Sojung Lee and Dr. Quyen Su have contributed their expertise and support throughout the completion of this project.

Statistically significant help was provided by statistician Anton Svendrovski.

Completion of this work brings great joy to my dear friends and family who will no longer need to hear me utter the words, “I’m working on my thesis” again. Thank you all for your patience and support in this process.

Tim, my love, thank you for your steadfast support and encouragement.
# Table of Contents

**Abstract** ............................................................................................................................................................................ii

**Acknowledgments** ..........................................................................................................................................................iii

**List of Tables** .................................................................................................................................................................vi

**List of Figures** .................................................................................................................................................................vii

**Introduction, Definitions and Statement of the Problem** ........................................................................................................1

## Chapter 1: Review of the Literature

1.1 Missing Maxillary Lateral Incisors
   - 1.1.1 Epidemiology of Missing Maxillary Lateral Incisors..........................................................2
   - 1.1.2 Etiology of Missing Maxillary Lateral Incisors.................................................................2
   - 1.1.3 Treatment Options and Case Selection.................................................................................3
     - 1.1.3.1 Canine Substitution........................................................................................................4
     - 1.1.3.2 Prosthetic Replacement: Single-Tooth Implant............................................................5
     - 1.1.3.3 Comparing Options: Patient Burden.........................................................................6
     - 1.1.3.4 Comparing Options: Existing Studies........................................................................8

1.2 Smile Esthetics
   - 1.2.1 Parameters of Smile Esthetics..........................................................................................9
   - 1.2.2 Studies on Smile Esthetics.............................................................................................11

1.3 Eye Tracking
   - 1.3.1 Eye Movements and Visual Attention...............................................................................12
   - 1.3.2 Terminology and Data Output..........................................................................................13
   - 1.3.3 Eye-tracking Studies in Orthodontics.............................................................................14

1.4 Objectives of the Study...........................................................................................................................................16

1.5 Hypotheses...............................................................................................................................................................17

## Chapter 2: Methods

2.1 Study Design
   - 2.1.1 Statistical Analysis and Sample Size Determination.....................................................18
   - 2.1.2 Photo selection..................................................................................................................18
   - 2.1.3 Rater Selection................................................................................................................26
   - 2.1.4 Creating the Experiment on Experiment Center 3.3 Software......................................27
   - 2.1.5 Experimental Protocol....................................................................................................30
2.2 Operational Definitions .................................................................................................................. 32
2.3 Statistical Analysis .......................................................................................................................... 32

Chapter 3: Results
3.1 Descriptive Statistics ...................................................................................................................... 33
3.2 Esthetic Ratings ............................................................................................................................... 34
3.3 Eye-Tracking Measures
   3.3.1 Static Eye-Tracking Measures .................................................................................................. 41
   3.3.2 Correlations: Esthetic Ratings and Static Eye-Tracking Measures ....................................... 50
   3.3.3 Dynamic Eye-Tracking Measures: Scan Path ......................................................................... 61

Chapter 4: Discussion
4.1 Summary of Esthetic Ratings and Static Tracking Measures ....................................................... 71
4.2 Correlations: Esthetic Ratings and Static Eye-Tracking Measures ............................................. 73
4.3 Existing Studies ............................................................................................................................... 75
4.4 Study Limitations
   4.4.1 Selection of Photos .................................................................................................................. 77
   4.4.2 Selection of Participants ....................................................................................................... 78
   4.4.3 Eye Tracking as the Measurement Tool ................................................................................. 80
   4.4.4 Duration of Viewing .............................................................................................................. 81
   4.4.5 Study Design .......................................................................................................................... 81
4.5 Future Directions for Esthetic Evaluation studies ......................................................................... 82
4.6 Clinical Significance ...................................................................................................................... 83
4.7 Conclusions .................................................................................................................................. 83

References ........................................................................................................................................... 84

Appendices
   Appendix A ........................................................................................................................................ 92
List of Tables

Table 1: Rater Age........................................................................................................... 33

Table 2: Rater Experience in Orthodontics................................................................. 33

Table 3: Rater Gender.................................................................................................. 34

Table 4: Mean Esthetic Ratings.................................................................................... 35

Table 5: Mean Esthetic Ratings by Treatment Group in Extra-Oral View............... 38

Table 6: Mean Esthetic Ratings by Treatment Group in Intra-Oral View............... 38

Table 7: Mean Esthetic Ratings by Treatment Group in Extra-Oral and Intra-Oral Views........................................................................................................... 38

Table 8: Mean AOI Fixation Count in Extra-Oral View............................................. 42

Table 9: Mean AOI Fixation Count in Intra-Oral View.............................................. 44

Table 10: Mean AOI Percent Dwell Time in Extra-Oral View................................. 46

Table 11: Mean AOI Percent Dwell Time in Intra-Oral View................................. 48
List of Figures

Figure 1: Control Photos in Extra-Oral View.................................................................20
Figure 2: Implant Photos in Extra-Oral View.................................................................21
Figure 3: Substitution Photos in Extra-Oral View..........................................................22
Figure 4: Control Photos in Intra-Oral View.................................................................23
Figure 5: Implant Photos in Intra-Oral View.................................................................24
Figure 6: Substitution Photos in Intra-Oral View..........................................................25
Figure 7: AOIs Defined for Extra-Oral View.................................................................28
Figure 8: AOIs Defined for Intra-Oral View.................................................................29
Figure 9: Range of Esthetic Ratings for Extra-Oral View................................................36
Figure 10: Range of Esthetic Ratings for Intra-Oral View...............................................37
Figure 11: Highest Esthetic Ratings by Orthodontists for Each Treatment Group........39
Figure 12: Highest Esthetic Ratings by Laypersons for Each Treatment Group..........40
Figure 13: Range of AOI Fixation Count for Extra-Oral View.........................................43
Figure 14: Range of AOI Fixation Count for Intra-Oral View.........................................45
Figure 15: Range of AOI Percent Dwell Time for Extra-Oral View...............................47
Figure 16: Range of AOI Percent Dwell Time for Intra-Oral View...............................49
Figure 17: Correlation between Duration and Fixation Count by Rater Group.............50
Figure 18: Correlation between Esthetic Rating and Fixation Count by Rater Group....51
Figure 19: Correlation between Esthetic Rating and Fixation Count in Extra-Oral View by Treatment Group.................................................................52
Figure 20: Correlation between Esthetic Rating and Duration by Treatment Group……53

Figure 21: Correlation between Esthetic Rating and Duration by Rater Group……54

Figure 22: Correlation between Esthetic Rating and Duration in Extra-Oral View by
Treatment Group………………………………………………………………………………55

Figure 23: Correlation between Esthetic Rating and Fixation Count by Treatment
Group…………………………………………………………………………………………56

Figure 24: Correlation between Esthetic Rating and Duration by Treatment Group for
Orthodontists…………………………………………………………………………….57

Figure 25: Correlation between Esthetic Rating and AOI Percent Dwell Time by Rater
Group……………………………………………………………………………………58

Figure 26: Correlation between Esthetic Rating and AOI Percent Dwell Time by
Treatment Group for Orthodontists………………………………………………….59

Figure 27: Correlation between Esthetic Rating and AOI Fixation Count by Treatment
Group for Orthodontists………………………………………………………………60

Figure 28: Scan Path for Control Photo by ‘Brief’ Layperson…………………………….61

Figure 29: Scan Path for Implant Photo by ‘Brief’ Layperson…………………………63

Figure 30: Scan Path for Substitution Photo by ‘Brief’ Layperson………………………64

Figure 31: Scan Path for Control Photo by ‘Brief’ Orthodontist………………………….65

Figure 32: Scan Path for Implant Photo by ‘Brief’ Orthodontist…………………………66

Figure 33: Scan Path for Substitution Photo by ‘Brief’ Orthodontist……………………67

Figure 34: Scan Paths for ‘Moderate’ Orthodontist and Layperson……………………69

Figure 35: Scan Paths for ‘Extended’ Orthodontist and Layperson…………………….70
Introduction, Definitions and Statement of the Problem

Patients who are missing maxillary lateral incisors (MLI) often seek treatment in order to restore form and function. As the missing tooth is apparent in the smile, the need for treatment is clear. Management of patients with missing MLI may involve a team of dental specialists, with the orthodontist playing a critical role in the diagnosis and treatment planning.

From the patient and orthodontist’s perspective, the ideal treatment option would combine the best esthetic outcome, lowest financial and shortest time burden. However, when considering the available treatment options, appearance, cost and time considerations may conflict.

Treatment of missing MLI may be broadly categorized into either opening the space for prosthetic replacement, or closing the space to position the canine tooth immediately adjacent to the central incisor, known as canine substitution.

Prosthetic replacement serves to restore the typical number and type of teeth expected in a smile. On the other hand, substituting the missing MLI with the maxillary canine tooth offers a solution by rearranging what is present naturally.

Due to facial and occlusal considerations, not every case of missing MLI will lend itself to both options. It is not clear which of these two options will meet the patient and practitioner’s aim for optimal esthetic outcome when both options are available.

To date, there have been few studies (Robertsson and Mohlin 2000; Armbruster et al. 2005; De-Marchi et al. 2014) published on the comparison of esthetic outcome of canine substitution and implant replacement for patients with missing MLI. The existing studies rely on esthetic ratings alone, with no objective assessment of how the smiles were viewed.
Chapter 1: Review of the Literature

1.1 Missing Maxillary Lateral Incisors

1.1.1 Epidemiology of Missing Maxillary Lateral Incisors

In population studies, the most commonly missing tooth, excluding third molars, is the mandibular second premolar followed by the maxillary lateral incisor (MLI) (Polder et al. 2004). There is a range of reported values for prevalence of hypodontia due to heterogeneous study designs: sample size, gender distribution of sample, records used to determine missing teeth and geographic differences reflecting ethnically distinct populations. A meta-analysis revealed that dental agenesis is 1.37 times more common in females than males (Polder et al. 2004). The prevalence of missing maxillary lateral incisors ranges from 0.95% in an American Caucasian sample (Meskin & Gorlin, 1963) to 2% in an Icelandic sample (Magnusson, 1977). A meta-analysis of ten studies, totaling 48274 subjects, found the prevalence of missing maxillary lateral incisors to be 1.6% (Polder et al. 2004). Orthodontists can expect a greater percentage of their patients to present with the chief complaint of missing maxillary lateral incisors. In one sample of orthodontic patients, missing teeth more commonly occurred in the maxilla with the maxillary lateral incisors cited to be the most commonly missing teeth (Celikoglu et al. 2009). This is likely related to the heightened awareness of the esthetic problem of a missing tooth in the maxillary anterior region.

1.1.2 Etiology of Missing Maxillary Lateral Incisors

Maxillary lateral incisors may be missing for different reasons, including agenesis, extraction and trauma. Agenesis may be unilateral or bilateral and may be an isolated dental anomaly or associated with other dental anomalies including microdontia (Mirabella et al. 2012) and palatally displaced maxillary canines (Brin, 1986). Numerous authors have proposed that missing and peg-shaped upper lateral incisors are different expressions of the same genetic anomaly (Grahnen, 1956, Alvesalo et al. 1969, Nieminen et al. 1995) and the findings of the study by Pinho et al. (2005) support this hypothesis. It is interesting to note that the last tooth to develop from tissue within each
different tooth family, namely the lateral incisor, second premolar and third molar, are most commonly affected by hypodontia which suggests that a defective gene may result in progressively impaired tooth formation (Thesleff, 1996). The cause of agenesis is not clear, however, the inheritance pattern of hypodontia indicates it is an autosomal dominant trait. While the identity of the specific genes involved remains elusive, the homeobox genes which regulate developmental patterning by controlling expression of other genes, remain as candidates (Nieminen et al. 1995). It was proposed that nonsyndromic hypodontia of incisors and premolars may be genetically heterogeneous (Thesleff, 1996).

1.1.3 Treatment Options and Case Selection

Modern dentistry can address the issue of missing maxillary lateral incisors with two different approaches: space opening and prosthetic replacement of the lateral incisors or closing space to substitute the canine tooth in place of the lateral incisor.

The facial profile, occlusion, space requirements and appearance of the canine tooth will be the guiding factors in whether opening space or closing space is appropriate (Kokich and Kinzer 2005). A balanced, straight profile or mildly convex profile would favor canine substitution, whereas a concave profile would favor space opening. In terms of occlusion, Angle Class II malocclusion of dentoalveolar origin is the ideal case for conventional canine substitution. Angle Class III malocclusion of dentoalveolar origin which may be treated by orthodontic camouflage lends itself to opening space for replacement of the missing MLI by dental implants. A non-conventional treatment strategy in Class III malocclusion would be canine substitution with space redistribution such that an implant is placed out of the esthetic zone between the natural first premolar and second premolar to act as a first premolar. It is interesting to note the reported association between maxillary tooth agenesis and a decreased maxillary jaw size (Tavajohi-Kermani et al. 2002). With this association, canine substitution may not be suitable in some cases wherein fewer teeth in the maxilla will result in an anterior crossbite. However, extraction of lower teeth may allow for canine substitution to be an
option. Alternatively, an orthognathic procedure may be chosen to advance the maxilla after the canines have substituted the missing lateral incisors.

Tooth size / arch length discrepancies, specifically the presence of more severe crowding that would require extractions, may tip the balance toward either space opening or space closing. For instance, an Angle Class I malocclusion with severe crowding in the lower arch and missing MLI may lend itself to canine substitution and extraction of two mandibular premolars.

The appearance of the maxillary canine teeth factors into whether these teeth will act as suitable substitutes for the missing MLI. Favorable attributes include tooth shade similar to the centrals, narrower mesiodistal dimension at the level of the cementoenamel junction, low gingival margin and a less prominent labial surface (Kokich and Kinzer 2005). While it would be advantageous to have these characteristics naturally, some of these attributes can be modified through extrusion, selective bleaching, reshaping and restorative techniques. With the natural arrangement of teeth, the gingival margin of MLI is incisal to both the central incisors and canines. It may be challenging to replicate this gingival architecture in canine substitution and hence a low lip line would be a favorable trait when considering canine substitution. Space closure using the natural dentition may involve some restorative procedures including veneers or composite resin or build-ups to reshape the canine tooth.

Case selection is critical for choosing the appropriate treatment approach, however, when both options are available, clinicians and patients want to know which option will lead to a better outcome.

1.1.3.1 Canine Substitution

Canine substitution, in which the maxillary canine teeth are orthodontically positioned adjacent to the maxillary central incisors, provides an attractive solution to missing MLI by using the natural dentition (Kokich and Kinzer 2005). The main advantages of this option include avoiding a period of retention in which there is an edentulous span in the
esthetic zone and bone resorption of the alveolar ridge; as well as employing fewer
dental procedures, which consequently means a lower financial burden for the patient.
The potential disadvantages of this option include esthetic challenges in cases where
the maxillary canines look out of place as MLI; the need for fixed retention to maintain
space closure; and the lack of symmetry in unilateral cases. This treatment option may
be most suitable when performed bilaterally in order to create symmetry. Given that
anomalous and missing MLI commonly occur together (Pinho et al. 2005), extraction of
a peg lateral may allow for bilateral canine substitution.

1.1.3.2 Prosthetic Replacement

The type of prosthetic replacement can range from complete replacement of the crown
and root with an intraosseous dental implant, complete replacement by
autotransplantation or replacement of the crown only with a tooth-supported restoration.
Autotransplantation is an infrequently utilized but interesting option, wherein another
tooth (e.g. a premolar) is removed and transplanted to replace the missing MLI (Kvint et
al. 2010, Patel et al. 2011). Autotransplantation has not found favor in North America
likely because it requires a tooth with approximately two-thirds root development to be
removed atraumatically and transplanted, and because it entails prosthetic treatment to
alter the crown appearance of the transplanted tooth. For the purpose of this study, the
focus was on replacement by an intraosseous dental implant. The advantages of this
prosthetic option include preservation of alveolar bone and complete preservation of
enamel on the adjacent teeth. However, the main setback of dental implants for
adolescent patients with agenesis of MLI is that the placement of the implant would
need to be delayed until growth is complete as confirmed by serial lateral
cephalograms. Furthermore, in this waiting period, the edentulous span will undergo
bone resorption at a rate of 23% in the first 6 months and 34% by 5 years (Kokich and
Spear 1997), resulting in a high chance of need of an alveolar bone graft prior to
placement of the dental implant. Bone grafting adds to the complexity and cost of
treatment. The conventional approach is a staged one during which bone grafting is
performed 6 to 9 months prior to placement of the implant and the final restoration is
placed 4 to 6 months later. The multiple procedures needed over a relatively long period of treatment may mean an increased financial and time burden and may ultimately carry a high risk of patient burn-out. In select cases, adjunctive procedures such as the split-crest technique (Simion et al. 1992) may allow for immediate placement of the dental implant in a narrow alveolar ridge to accelerate the treatment process. Intra-osseous implants in the anterior maxilla pose numerous soft tissue challenges with varying levels of esthetic importance depending on the level of the lip line. Specifically, restorations in patients that display all gingival margins when smiling carry higher esthetic demands. The need to create a gingival papilla between the implant and canine tooth poses and additional esthetic challenge. Orthodontic distalization of the canine away from the central incisor leads to the creation of a depression of the gingiva, known as Atherton’s patch. In most such situations the papilla is known to remain distal to the central incisor (at the mesial aspect of the created edentulous space) (Atherton, 1970). A non-conventional approach to placement of a single dental implant involves a combination of the canine tooth substituting the missing MLI and a dental implant replacing the canine (Lai et al. 2007). This approach would be applicable in a case where the patient delayed orthodontic treatment until growth is complete and the canine erupted mesially while the deciduous canine is maintained. In addition to the longer treatment time, potential orthodontic distalization of the canine into a narrow edentulous ridge may risk labial bone dehiscence. Given that most patients prefer to address anterior esthetics during adolescent years, this option is novel but limited in application.

### 1.1.3.3 Comparing Options: Patient Burden

The argument for space opening versus space closure is largely based on case selection as described previously. Other considerations may include financial burden, treatment duration and long-term maintenance.
A study by Fekonja (2005) found that 87.5% of cases with hypodontia are resolved by space closure. The main factors for treatment decisions were based on severity of crowding, malocclusion and facial profile (Fekonja, 2005).

A comprehensive analysis of the socio-economic burden for each treatment option would require an extensive chart review and would belong in a category of its own. Nguyen et al. (2004) conducted a study of this nature for the cost of replanting avulsed permanent incisors. Since that was not the focus of this study, but rather merely one of the considerations, a brief comparison of the financial and time burden of the two treatment options for missing MLI using estimates from the 2015 ODA Suggested Fee Guide follows. The financial costs alone are an under-estimation of true cost that could include an intangible time burden to the patient from missed school and work hours.

Orthodontic treatment is required for both options, with the cost and duration of treatment varying depending on the complexity of the overall malocclusion. The difference in cost and duration of orthodontic treatment between the two options is likely insignificant. It is the restorative aspect that differentiates the two options.

For the space-opening option, especially if there are several years until growth is complete, the retention requirements may involve a resin-bonded bridge which currently costs anywhere in the range of $1500 to $4000, depending on the materials used and whether it was performed by a specialist or general practitioner. Alternatively, if only a removable retainer is used then occasional repair or replacement of the retainer may be needed, at a cost of $138 and $187, respectively. When growth is complete, an implant and bone grafting would cost $1857 and $1771 at each site, respectively. Finally, restoration of the implant would cost $1626.

For the space-closing option, gingival recontouring, selective bleaching ($69), composite restorations ($250 to $300) or veneers ($1200) may be indicated to improve the esthetics of canine substitution. The key difference is that this option obviates the need for an implant and/or for bone grafting.
In everyday practice, the type of treatment recommended may depend not on what is the best outcome, but rather on availability of resources. This may be a limiting factor in some geographical areas. However, for urban centers with many specialists available, the treatment chosen should not be limited by practice environment (Louw et al. 2007, Andrade et al. 2012).

1.1.3.4 Comparing Options: Existing Studies

Finally, the long-term maintenance involved in the two options differs. For canine substitution wherein composite build-up and selective bleaching were sufficient for camouflaging the canines, maintenance only involves occasional replacement of the composite restoration. For cases where veneers are used to enhance the camouflage, the restoration can be expected to last up to ten years (Burke 2012) with no studies surpassing this follow-up period. For space opening and replacement of the missing MLI with dental implants, the implants need maintenance every three to six months, which may be associated with a cost depending on the dental practice. The typical lifespan of single-tooth anterior implants is not well established, with current studies having a maximum of fifteen years follow-up (Jemt, 2008, Gottfredsen, 2012).

Existing studies that compare the treatment options for missing MLI include ones that focus on esthetics (Armbruster et al. 2005); patient satisfaction (Robertsson and Mohlin, 2000); and periodontal health (Nordquist and McNeill, 1975).

Armbruster et al. (2005) asked general dentists, orthodontists, other dental specialists, and laypeople to rate the relative attractiveness of treatment outcomes for patients with missing MLI. The photographs included subjects with resin-bonded bridges, implants, canine substitution and subjects with no missing teeth as controls. The results indicated that the lay population ranked photographs of the canine substitution as the best of all options. The orthodontists rated each category significantly different from each other in the following order from best to worst: no missing teeth, canine substitution, resin-bonded bridges and implants. Compared with orthodontists, a significantly greater percentage of general dentists and non-orthodontic dental specialists claimed they
would restore the lateral incisors with implants and would do so primarily for esthetic reasons. An interesting finding was that for dentists and non-orthodontic dental specialists, they rated photos of canine substitution esthetically superior to implants which is contradictory to their treatment recommendation in practice.

Robertsson and Mohlin (2000) conducted a retrospective study on a random sampling of patients who had missing MLI to determine patient satisfaction, comparing space closure to space opening and restoration with a bridge. Based on ratings using a questionnaire, the thirty subjects treated with orthodontic space closure were more satisfied with the appearance of their teeth than the twenty subjects treated with space opening and a fixed bridge. Nordquist and McNeill (1975) found more plaque accumulation and gingivitis in patients treated with prostheses than in those treated with canine substitution.

1.2 Smile Esthetics

1.2.1 Parameters of Smile Esthetics

A growing emphasis on soft tissues and esthetics is reflected in current orthodontic literature. Ackerman et al. (1999) discussed a paradigm shift in orthodontics from the traditional concept where diagnosis and treatment planning were based around hard tissue structures to the emerging paradigm where soft tissues are given more attention because they often dictate function, stability and esthetics. Smile esthetics is an area of particular interest. According to Ackerman et al. (1998), not all orthodontically well treated patients, as demonstrated by plaster casts, exhibit desirable anterior tooth display while smiling. Sarver and Ackerman (2000) were bold enough to state that anterior tooth display is more important than tooth prominence in profile views.

To address this shortcoming in diagnosis and treatment planning, several authors (Ackerman et al. 1998, Sarver and Ackerman, 2003, Sabri, 2005) have proposed different analyses for the smile. The traditional orthodontic records with photographs of frontal smile, frontal at rest and profile at rest may not be sufficient to capture all aspects of a smile (Sarver and Ackerman, 2003). The posed or social smile is suitable for
orthodontic records and for use in studies because it is reproducible (Ackerman et al. 1998). Sabri (2005) describes eight components of a balanced smile: lip line, smile arc, upper lip curvature, lateral negative space (buccal corridors), smile symmetry, occlusal frontal plane, dental components and gingival components. The lip line, defined as the height of the upper lip relative to the maxillary central incisors, determines the amount of incisor display upon smiling. A high lip line exposes a band of gingival tissue whereas a low lip line displays less than 75% of the incisor. A high lip line is of particular interest in patients with missing MLI because the gingival margin of both a canine in place of the lateral incisor and a dental implant will vary from the natural MLI. For a MLI implant, peri-implantitis and metallic show of the implant may compromise the esthetics of the smile in patients with a high lip line. The term 'smile arc' describes the curve drawn along the edges of maxillary anterior teeth in relation to the inner contour of the lower lip in a smile (Sabri, 2005). A smile arc where the curve of teeth parallels the curve of the lower lip is described as 'consonant'. Studies have shown that consonant smiles are correlated with more esthetically pleasing ratings by both laypeople and dental professionals (Parekh et al. 2006, Krishnan et al. 2008). This component of the smile deserves attention since orthodontic mechanotherapy can either create a more pleasing smile arc or flatten the arc. Buccal corridors, the transverse space between the posterior teeth and commissures of the mouth when smiling, have been the focus of several studies with conflicting results on their influence on smile esthetics. Schabel et al. (2009), McNamara et al. (2008) and Ritter et al. (2006) found no correlation between buccal corridor width and attractiveness of a smile. However, Parekh et al. (2006) and Moore et al. (2005) found minimal buccal corridors to be generally preferred. The dental components, including size, shape, shade, alignment, crown tip, midline and arch symmetry, must also be considered in smile esthetics (Sabri, 2005). The ideal ratio between the mesiodistal width of the central incisor-to-lateral incisor varies, with the golden proportion dictating lateral : central = 0.618 and natural ratios ranging from 0.75 to 0.79. Much of this variation can be attributed to the lateral incisors, such as in the case of microdontic or peg-shaped laterals. While an exact ratio cannot be dictated, a guideline is to establish dominance of the central incisors (Chiche, 1994). Smile symmetry can be especially challenging in cases of unilaterally missing or peg-shaped lateral incisors.
1.2.2 Studies on Smile Esthetics

Schabel et al. (2009) conducted a study to compare orthodontically treated smiles as evaluated subjectively by orthodontists and parents, and quantitatively by a software program. Measurements by the software program were not predictive of what the raters considered an attractive smile. Unlike most studies of this nature where the visual analog scale (VAS) is used, raters were trained to utilize the Q-sort system of evaluation whereby all 48 photographs were ranked in order from most attractive to most unattractive. The amount of lower incisor display was significantly different between the smiles ranked most attractive and most unattractive, with a greater amount of lower incisor display ranked the most unattractive. Another characteristic that differed between the extremes of attractiveness was smile index, which is calculated as the smile width from commissure to commissure divided by the interlabial gap. Smiles that were considered the most unattractive had lower smile index, indicating either deficient smile width or excessive smile height, consistent with more lower incisor display.

Brough et al. (2010) designed a study where digitally altered photographs were ranked for smile attractiveness by orthodontists, dentists and laypeople. The results showed good general agreement between the three groups of judges for all parameters of smile attractiveness. This trend differs from the frequently cited Kokich study (1999) where there were differences between the same three groups of raters in terms of threshold levels and ability to notice midline deviation.

Kokich et al. (1999) designed a study where smiling photographs were digitally altered to produce graduated degrees of abnormality. Three groups of raters, orthodontists, general dentists and lay people, rated the photographs on a visual analogue scale and completed questionnaires. The aim of this study was to establish thresholds for esthetic criteria to aid in treatment planning. Results showed that lay people focus on non-dental features (hairstyle, mouth expression, lip shape). Orthodontists noticed a midline deviation at the 4mm threshold while this went unnoticed by dentists and laypeople. None of the respondents detected a peg-shaped lateral incisor until it was 3mm narrower than its ideal proportional width, contradicting the commonly quoted golden proportion. Orthodontists and dentists rated incisal plane asymmetry as the most noticeable
dimension, whereas laypeople rated incisor angulation as the most noticeable, with 2mm as the detectable threshold.

Most studies in smile esthetics use post-orthodontic photographs, however a study by McNamara et al. (2008) used pre-treatment photographs to more closely represent typical orthodontic patients as they present for treatment. Some features important to smile esthetics are quantifiable including: buccal corridors, gingival display, incisor display and smile arc. Results showed no correlation between an esthetic smile as judged by viewer groups using the VAS and the quantifiable features.

1.3 Eye tracking

1.3.1 Eye Movements and Visual Attention

Eye tracking is a method of recording eye movements, which are subsequently analyzed in terms of fixations and saccades (Savucci, 2000). Fixations are pauses over regions of interest and saccades are rapid movements between fixations, during which little or no visual processing can be achieved (Savucci, 2000). Eye tracking was initially used to discover basic eye movements. More recently, improved accuracy and ease of obtaining eye movement recordings has allowed for diagnostic applications in the fields of psychology, aviation, driving, marketing and computer science (Duchowski, 2002). A study using functional MRI to map brain activity during eye-fixation tasks demonstrated an anatomical overlap in areas of the parietal, frontal and temporal lobes to suggest that attentional and oculomotor processes are integrated at the neural level (Corbetta et al. 1998).

By using eye tracking, one can follow along the path of attention and this may give some insight into what the observer found interesting (Duchowski, 2007). The inner cognitive process is known as visual attention. The ‘where’ aspect of visual attention corresponds to the visual selection of specific regions of interest from the entire visual field for detailed inspection. With the exception of peripheral vision, eye-tracking measures can readily show the ‘where’ aspect of visual attention. The ‘what’ aspect of visual attention corresponds to the detailed inspection of the spatial region through a
perceptual channel limited in spatial extent. Eye-tracking measures alone cannot show the significance of the area the viewer chose to focus on.

Looking at an image involves a complex process that one may not be conscious of. Given a visual stimulus, the entire scene is first seen mostly in peripheral vision. Next, interesting features may 'pop out' in the field of view, directing attention to their location for further detailed inspection. Attention is thus turned off and the eyes are quickly repositioned to the first region that attracted attention. Once the eyes complete their movement, the fovea is now directed at the region of interest, and attention is now engaged to perceive the feature under inspection at high resolution (Duchowski, 2007). These are the types of eye movements that can be captured by eye tracking.

1.3.2 Terminology and Data Output

The eye tracker is comparable to a video camera that captures eye movements and records this information in the form of a video. From the raw data, specific eye-tracking software programs allow the data to be analyzed and viewed in different formats. For instance, the bee swarm is a video that allows anyone to appreciate the ‘where’ aspect of visual attention and in essence see the image through the eyes of the observer. The scan path is similar, except that it is composed of lines and circles which cover the image to show where the viewer looked from start to finish, analogous to ‘visual footprints.’ The heat map is a static image that summarizes the portions of the image which received the most visual attention. The number of fixations for the entire image is a standard output of most eye-tracking software, whereas a user-defined area of interest (AOI) can allow for custom output. For example, if a photograph of a face is presented to the observer, then the user may draw an outline around the eyes to determine what percentage of time the viewer spent looking at the eyes, which would be reported as ‘AOI percent dwell time.’ The raw data file is a wealth of information from which a large range of eye-tracking measures can be extrapolated.
1.3.3 Eye-tracking Studies in Orthodontics

There are limited eye-tracking studies in the dental field and even fewer in orthodontics. Meyer-Marcotty et al. (2010) designed a study where pictures of subjects with and without repaired unilateral cleft lip and palate were evaluated by two groups of viewers: laypeople and patients with cleft lip and palate. Viewers were told “they would see a series of different faces and they were allowed to look at them in any manner they wished”, and were given five seconds to view each photograph. The results of this study showed that fixations of viewers were more frequently on the nose and mouth areas of subjects with cleft lip and/or palate. As well, the viewers who had cleft lip and/or palate gazed at the nose for a longer duration and the eyes for a shorter one. These objective data further support the idea that for patients with cleft lip and palate, the appearance of the lip and nose repair is important in the way the face is perceived.

An eye-tracking study by Hickman et al. (2010) aimed at determining which part of the face draws first attention and holds the most visual attention. Fifty laypersons from the university campus were shown a series of sixty facial photographs for six seconds each. Their eye movements were recorded with a head-mounted eye tracker and following the viewing they completed a questionnaire that asked: “When you meet someone for the first time, which facial feature do you look at first? And where do you look the longest?”

The sixty photos comprised three extra-oral views including frontal smile, frontal "nonsmile", and profile of twenty patients who had completed orthodontic treatment and had average soft-tissue profiles. Photos were divided into six areas of interest: eyes, ears, nose, mouth, chin and other (all of face that is not contained in the previous five areas, such as forehead, cheeks, hair, throat, neck and background). The three eye-tracking measures in this study were: location of first fixation, location of area with maximum fixation duration, and location of area with maximum number of fixations. Two assumptions were stated by the authors: Firstly, if the viewer’s eyes are drawn consistently to particular features of the face, one can assume that those features are of greatest interest to the viewer. Secondly, features that are more interesting to a viewer are likely to lead to longer gaze duration when he/she views those features. The findings of this study showed that viewers were “consistently inconsistent” with respect
to all three eye-tracking measures. The category of ‘other’ drew the first fixation most frequently. Of interest to dental professionals is that the mouth in a smile image did not draw first fixation anymore than the mouth in a nonsmiling or profile image. Furthermore, the mouth was viewed first, most frequently and longest in less than 10% of the images. Interestingly, answers from the questionnaire did not match up with the results from eye tracking, in that viewers claimed to looked at eyes first, but in fact look at ‘other’ first. For the smile image, first fixation, the most frequent and longest fixations were: other > eye > nose > mouth > ear > chin.

Most recently, Richards et al. (2015) conducted an eye-tracking study with a similar aim to the study by Hickman et al. (2010). In this study, seventy-six laypersons viewed photographs that were divided into the same six areas of interest. Unique to this study was the use of ‘composite’ images which are digitally-created images wherein different malocclusions were superimposed on different faces. There were four levels of malocclusion: repaired unilateral cleft lip, levels 1, 7 and 10 of the Aesthetic Component of the Index of Orthodontic Treatment Need (AC-IOTN). There were three different levels of facial attractiveness: attractive, average, unattractive. The findings showed that the eyes received the most visual attention, with the mouth second. Interesting trends noted were that when the malocclusion became more severe, visual attention to the mouth increased. As well, the more severe malocclusions (AC-IOTN levels 7 and 10) received more visual attention as facial attractiveness increased.
1.4 Objectives of the study

The objectives of the study were:

- To compare the esthetic outcomes of canine substitution and implant replacement for patients with bilaterally missing maxillary lateral incisors, as judged by dental specialists (orthodontists) and laypersons.

- To compare quantifiable objective parameters affecting the evaluation of treatment outcomes in patients with bilaterally missing maxillary lateral incisors through the use of eye-tracking technology.
1.5 Hypotheses

**Null Hypotheses**

**H₀₁**: The esthetic rating does not differ between the three treatment groups (no missing teeth, implants, canine substitution) given by either orthodontists or laypersons.

**H₀₂**: There are no differences in tracking measures (dwell time percentage and fixation count) between treatment options for missing MLI as rated by either orthodontists or laypersons.

**H₀₃**: There are no observable differences between the scan paths that orthodontists and laypersons follow when viewing a smile of a post-orthodontic patient with intact dentition, versus one with canine substitution, or one with implant-supported crowns to replace missing MLI.

**Alternate Hypotheses**

**H₁**: There are significant differences between the esthetic ratings of the three treatment groups (no missing teeth, implants, canine substitution) by orthodontists and laypersons.

**H₂**: There are significant differences between tracking measures (dwell time percentage and fixation count) between treatment options for missing MLI as rated by orthodontists and laypersons.

**H₃**: There are observable differences between the scan paths that orthodontists and laypersons follow when viewing a smile of a post-orthodontic patient with intact dentition, versus one with canine substitution, or one with implant-supported crowns to replace missing MLI.
Chapter 2: Methods

2.1 Study Design

2.1.1 Statistical analysis and sample size determination

Since there were no published eye-tracking studies on smile esthetics limited to the mouth, a pilot study was conducted to determine the standard deviation of two eye-tracking parameters: dwell time percentage, and fixation count. This was carried out using the same protocol on a sample of raters consisting of eleven graduate students from various dental specialties at the University of Toronto.

Assuming an alpha risk of 0.05 and a standard deviation of 2.63 for mean dwell time percentage, a sample size of 39 viewers per group would be required to demonstrate a difference of ±25% of the mean dwell time percentage with a power of 90%. On the other hand, fixation count, showed a standard deviation of 1.15 meaning that a sample size of 34 viewers per group would be required to demonstrate a difference of ±25% of the mean fixation count with a power of 90%.

2.1.2 Photo Selection

The following inclusion criteria were agreed upon for the photographs to be used in the study:

• Bilaterally missing maxillary lateral incisors treated by canine substitution on both sides
• Bilaterally missing maxillary lateral incisors treated by space opening for implants on both sides
• Completed orthodontic treatment with photographs after removal of orthodontic appliances
• In cases of space opening/dental implant, photographs of final restorations in place
• For control cases, all teeth present, non-extraction orthodontic treatment
• Male and female patients
• All ethnicities
Exclusion criteria for photographs:

- Generalized gingival hypertrophy
- Grossly apparent poor oral hygiene (heavy plaque, visible calculus, decalcification, visible caries)
- In cases of space opening, space not restored or temporary restoration in place
- In cases of space opening, restorations on any of the maxillary anterior teeth other than the implant-supported crown at the site of the lateral incisors
- In cases of space closure, crown or veneer placed on any of the maxillary anterior teeth (reshaping of the canines was permissible)
- In control cases, missing teeth or extraction orthodontic treatment
- Patients with craniofacial anomalies
- Midline deviation >4mm

Collecting photographs

A hand search of all printed records of retention files of the Graduate Orthodontic Clinic at the University of Toronto was conducted by the primary researcher to identify all cases diagnosed with missing or anomalous MLI. Forty-two cases were identified. Of these, seven were treated by closing space on both sides where the MLI was missing or extracted. Eleven cases were treated by opening space on both sides where the maxillary lateral incisor was missing or extracted. These cases treated by space opening were all excluded from the study because there were no available photographs of the final implant-supported restorations. The remaining cases either had incomplete records or involved unilaterally missing or restored lateral incisors. At this point it was decided that photographs of cases where bilaterally missing MLI that were restored with dental implants be sought from a prosthodontist. Seven cases from private practice were provided by a clinical instructor in the Department of Prosthodontics. All seven cases were included in the pilot study, and the four with the highest esthetic scores were chosen for the current study as shown in Figures 2 and 5. All seven cases of bilaterally missing maxillary lateral incisors treated by closing space had less than 50% incisor display on smiling photos, or incomplete records. Consequently, the canine substitution photographs were obtained from private practice by a clinical instructor in the Department of Orthodontics. Seven canine substitution cases were included in the pilot study, and the four with the highest esthetic scores chosen for the current study as shown in Figures 3 and 6. Five well-treated nonextraction cases from the Graduate Orthodontic Clinic at the University of Toronto were chosen for the control group in the
pilot study, and the four with the highest esthetic scores were chosen for the actual study as shown in Figures 1 and 4.

Figure 1. Control Photos in Extra-Oral View. Implant photos in extra-oral view (view A), henceforth abbreviated as Con A.
Figure 2. Implant Photos in Extra-Oral View. Implant photos in extra-oral view (view A), henceforth abbreviated as Imp A.
Figure 3. Substitution Photos in Extra-Oral View. Substitution photos in extra-oral view (view A), henceforth abbreviated as Sub A.
Figure 4. Control Photos in Intra-Oral View. Control photos in intra-oral view (view B), henceforth abbreviated as Con B.
Figure 5. Implant Photos in Intra-Oral View. Implant photos in intra-oral view (view B), henceforth abbreviated as Imp B.
Figure 6. Substitution Photos in Intra-Oral View. Substitution photos in intra-oral view (view B), henceforth abbreviated as Sub B.
2.1.3 Rater Selection

Orthodontists:
- Inclusion criteria:
  - Orthodontists active in clinical practice or education
  - Male and female
  - No age limitations
  - Varying years of experience

Exclusion criteria:
- Participant could not complete calibration stage

Laypersons:
- Inclusion criteria:
  - First year dental students with less than 3 months of dental education
  - Male and female
  - No age limitations

Exclusion criteria:
- Participant could not complete calibration stage
- Completed more than 3 months of dental education in Canada or another country

Ethical approval was obtained from the University of Toronto Research Ethics Board to conduct this study.

Recruitment of laypersons was completed by sending an invitation by email and by classroom announcement to the entire first year DDS class at the University of Toronto. Several students attended the study session but could not calibrate due to fatigue or presence of mascara.

Recruitment of orthodontists was done by sending an invitation by email to orthodontists who are instructors in the Graduate Orthodontics Clinic at the University of Toronto, and by placing posters and announcements at the national orthodontic conference (Canadian Association of Orthodontists) and three regional orthodontic continuing education meetings (Toronto Orthodontic Study Club, Ontario Association of Orthodontists annual general meeting, University of Toronto Orthodontic Alumni Day).

Forty (n=40) orthodontists and thirty five (n=35) first-year dental students completed the study. Participation was voluntary and participants were not compensated for their time.
2.1.4 Creating the Experiment on Experiment Center 3.3 Software

Defining the “Teeth”

Throughout the study teeth are counted laterally starting from the midline, such that the central incisors the “first tooth” and the tooth distal to the central called the “second tooth” and the tooth distal to that called the “third tooth”. This descriptive system allows us to describe all photographs consistently. Specifically, in the control photos, the “first tooth” is the central incisor, the “second tooth” is the lateral incisor and the “third tooth” is the canine. In the implant group, the “first tooth” is the central incisor, the “second tooth” is an implant and the “third tooth” is the canine. In the substitution group, the “first tooth” is the central incisor, the “second tooth” is the canine, the “third tooth” is the first premolar.

Defining the Areas of Interest (AOI)

Analysis of the eye tracking data involves defining areas of interest (AOI). The tracking parameters, ‘dwell time percentage’ and ‘fixation count’, were calculated by the software with respect to AOI that we determined ahead of time. The AOI included the second and third teeth on both upper right and upper left. These AOI were selected because they include the teeth that differ among the two treatment options of space opening and space closure, and these teeth are prominent in the smile. They are in the same relative location for both treatment options. The primary researcher traced the outline of these 4 teeth to include the incisal and proximal margins of the teeth and approximately 1 to 2 millimeters of the gingival margins. Including the edges of the teeth was important because the human visual system has been reported to respond strongly to edges and weakly to homogenous areas (Duchowski, 2007).

The AOI were defined on the photographs to include the second and third tooth from the center, both left and right and was named “L+R”. Since the size of this area varies (78793 pixels, 93689 pixels, 82935 pixels for the extra-oral view (view A); 190318, 217499, 184116 for the intra-oral view (view B) between photographs due to size differences in teeth, an area of the same pixel size (18700, 1.4% of the total photo area) in the “center” of the photograph, which includes maxillary and mandibular midlines,
was defined for consistent comparison across all photographs. Figures 7 and 8 illustrate the defined AOI.

Figure 7. AOIs Defined for Extra-Oral View (view A). The AOI defined for one of the four extra-oral control photos belonging to group Con A. The AOI labeled as ‘center’ is a rectangular area defined with identical size and position across all twenty-four photos. The AOI labeled as ‘L+R’ includes four teeth, the second and third teeth for both sides.
**Figure 8. AOIs Defined for Intra-Oral View (view B).** The AOI defined for one of the four intra-oral canine substitution photos belonging to group Sub B. The AOI labeled as ‘center’ is a rectangular area defined with identical size and position across all twenty-four photos. The AOI labeled as ‘L+R’ includes four teeth, the second and third teeth for both sides.

The Experiment Center 3.3 (Sensomotoric Instruments, Teltow, Germany) software was used to build the experiment. The protocol consisted of rating 12 smiling images (view A) each followed by 2 questions, a brief break, and concluding with rating 12 retracted images (view B) each followed by 2 questions. The software has the capability to present photos in randomized order for the 12 smiling views and also for the 12 retracted views for each participant. For any given rater, the order in which a photo is presented may have an effect on the score assigned. Since the order was randomized, the bias due to the order of presentation is assumed to be minimized.

The type of eye tracking used in this study is termed “non-invasive” or “remote”. It relies on the movement of visible features of the eye. This technique involves automatic (computer-based) analysis of video recordings of the movement of the eyes (Duchowski 2007). No head stabilization devices were used.
2.1.5 Experimental Protocol

All participants, orthodontists and laypersons, were provided the same consent form which stated:

“In orthodontic treatment, the esthetic outcome is important for both the patient and the clinician. Moreover, the opinions of both the dental specialist (orthodontist) and the people that the patient interacts with on a daily basis are valuable in determining successful treatment. The current study attempts to evaluate the esthetics of smiles which have completed orthodontic treatment.”

Prior to starting eye tracking, each participant was briefed by the primary researcher (CC) as follows: “A series of 24 photographs of smiles of patients who have had orthodontic treatment will be shown on a computer display. Following each photograph there will be two questions to be answered by the viewer. You may take as much time as you require to view each photograph, but once you move on to the next, you cannot return to the previous image.” Participants were made aware that they would be recorded by an eye tracker. Participants were not made aware that some of the patients in the photographs had missing teeth or dental implants.

The primary researcher helped to position each participant by adjusting the height and location of the chair and/or laptop computer such that they were within the operating range of the eye tracker, between 50cm and 75cm from the participant to the eye tracker, and the rater was able to reach the keyboard and track pad to enter their responses for the questions.

Once in a suitable position, the rater was calibrated with a four-point calibration. Matsumoto (2011) and Turgeon (2014) accepted calibration with <1° in their respective eye tracking studies. For this experiment, a calibration result of <1° was considered accurate. Once the viewing was complete, the BeGaze software was able to provide a ‘tracking percentage’ which describes the percentage of time the eye-tracker was able to record the rater’s gaze. Upon reviewing the data, some raters were found to have a low tracking percentage. Eye-tracking parameters from raters with low tracking percentages would not be reliable, hence a threshold for tracking percentage was
established. For this study, the tracking percentage threshold was arbitrarily set at 80%. With this threshold, tracking data of 10 orthodontists and 5 lay viewers were eliminated, resulting in sample sizes of 30 raters per group for eye-tracking parameter analysis. Esthetic ratings from all 40 orthodontists and 35 laypersons were still included in the data analysis.

Participants were instructed to rate the esthetics of the smile on a scale from 0 to 10, with 0 = extremely poor esthetics and 10 = excellent esthetics. The two questions following each image were:

1. Please rate the esthetics of the smile on a scale from 0 (extremely poor esthetics) to 10 (excellent esthetics)
2. Please briefly explain the reason for the score you assigned.

For the first question, there were 11 choices for an esthetic rating (0, 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10). For the second question, the participant was allowed to type any answer in a blank box.

All sessions for laypersons were conducted in a seminar room at the University of Toronto, Faculty of Dentistry. Sessions for orthodontists were conducted at various locations. The same laptop (iViewREDm PC, 15.6-inch Dell Latitude E6530) and portable eye tracker (RED-m Eye Tracker manufactured by SensoMotoric Instruments SMI) were used for every session. The display resolution was 1440 by 900 pixels.

Each viewer was shown twelve ‘extra-oral view’ photographs with teeth and lips, and twelve ‘intra-oral view’ photographs with teeth and gingiva. Within the extra-oral view pictures (view A), there were twelve unique patients, four of which were controls with all teeth present, four had implants replacing missing maxillary lateral incisors, and another four were treated with bilateral canine substitution. An intra-oral view (view B) of the same twelve patients was also shown. Intentionally, viewers were not informed that the twenty-four photographs represent the same twelve patients shown in two separate views.
2.2 Operational Definitions

Refer to Appendix A for operational definitions for the terms fixation, fixation count, AOI fixation count, AOI dwell time (%), duration/duration of view/viewing duration, esthetic rating.

2.3 Statistical Analysis

Raw data were compiled by BeGaze software, exported to Microsoft Excel for Mac (version 14.4.9) and analyzed using SPSS software. ANOVA and Tukey’s Post-hoc tests were performed to determine statistical significant differences with significance level set at p<0.05. Pearson correlation coefficients were calculated for correlations between esthetic rating and eye-tracking measures.
Chapter 3: Results

3.1 Descriptive statistics

Rater characteristics are summarized in Tables 1 to 3. Laypersons were younger and less experienced than orthodontists. These characteristics placed the rater groups in mutually exclusive categories. Gender distribution was significantly different between the rater groups. Females comprised 66% of the laypersons but only 28% of the orthodontists. Rater gender in relation to the esthetic ratings was not significant (view A: p=0.79; view B: p=0.22).

<table>
<thead>
<tr>
<th>Table 1. Rater Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rater Group</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Laypersons</td>
</tr>
<tr>
<td>Orthodontists</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2. Rater Experience in Orthodontics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rater Group</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Laypersons</td>
</tr>
<tr>
<td>Orthodontists</td>
</tr>
</tbody>
</table>
Table 3. Rater Gender

<table>
<thead>
<tr>
<th></th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laypersons</td>
<td>23</td>
<td>12</td>
</tr>
<tr>
<td>Orthodontists</td>
<td>11</td>
<td>29</td>
</tr>
</tbody>
</table>

Chi square test: P=0.0012

3.2 Esthetic Ratings

The esthetic ratings were completed by forty orthodontists and thirty-five laypersons. Each rater contributed twenty-four raw scores that were grouped into six means, one for each of the six groups listed below. To provide a ‘mean esthetic rating’ for each photo group, the twenty-four photographs were categorized into six treatment groups:

- Extra-oral view, Control treatment group: Con A
- Extra-oral view, Implant treatment group: Imp A
- Extra-oral view, Substitution treatment group: Sub A
- Intra-oral view, Control treatment group: Con B
- Intra-oral view, Implant treatment group: Imp B
- Intra-oral view, Substitution treatment group: Sub B

For example, a given lay rater contributed four raw esthetic ratings (one for each of the four extra-oral view photos) in the control treatment group (Con A). These four raw scores were averaged to provide one mean esthetic rating for this rater for the group Con A. The overall mean score for Con A was calculated by taking into account the contributions of all thirty-five laypersons. This was repeated for each of the other five groups, Imp A, Sub A, Con B, Imp B and Sub B. Again, the same process was followed for all forty orthodontists. The summary of these results is displayed in Table 4. For both views A and B, there was a significant interaction between treatment group and rater group (p < 0.0001 and p =0.0005, respectively). This means that generalizations cannot be made about differences between the average esthetic rating among rater groups or treatment groups. However it can be stated that esthetic ratings differ between treatment groups, depending on rater group.
Table 4. Mean Esthetic Ratings
Mean esthetic ratings for three treatment groups in two views by two rater groups. Forty orthodontists (n=40) and thirty-five laypersons (n=35) contributed to these mean values.

<table>
<thead>
<tr>
<th>View</th>
<th>Rater Group</th>
<th>Treatment Group</th>
<th>Mean Esthetic Rating</th>
<th>SE</th>
<th>Significant Differences (p&lt;0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra-oral (A)</td>
<td>Lay</td>
<td>Control</td>
<td>7.9</td>
<td>0.14</td>
<td>C-I (0.03)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Implant</td>
<td>6.6</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Substitution</td>
<td>6.4</td>
<td>0.20</td>
<td>C-S (0.01)</td>
</tr>
<tr>
<td></td>
<td>Ortho</td>
<td>Control</td>
<td>7.3</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Implant</td>
<td>6.6</td>
<td>0.12</td>
<td>I-S (0.05)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Substitution</td>
<td>5.6</td>
<td>0.15</td>
<td>C-S (0.005)</td>
</tr>
<tr>
<td>Intra-oral (B)</td>
<td>Lay</td>
<td>Control</td>
<td>7.6</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Implant</td>
<td>6.9</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Substitution</td>
<td>6.9</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ortho</td>
<td>Control</td>
<td>7.9</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Implant</td>
<td>6.7</td>
<td>0.14</td>
<td>C-I (0.05)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Substitution</td>
<td>6.5</td>
<td>0.17</td>
<td>C-S (0.04)</td>
</tr>
</tbody>
</table>

Comparisons between Rater Groups: View A – C-C (0.02), I-I (0.17), S-S (0.0003); View B – C-C (0.02), I-I (0.4), S-S (0.1).

As can be seen on Table 4, there were statistically significant differences between the mean esthetic ratings of the control and implant treatment groups in the extra-oral view (view A) as given by laypersons. As well, there was a significant difference between the mean esthetic ratings of control and substitution groups as determined by the laypersons assessing the extra-oral view (view A). The control group received significantly higher ratings than both the implant and substitution groups. There was no significant difference between the esthetic ratings given by laypersons to the implant and substitution groups in view A.

There were statistically significant differences in mean esthetic ratings attributed by orthodontists to the three treatment groups in the extra-oral view (view A). Control and implant photos were given higher esthetic ratings than substitution photos, however there was no significant difference between the ratings of control and implant photos.

In the extra-oral view, laypersons gave higher esthetic ratings than orthodontists for the control and substitution photos.
Figure 9 shows the range of mean esthetic ratings for each treatment group in the extra-oral view for each rater (3 means per rater). Scores of laypersons were more variable than the scores of orthodontists (the data have a wider range).

![Box plots showing the range of values for mean esthetic ratings contributed by 35 laypersons and 40 orthodontists to the three treatment groups in the extra-oral view (view A). Boxes enclose the middle 50% of observations and vertical bars extend out to include approximately 95% of the observations. Plus signs show outlying data points. The horizontal bars within boxes represent the median values.](image)

**Figure 9. Range of Esthetic Ratings for Extra-Oral View.** Box plots showing the range of values for mean esthetic ratings contributed by 35 laypersons and 40 orthodontists to the three treatment groups in the extra-oral view (view A). Boxes enclose the middle 50% of observations and vertical bars extend out to include approximately 95% of the observations. Plus signs show outlying data points. The horizontal bars within boxes represent the median values.

Figure 10 shows the range of mean scores for each patient group for each rater for each intra-oral view photos (3 means per rater). This figure shows the same trend as did the statistical analysis. There is similar variability in the scores given by either rater group (the data have a similar range).
**Figure 10. Range of Esthetic Ratings for Intra-Oral View.** Box plots showing the range of values for mean esthetic ratings contributed by 35 laypersons and 40 orthodontists for the three treatment groups in the intra-oral view (view B). Boxes enclose the middle 50% of observations and vertical bars extend out to include approximately 95% of the observations. The horizontal bars within boxes represent the median values.

Table 5 shows that for the extra-oral view, if the esthetic ratings given by all the raters, orthodontists and laypersons, were combined and only stratified according to the treatment group, then it was seen that esthetic ratings differ significantly, with the highest rating for control > implant > substitution. Table 6 shows that for the intra-oral view, if the esthetic ratings given by orthodontists and layperson were combined, then controls rated better than both implants and substitution, with no difference between the latter two treatment groups. Table 7 shows the same trend when both extra-oral and intra-oral views are combined, with the only the treatment group used for stratification.
Table 5. Mean Esthetic Ratings by Treatment Group in the Extra-Oral View
Mean esthetic ratings for the three treatment groups in the extra-oral view (view A). Seventy-five raters (n=75), forty orthodontists and thirty-five laypersons, contributed to these mean values.

<table>
<thead>
<tr>
<th>Treatment Group</th>
<th>Mean Esthetic Rating</th>
<th>SE</th>
<th>Significant Differences (p&lt;0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>7.8</td>
<td>0.14</td>
<td>C-I (&lt; 0.01)</td>
</tr>
<tr>
<td>Implant</td>
<td>6.7</td>
<td>0.13</td>
<td>I-S (&lt; 0.01)</td>
</tr>
<tr>
<td>Substitution</td>
<td>6.1</td>
<td>0.14</td>
<td>C-S (&lt; 0.01)</td>
</tr>
</tbody>
</table>

Table 6. Mean Esthetic Ratings by Treatment Group in the Intra-Oral View
Mean esthetic ratings for three treatment groups in the intra-oral view (view B). Seventy-five raters (n=75), forty orthodontists and thirty-five laypersons, contributed to these mean values.

<table>
<thead>
<tr>
<th>Treatment Group</th>
<th>Mean Esthetic Rating</th>
<th>SE</th>
<th>Significant Differences (p&lt;0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>7.9</td>
<td>0.13</td>
<td>C-I (&lt; 0.01)</td>
</tr>
<tr>
<td>Implant</td>
<td>6.8</td>
<td>0.13</td>
<td>I-S (ns)</td>
</tr>
<tr>
<td>Substitution</td>
<td>6.9</td>
<td>0.14</td>
<td>C-S (&lt; 0.01)</td>
</tr>
</tbody>
</table>

ns = not significant

Table 7. Mean Esthetic Ratings by Treatment Group in both Extra and Intra-Oral Views
Mean esthetic ratings for three treatment groups in both intra-oral and extra-oral views (views A and B) pooled together. Seventy-five raters (n=75), forty orthodontists and thirty-five laypersons, contributed to these mean values.

<table>
<thead>
<tr>
<th>Treatment Group</th>
<th>Mean Esthetic Rating</th>
<th>SE</th>
<th>Significant Differences (p&lt;0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>7.9</td>
<td>0.10</td>
<td>C-I (&lt; 0.01)</td>
</tr>
<tr>
<td>Implant</td>
<td>6.7</td>
<td>0.09</td>
<td>I-S (ns)</td>
</tr>
<tr>
<td>Substitution</td>
<td>6.5</td>
<td>0.11</td>
<td>C-S (&lt; 0.01)</td>
</tr>
</tbody>
</table>

ns = not significant

Figures 11 and 12 show the 6 photos that achieved the highest esthetic rating as given by orthodontists and laypersons, respectively, for each of the 6 treatment groups: Con A, Con B, Imp A, Imp B, Sub A and Sub B.
**Figure 11. Highest Esthetic Ratings by Orthodontists for Each Treatment Group.** The photos in each Treatment Group (Con A, Con B, Imp A, Imp B, Sub A, Sub B) that achieved the highest esthetic rating by orthodontists.
**Figure 12. Highest Esthetic Ratings by Laypersons for Each Treatment Group.**

The photos in each Treatment Group (Con A, Con B, Imp A, Imp B, Sub A, Sub B) that achieved the highest esthetic rating by laypersons.
3.3 Eye-Tracking Measures

3.3.1 Static Eye-Tracking Measures

Duration of Viewing

On average, there were no statistically significant differences (F(5, 174) = 0.34, p = 0.71) in the duration of viewing for each photo by orthodontists and laypersons. However, upon inspection, there appear to be significant differences among the raters such that when given an unlimited amount of time to view the photos, there were viewing durations that were ‘brief’, ‘moderate’ and ‘extended’ which was independent of the treatment group, but dependent on the individual rater. This is seen in both the laypersons and orthodontists.

Total Number of Fixations

The total number of fixations did not differ significantly (F(5, 174) = 0.19, p = 0.82). The mean values differ but it was not statistically significant because of the large values for standard deviation.

Fixation Count in AOI

Fixations are defined as scan path data limited to a maximum radius of 2.02° visual angle for at least 80 milliseconds. From Table 8 it was seen that there were no significant differences in mean number of fixations by laypersons and orthodontists when viewing the ‘center AOI.’

Although not statistically significant, there was a greater mean number of fixations by laypersons when viewing the ‘L+R AOI’ for the implant and substitution treatment groups compared to those for the control treatment group in the extra-oral view. The same trend was seen for orthodontists.
Table 8. Mean Number of AOI Fixation Count in Extra-Oral View (View A)
Mean number of fixations for two AOI in three treatment groups in view A by the two rater groups. Thirty orthodontists (n=30) and thirty laypersons (n=30) contributed to these mean values.

<table>
<thead>
<tr>
<th>View</th>
<th>Rater Group</th>
<th>Treatment Group</th>
<th>AOI</th>
<th>Mean Number of Fixations</th>
<th>SE</th>
<th>Significant Differences (p&lt;0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Lay</td>
<td>Control</td>
<td>Center</td>
<td>8.46</td>
<td>1.16</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Implant</td>
<td>8.90</td>
<td>1.19</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Substitution</td>
<td>8.53</td>
<td>1.36</td>
<td>ns</td>
</tr>
<tr>
<td>A</td>
<td>Ortho</td>
<td>Control</td>
<td>Center</td>
<td>10.39</td>
<td>0.92</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Implant</td>
<td>8.76</td>
<td>0.81</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Substitution</td>
<td>9.15</td>
<td>0.90</td>
<td>ns</td>
</tr>
<tr>
<td>A</td>
<td>Lay</td>
<td>Control</td>
<td>L+R</td>
<td>16.82</td>
<td>2.26</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Implant</td>
<td>23.62</td>
<td>3.36</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Substitution</td>
<td>23.21</td>
<td>2.56</td>
<td>ns</td>
</tr>
<tr>
<td>A</td>
<td>Ortho</td>
<td>Control</td>
<td>L+R</td>
<td>20.44</td>
<td>2.53</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Implant</td>
<td>24.07</td>
<td>2.30</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Substitution</td>
<td>30.81</td>
<td>3.47</td>
<td>ns</td>
</tr>
</tbody>
</table>

Figure 13 shows the range of values for mean fixation count in the 'L+R AOI' for each treatment group for each rater for photo view A.
Figure 13. Range of AOI Fixation Count for Extra-Oral View. Box plots showing the range of values for mean fixation count in ‘L+R AOI’ of 30 laypersons and 30 orthodontists viewing smiles of photos of four photos in each of three treatment groups. Photos show an extra-oral view of lips and teeth (View A). Boxes enclose the middle 50% of observations and vertical bars extend out to include approximately 95% of the observations. The horizontal bars within boxes show the median values. (°) and (*) represent outliers. No significant difference indicated by (NS).

There were no significant differences in mean number of fixations by laypersons and orthodontists when viewing the ‘center AOI’ between the different treatment groups in the intra-oral view (view B) (Table 9). There was also no significant difference between
the mean number of fixations by laypersons when viewing the ‘L+R AOI’ between the three different treatment groups in view B.

Although not statistically significant, there was a greater mean number of fixations by orthodontists when viewing the ‘L+R AOI’ for the substitution photo group than control and implant treatment groups in view B.

Table 9. Mean Number of AOI Fixation Count in Intra-Oral View (View B)
Mean number of fixations for two AOI in three treatment groups in view B by the two rater groups. Thirty orthodontists (n=30) and thirty laypersons (n=30) contributed to these mean values.

<table>
<thead>
<tr>
<th>View</th>
<th>Rater Group</th>
<th>Treatment Group</th>
<th>AOI</th>
<th>Mean Number of Fixations</th>
<th>SE</th>
<th>Significant Differences (p&lt;0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Lay</td>
<td>Control</td>
<td>Center</td>
<td>6.01</td>
<td>0.85</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Implant</td>
<td>5.26</td>
<td>0.85</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Substitution</td>
<td>5.18</td>
<td>0.68</td>
<td>ns</td>
</tr>
<tr>
<td>B</td>
<td>Ortho</td>
<td>Control</td>
<td>Center</td>
<td>6.79</td>
<td>0.69</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Implant</td>
<td>5.30</td>
<td>0.53</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Substitution</td>
<td>6.84</td>
<td>0.68</td>
<td>ns</td>
</tr>
<tr>
<td>B</td>
<td>Lay</td>
<td>Control</td>
<td>L+R</td>
<td>16.23</td>
<td>2.20</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Implant</td>
<td>18.11</td>
<td>2.38</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Substitution</td>
<td>19.13</td>
<td>2.45</td>
<td>ns</td>
</tr>
<tr>
<td>B</td>
<td>Ortho</td>
<td>Control</td>
<td>L+R</td>
<td>24.09</td>
<td>3.59</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Implant</td>
<td>26.00</td>
<td>3.29</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Substitution</td>
<td>35.10</td>
<td>3.92</td>
<td>ns</td>
</tr>
</tbody>
</table>

Figure 14 shows the range of values for mean fixation counts in the ‘L+R AOI’ for each treatment group for each rater for photo view B.
Figure 14. **Range of AOI Fixation Count for Intra-Oral View.** Box plots showing the range of values for mean fixation count in 'L+R AOI' of 30 laypersons and 30 orthodontists viewing smiles of photos of four photos in each of three treatment groups. Photos show an intra-oral view of teeth and gingiva (View B). Boxes enclose the middle 50% of observations and vertical bars extend out to include approximately 95% of the observations. The horizontal bars within boxes represent the median values (°) and (*) represent outliers. No significant difference indicated by (NS).
Percent Dwell Time in AOI

Table 10. Mean Percent Dwell Time in Extra-Oral View (View A)
Mean percent dwell time for two AOI in three treatment groups in View A by the two rater groups. Thirty orthodontists (n=30) and thirty laypersons (n=30) contributed to these mean values.

<table>
<thead>
<tr>
<th>View</th>
<th>Rater Group</th>
<th>Treatment Group</th>
<th>AOI</th>
<th>Mean Percent Dwell Time</th>
<th>SE</th>
<th>Significant Differences (p&lt;0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Lay</td>
<td>Control</td>
<td>Center</td>
<td>12.98</td>
<td>1.27</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Implant</td>
<td>Center</td>
<td>11.41</td>
<td>1.16</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Substitution</td>
<td>Center</td>
<td>10.63</td>
<td>1.24</td>
<td>ns</td>
</tr>
<tr>
<td>A</td>
<td>Ortho</td>
<td>Control</td>
<td>Center</td>
<td>15.32</td>
<td>1.04</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Implant</td>
<td>Center</td>
<td>11.10</td>
<td>0.84</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Substitution</td>
<td>Center</td>
<td>10.72</td>
<td>0.75</td>
<td>ns</td>
</tr>
<tr>
<td>A</td>
<td>Lay</td>
<td>Control</td>
<td>L+R</td>
<td>22.84</td>
<td>1.53</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Implant</td>
<td>L+R</td>
<td>24.32</td>
<td>1.52</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Substitution</td>
<td>L+R</td>
<td>28.31</td>
<td>1.56</td>
<td>ns</td>
</tr>
<tr>
<td>A</td>
<td>Ortho</td>
<td>Control</td>
<td>L+R</td>
<td>23.71</td>
<td>1.52</td>
<td>C-S (0.0001)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Implant</td>
<td>L+R</td>
<td>27.56</td>
<td>1.60</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Substitution</td>
<td>L+R</td>
<td>33.45</td>
<td>1.87</td>
<td>-</td>
</tr>
</tbody>
</table>

There were no significant differences in mean percent dwell time by laypersons and orthodontists when viewing the 'center AOI' between the different treatment groups in view A. There was also no significant difference between the mean number of fixations by lay observers when viewing the 'L+R AOI' between the different treatment groups in view A (Table 10).

For view A as viewed by Orthodontists, the mean percent dwell time in ‘L+R AOI’ was higher for the 'substitution' treatment Group than 'control' treatment Group.

Figure 15 shows the range of values for mean percent dwell time in the 'L+R AOI' for each treatment group for each rater for photo view A.
Figure 15. Range of AOI Percent Dwell Time for Extra-Oral View. Box plots showing the mean dwell time percentage in 'L+R AOI' of 30 laypersons and 30 orthodontists viewing smiles of photos of four photos in each of three treatment groups. Photos show an extra-oral view of lips and teeth (View A). Boxes enclose the middle 50% of observations and vertical bars extend out to include approximately 95% of the observations. The horizontal bars within boxes represent the median values. (*) represent outliers. Significant difference indicated by (*).
Table 11. Mean Percent Dwell Time in Intra-Oral View (View B)
Mean percent dwell time for two AOI in three treatment groups in View B by the two rater groups. Thirty orthodontists (n=30) and thirty laypersons (n=30) contributed to these mean values.

<table>
<thead>
<tr>
<th>View</th>
<th>Rater Group</th>
<th>Treatment Group</th>
<th>AOI</th>
<th>Mean Percent Dwell Time</th>
<th>SE</th>
<th>Significant Difference (p&lt;0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Lay</td>
<td>Control</td>
<td>Center</td>
<td>9.09</td>
<td>1.16</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Implant</td>
<td>6.98</td>
<td>0.92</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Substitution</td>
<td>7.82</td>
<td>0.95</td>
<td>ns</td>
</tr>
<tr>
<td>B</td>
<td>Ortho</td>
<td>Control</td>
<td>Center</td>
<td>10.63</td>
<td>0.95</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Implant</td>
<td>6.94</td>
<td>0.66</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Substitution</td>
<td>8.67</td>
<td>0.77</td>
<td>ns</td>
</tr>
<tr>
<td>B</td>
<td>Lay</td>
<td>Control</td>
<td>L+R</td>
<td>22.12</td>
<td>1.42</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Implant</td>
<td>21.53</td>
<td>1.25</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Substitution</td>
<td>24.91</td>
<td>1.51</td>
<td>ns</td>
</tr>
<tr>
<td>B</td>
<td>Ortho</td>
<td>Control</td>
<td>L+R</td>
<td>28.30</td>
<td>1.54</td>
<td>C-S (0.0001)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Implant</td>
<td>32.27</td>
<td>1.83</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Substitution</td>
<td>37.53</td>
<td>1.41</td>
<td>-</td>
</tr>
</tbody>
</table>

There were no significant differences in mean percent dwell time by laypersons and orthodontists when viewing the 'center AOI' between the different treatment groups in the intra-oral view. There was also no significant difference between the mean percent dwell time by laypersons when viewing the ‘L+R AOI’ between the different treatment groups in view B. (Table 11)

For view B as viewed by orthodontists, the mean percent dwell time in ‘L+R AOI’ was higher for the ‘substitution’ treatment group than for the ‘control’ treatment group.

Figure 16 shows the range of values for mean percent dwell time in the ‘L+R AOI’ for each treatment group for each rater for the intra-oral view.
Figure 16. Range of AOI Percent Dwell Time for Intra-Oral View. Box plots showing the mean dwell time percentage in 'L+R AOI' of 30 layperson and 30 orthodontists viewing smiles of photos of four photos in each of three treatment groups. Photos show an intra-oral view of teeth and gingiva (View B). Boxes enclose the middle 50% of observations and vertical bars extend out to include approximately 95% of the observations. The horizontal bars within boxes show the median values. (°) represent outliers. Significant difference indicated by (*).
3.3.2 Correlations: Esthetic Ratings and Static Eye-Tracking Measures

A statistically significant, strong positive correlation was found between duration and fixation count for both laypersons ($r = 0.95$, $p < 0.001$) and orthodontists ($r = 0.95$, $p < 0.001$) as shown in Figure 17.

Figure 17. Correlation between Duration and Fixation Count by Rater Group. Correlation between duration and fixation count for each rater group of 30 orthodontists and 30 laypersons.
Figure 18. Correlation between Esthetic Rating and Fixation Count by Rater Group. Correlation between esthetic rating and fixation count for each rater group of 30 orthodontists and 30 laypersons.

A statistically significant, moderate negative correlation was found between fixation count and esthetic score for both laypersons ($r = -0.22$, $p < 0.01$) and orthodontists ($r = -0.25$, $p < 0.01$) as shown in Figure 18.
Figure 19. Correlation between Esthetic Rating and Fixation Count in Extra-Oral view by Treatment Group. Correlation between esthetic rating and fixation count for each treatment group (n=60) in view A.

Figure 19 shows there was a weakly significant negative correlation ($r = -0.31, p = 0.02$) between esthetic rating and fixation count for the treatment group Con A. There was not a significant correlation for the two other treatment groups, Imp A and Sub A ($r = -0.05, p = 0.72$), ($r = -0.10, p = 0.46$), respectively.
Figure 20. Correlation between Esthetic Rating and Duration by Treatment Group. Correlation between esthetic rating and fixation count for each treatment group (n=60) in both views A and B.

Figure 20 shows there was a significant negative correlation between esthetic rating and duration for all the treatment groups control (r = -0.35, p < 0.01), implant (r = -0.18, p = 0.05) and substitution (r = -0.27, p < 0.01) when both views A and B are pooled together.
In Figure 21, when all six treatment groups are considered collectively for each rater group, there was a significant negative correlation for the orthodontists \( r = -0.30, \ p<0.01 \) and laypersons \( r = -0.18, \ p = 0.02 \) such that longer total view time was associated with lower esthetic ratings.
Figure 22. Correlation between Esthetic Rating and Duration in Extra-Oral View by Treatment Group. Correlation between esthetic rating and viewing duration for each treatment group (n=60) in view A.

Figure 22 shows there was a significant negative correlation ($r = -0.32$, $p = 0.01$) between esthetic rating and fixation count for the treatment group Con A. There was not a significant correlation for the two other treatment groups, Imp A and Sub A ($r = -0.06$, $p = 0.63$), ($r = -0.16$, $p = 0.22$), respectively.
Figure 23. Correlation between Esthetic Rating and Fixation Count by Treatment Group. Correlation between esthetic rating and fixation count for each treatment group (n=60) in both views A and B.

Figure 23 shows there was a significant negative correlation between esthetic rating and fixation count for the control group ($r = -0.31$, $p < 0.01$) and substitution group ($r = -0.21$, $p = 0.03$) when both views A and B are pooled together. There was not a significant correlation for the implant groups ($r = -0.17$, $p = 0.06$).
In Figure 24, the correlation between esthetic rating and total view time for the 6 treatment groups, con A, imp A, sub A, con B, imp B and sub B, was examined separately for the Orthodontists. There was a negative correlation for all treatment groups as rated by Orthodontists, with significance for two groups: Control view B (con B) and Implant view B (imp B). For these two groups, it was found that greater total view time to be correlated with lower esthetic ratings.
Figure 25. Correlation between Esthetic Rating and AOI Percent Dwell Time by Rater Group. Correlation between esthetic rating and mean percent dwell view time for each rater group of 30 orthodontists and 30 laypersons.

When all six photo groups were considered collectively for each rater group, the correlation between esthetic rating and mean percent dwell time was not significant for the laypersons \((r = -0.63, p = 0.40)\). In contrast, there was a statistically significant, weak positive correlation for the orthodontists such that greater mean dwell time percentage was associated with higher esthetic ratings (Fig. 25).
Figure 26. Correlation between Esthetic Rating and AOI Percent Dwell Time by Treatment Group for Orthodontists. Correlation between esthetic rating and dwell time percentage for each of the three treatment groups in two views as contributed by orthodontists (n=30).

The correlation between mean esthetic rating and mean AOI dwell time for the six treatment groups (con A, imp A, sub A, con B, imp B and sub B) separately for orthodontists can be seen on Fig. 20. There was a moderate positive correlation for all treatment groups as viewed by orthodontists, with statistical significance for two groups: implant view A ($r = 0.59$, $p < 0.01$) and substitution view B ($r = 0.48$, $p < 0.01$). For these two groups, it was found that greater percent dwell time was correlated with higher esthetic ratings. Alternatively, a lower percentage of time spent looking at the AOI was correlated with lower esthetic ratings.
Figure 27. Correlation between Esthetic Rating and AOI Fixation Count by Treatment Group for Orthodontists. Correlation between esthetic rating and fixation count for each of the three photo groups in two views as viewed by orthodontists (n=30).

The correlation between mean esthetic rating and mean AOI fixation count for the six groups (con A, imp A, sub A, con B, imp B and sub B) separately for orthodontists can be seen on Figure 27. There was a negative correlation for all treatment groups as viewed by orthodontists ($r = -0.24$, $p < 0.01$), with significance for one group: control view B (con B) ($r = -0.42$, $p = 0.02$). For this group, a greater fixation count was correlated with lower esthetic ratings. Alternatively, fewer fixations in the AOI were correlated with higher esthetic ratings.
3.3.3 Dynamic Eye-Tracking Measures: Scan Path

Figure 28. Time lapse of scan path for a layperson viewing an extra-oral view of one of the implant group photographs. This rater (n=1) had a total viewing time of 4.4 seconds which we categorized as ‘brief.’ Three time points are shown, as indicated by the time at lower right corner. The black circle indicates the point of first fixation. The green circle indicates the most recent point of fixation. The red circle indicates the most recent point of fixation in the previous time point. The green line(s) indicate(s) the saccade(s) leading to the most recent point of fixation.
Figures 28 to 30 show the scan path of one layperson whom were categorized as having a ‘brief’ duration of rating session for all photos. Figure 28 demonstrates the scan path for the extra-oral view of a control image. This rater had a low number of fixations and the scan path did not include many of the teeth, gingival margins or the lips. Figure 29 shows the scan path for the extra-oral view of an implant image. This layperson focused on the incisal edges of the incisors and did not fixate on the lips or posterior teeth on the image. Figure 30 shows the scan path for the extra-oral view of a substitution image. This rater had fixations on the incisal edges of teeth with no fixations on the excessive gingival display.
Figure 29. Time lapse of scan path for a layperson viewing an extra-oral view of one of the implant group photographs. This rater (n=1) had a total viewing time of 7.6 seconds which we categorized as ‘brief.’ Four time points are shown, as indicated by the time at lower right corner. The black circle indicates the point of first fixation. The green circle indicates the most recent point of fixation. The red circle indicates the most recent point of fixation in the previous time point. The green line(s) indicates the saccade(s) leading to the most recent point of fixation.
Figure 30. Time lapse of scan path for a layperson viewing an extra-oral view of one of the substitution group photographs. This rater (n=1) had a total viewing time of 7.6 seconds which we categorized as 'brief.' Four time points are shown, as indicated by the time at lower right corner. The black circle indicates the point of first fixation. The green circle indicates the most recent point of fixation. The red circle indicates the most recent point of fixation in the previous time point. The green line(s) indicates the saccade(s) leading to the most recent point of fixation.
Figure 31. Time lapse of scan path for an orthodontist viewing an extra-oral view of one of the control group photographs. This rater (n=1) had a total viewing time of 14.3 seconds which we categorized as 'brief.' Four time points are shown, as indicated by the time at lower right corner. The black circle indicates the point of first fixation. The green circle indicates the most recent point of fixation. The red circle indicates the most recent point of fixation in the previous time point. The green line(s) indicates the saccade(s) leading to the most recent point of fixation.
Figure 32. Time lapse of scan path for an orthodontist viewing an extra-oral view of one of the implant group photographs. This rater (n=1) had a total viewing time of 8.8 seconds which we categorized as 'brief.' Four time points are shown, as indicated by the time at lower right corner. The black circle indicates the point of first fixation. The green circle indicates the most recent point of fixation. The red circle indicates the most recent point of fixation in the previous time point. The green line(s) indicates the saccade(s) leading to the most recent point of fixation.
Figure 33. Time lapse of scan path for an orthodontist viewing an extra-oral view of one of the substitution group photographs. This rater (n=1) had a total viewing time of 13.2 seconds which we categorized as ‘brief.’ Five time points are shown, as indicated by the time at lower right corner. The black circle indicates the point of first fixation. The green circle indicates the most recent point of fixation. The red circle indicates the most recent point of fixation in the previous time point. The green line(s) indicates the saccade(s) leading to the most recent point of fixation.
Figures 31 to 33 show the scan path of one orthodontist whom we categorized as having a ‘brief’ duration of rating session for all photos. Figure 31 shows the scan path for the extra-oral view of a control image. This rater appeared to compare corresponding teeth on the right and left and the scan path spanned from the right first premolar to the left canine but did not include the lips. Similarly, Figure 32 shows the scan path for the extra-oral view of an implant image. This layperson focused on the central portion of the crowns from canine to canine. Figure 33 shows the scan path for the extra-oral view of a substitution image. This rater had many fixations on the gingival area between the lateral and central incisors, and showed frequent crossing of the midline from side to side.

Figure 34 shows the scan paths of an orthodontist (left column) and a layperson (right column), whom we categorized as having 'moderate' viewing duration of rating sessions. For the control image (top row), the orthodontist and layperson both had scan paths with broad coverage to include all the teeth. For the implant image (middle row), the orthodontist had nearly all fixations concentrated on the incisal edges, while the layperson had fixations and saccades that covered more of the crowns. For the substitution image (bottom row), the orthodontist had more fixations and saccades on the gingiva while the layperson had a somewhat evenly distributed pattern of fixations and saccades over the clinical crowns of the eight anterior teeth.

Figure 35 shows the scan paths of an orthodontist (left column) and a layperson (right column) whom were categorized as having 'extended' viewing durations. For the control image (top row), the orthodontist had a large number of fixations and saccades limited to the area of the teeth, whereas the layperson had a broader scan path that included the lips and did not have distinct pattern. When examining the scan paths for the implant image (middle row) and substitution image (bottom row), it was noted that the pattern appears somewhat consistent for the same rater. For the orthodontist the scan path consisted mainly of horizontal saccades from side to side over the teeth. For the layperson, there was a mix of vertical and horizontal saccades with fixations on both the teeth and lips.
Figure 34. Scan Paths for ‘Moderate’ Orthodontist and Layperson. From top left to bottom left, scan path (purple) of one orthodontist rating extra-oral views of a control, implant and substitution photographs, respectively. From top right to bottom right, scan path (orange) of one layperson rating extra-oral views of a control, implant and substitution photographs, respectively. The black circle represents the point of first fixation. Circles represent fixations and lines represent saccades. Total duration of the rating session is shown in the lower right corner of each photo. We categorized
Figure 35. Scan Paths for ‘Extended’ Orthodontist and Layperson. From top left to bottom left, scan path (red) of one orthodontist viewing an extra-oral view of a control, implant and substitution photograph, respectively. From top right to bottom right, scan path (green) of one layperson viewing an extra-oral view of a control, implant and substitution photograph, respectively. The black circle represents the point of first fixation. Circles represent fixations and lines represent saccades. Total view duration is shown in the lower right corner of each photo. These viewers were both categorized as having ‘extended’ viewing durations.
Chapter 4: Discussion

4.1 Esthetic Ratings and Static Tracking Measures

For the extra-oral view, both orthodontists and laypersons rated the control photos as the most esthetic. However, their preferences differed when comparing implant photos with substitution photos. Orthodontists found the implant photos to be more esthetic than substitution, whereas laypersons rated implant and substitution photos as not significantly different. For the intra-oral view, orthodontists and laypersons had different esthetic preferences. Orthodontists gave higher esthetic ratings for the control group than both the implant and substitution groups. In contrast, the laypersons did not show any preference in their esthetic ratings of the three groups. When comparing the esthetic ratings given to the extra-oral view and intra-oral view of the same patient, it was interesting to note higher ratings for the intra-oral view than the extra-oral one. In contrast, Flores-Mir et al. (2004) found that laypersons assigned higher scores for the “lower third view” (extra-oral view) than for the “dental view” (intra-oral view) of the same patient, which they felt suggested that the ‘context’ of the smile has an effect on how well the smile is perceived. It was not expected that higher ratings were given for the intra-oral view since this view may reveal details of the gingiva and enamel, which were likely to appear less esthetic immediately upon removal of orthodontic appliances due to gingival inflammation and scratches on the enamel. Possible explanations for lower ratings for the extra-oral view include lips, facial hair, facial blemishes and excessive gingival display (“gummy smile”).

A summary of the esthetic scores can be seen in Table 4. The mean values presented in Table 4 were based on esthetic ratings from 0 to 10 given by raters who assigned scores without a standard for comparison. In other studies (Richards et al. 2015), a classification system, such as the Index of Orthodontic Treatment Need (IOTN) esthetic scale, was used to provide some guidance and “standardization” of the raters. Similarly, in cleft palate research, raters participating in outcome studies such as Americleft and Eurocleft undergo some calibration training prior to rating the esthetics of the nose and lip following repair (Asher-McDade 1991, Mercado 2011). Such approaches are used to reduce the variability (“scatter”) of the possible ratings to a
more manageable degree. In the current study, a calibration protocol was not used due to the associated time burden and also because it was felt that laypersons are not standardized in real life (in contrast, the orthodontists' approach to assessing a smile may be somewhat similar due to comparable training in graduate school). In addition, pre-calibration of the raters would defeat the purpose of this study. In some ways the eye-tracking equipment is substituting the pre-calibration in that it can be used to analyze the variability of approaches used by the different raters when assessing a smile, offering insight into the validity of the subjective ratings. In a smile esthetics study, Krishnan (2008) found that none of the smiles were considered “very good” by expert and lay raters, but rather, most were rated as “good” or “average”. This clearly represents a regression to the mean. To address the issue of raters having differences of range in scoring, such as a generous or miserly tendency, the esthetic ratings were also calculated using the formula proposed by Geron (2005):

\[
\text{standardized score} = \frac{\text{raw score} - \text{mean score}}{\text{standard deviation}}
\]

The standardized esthetic ratings showed the same trends as the raw scores. An additional statistically significant difference was revealed in that laypersons rated control photos higher than both implant and substitution photos in the intra-oral view.

In the questionnaire, raters were asked to rate the esthetics of the smile from 0 to 10, and then provide an explanation for the rating assigned. Most raters described the negatives or what made this smile less than a '10'. Comments from laypersons for the extra-oral view were related to shade of teeth, midline discrepancy, gum line, lack of lower tooth show, mamelons, increased overbite, size or proportion of teeth, and narrow smile. Missing teeth were identified by several viewers for two of the four substitution photos. Comments from laypersons for the intra-oral view were related to shade of teeth, color of gingiva, stains, midline discrepancies and enamel flaws, occlusion, size of teeth and inflamed gums. Missing teeth were identified by only two viewers in one of the four substitution photos. Comments from orthodontists for the extra-oral view were related to smile arc, midlines, facial-lingual inclination of teeth, gingival heights and contours, tooth size proportions, coloration of teeth, width of smile, incisor display and gingival display. For one of the four implant photos, six viewers identified the “second
tooth” as a prosthesis. For all four substitution photos, at least 25% of the viewers identified the “second tooth” as a canine.

Comments from orthodontists for the intra-oral view were related to gingival recession of posterior teeth, gingival height discrepancies, smile arc, midlines, enamel damage, gingival papillae, occlusion, gingiva around “second tooth”, tooth shade and tooth size proportion. Many viewers identified substitution photos as canine substitution. In summary, the negative comments unrelated to the difference in outcome between opening space and closing space were an indication of confounding factors. The most prominent confounders were tooth shade and enamel flaws. In the study by Havens et al. (2010), raters were explicitly asked to rank the importance of nine dental/facial characteristics that influenced their esthetic rankings of facial attractiveness. Such an approach provides results that are more easily compared statistically, however poses a risk of bias by suggestion.

4.2 Correlations: Esthetic Ratings and Static Eye-Tracking Measures

This study was novel in that it was the first to use eye tracking to record how people look at smiles while they decided how to rate the esthetics. One of the objectives of this study was to explore whether a correlation exists between subjective and objective measures when viewing a smile. To do this, the relationship between esthetic ratings and various eye-tracking measures was measured and shown in Figures 18 to 27. Analysis was performed by categorization by rater group (orthodontists and laypersons) as well as by treatment group (control, implant and substitution). It was found that a negative correlation exists between esthetic rating and duration of viewing. The same trend was found for esthetic rating and fixation count, which is not surprising since duration of viewing and fixation count have a strong positive correlation (as shown in Figure 17). A similar trend was observed for esthetic rating and AOI fixation count (Figure 27). In contrast, a positive correlation was observed for esthetic rating and AOI dwell time percentage (Figures 25 and 26). In general, the longer the viewing duration or greater the fixation count, the lower the esthetic rating. This may be explained in part by the fact that people tend to look at things longer if they find them novel (Langer et al.
1976). To truly explain this it would first require knowing whether raters make the decision of the esthetic rating immediately upon seeing the photograph or whether they first examine the photograph and then decide upon the esthetic rating at the end of viewing. One of the difficulties in eliciting the answer to this is that raters were asked to give a reason for their rating. In anticipation of answering this question, raters may in fact take more time to look for problems to justify their rating. The purpose of asking why a score was assigned was mainly to determine whether raters would explicitly identify implants or canine substitution. As an open-ended question, the content of the answers were not consistent and some orthodontists explicitly identified canine substitution, while only a few orthodontists identified implants for the MLI and very few laypersons identified that some “teeth seem to be missing” in canine substitution cases.

For orthodontists, the greater the percentage of time spent looking at the AOI (2nd and 3rd teeth on both sides), the higher the esthetic rating. This was surprising because it was expected that raters who spent more time looking at the AOI would do that because they notice something “off” about these teeth and hence give a lower esthetic rating. Perhaps orthodontists were alerted to spend a greater percentage of time looking at the AOI due to the greater than usual (66% of the photos in this study versus 2% in the general population) proportion of cases with missing MLI. For laypersons, there was non-significant negative correlation between esthetic rating and AOI dwell time percentage.

The study by Schabel (2009) shares similarities to the current study because they looked for a correlation between subjective and objective evaluations. The subjective component was esthetic ratings by participants using the Q-sort method and the objective component was a software program named Smile Mesh that quantifies fifteen characteristics of anterior tooth display. They found no correlation between the two, meaning that measurements of all these characteristics were not predictors for esthetic ratings as judged by people. In the present study there was an attempted comparison between subjective and objective values as well. While Schabel’s study compares the rater’s opinion to values measured on the photo, a comparison of two variables generated by the same human subject, their visual attention as measured by eye tracking and the esthetic ratings that they assigned to the particular smile.
4.3 Existing Studies

In a recent eye-tracking study, Turgeon (2014) used eye tracking to examine the search strategies that novice and expert viewers use to examine panoramic radiographs. The study revealed that experts were consistent in their search strategies to ensure complete image interpretation regardless of abnormalities present, whereas novice viewers were inconsistent in their scan paths. The difference is that a systematic search strategy is taught to dental students for image interpretation so that areas will not be overlooked. In contrast, the current study does not have an expectation of a specific strategy for how a viewer analyzes a photograph of a smile. In fact, it is more of an exploratory study to see how laypersons and orthodontists analyze a smile. It was seen that viewers were somewhat consistent when compared with themselves, but there was not much consistency between viewers within the same rater group or from different rater groups. There were clearly some orthodontists who focused on incisal edges, while others focused on the gingival margins. There were also some viewers who limited their scan path to the six anterior teeth, while others had broad coverage to include all teeth, gingiva and lips. A great deal of variability was seen in scan paths, total number of fixations, total number of saccades and viewing duration. According to Turgeon (2014), when interpreting a panoramic image students are taught to be systematic in their search. This cannot be directly applied to ‘analysis of a smile’ since dental students and orthodontists are not taught a systematic approach to analyzing a smile. There was not an expectation of the scan path for analyzing a smile since this study was novel. Clearly there were differences in the scan paths between all the raters with no two identical scan paths. It was expected that a higher degree of concordance among the orthodontists due to similar training they receive, which presumably creates a bias toward similar characteristics (Havens et al. 2010).

When all orthodontists were considered together there was no significant difference in terms of the viewing duration, total number of fixations and total number of saccades between different treatment groups (ie. Con A vs Imp A vs Sub A). However, if one examines the data by stratifying the orthodontists into different categories according to the viewing duration (‘brief’, ‘moderate’ and ‘extended’), trends emerge which show that orthodontists with ‘brief’ and ‘moderate’ viewing duration spent more time viewing the
substitution photos than control and implant photos. This is likely because they identified these photos as canine substitution (which was demonstrated by their written comments) and hence spent more time looking at these interesting smiles. Viewing time was not noticeably extended for the implant photos and this is consistent with the scarcity of written comments that mentioned implants. Orthodontists in the 'extended' viewing duration group view all treatment groups similarly.

For the laypersons, there was no significant difference in terms of the viewing duration, total number of fixations and total number of saccades between different photo groups (ie. Con A vs Imp A vs Sub A). Even when laypersons were stratified into different categories according to their viewing duration ('brief', 'moderate' and 'extended'), no apparent differences emerged in terms of the way they view the different treatment groups.

In a study by Armbruster et al. (2005), a difference was identified in the preferences of the lay population. In that study, laypersons ranked photographs of the canine substitution as the highest of all options. The orthodontists rated each category significantly different from each other in the following order from best to worst: no missing teeth, canine substitution, resin-bonded bridges and implants. In the current study, both laypersons and orthodontists gave the highest esthetic ratings to no missing teeth, with equivocal ratings for canine substitution and implants given by laypersons and orthodontists rating implants higher than canine substitution.

An eye-tracking study by Halioua et al. (2011) examined whether laypersons looked at people with facial disfigurement differently than those without facial disfigurement. They found that the viewers stared at the photos of people with facial disfigurement longer (fixation duration) and perceived the subjects less positively in terms of capability, popularity, optimism, attractiveness, intelligence, employability and effectiveness. They explained their findings with the 'novel stimulus hypothesis', which states that novel stimuli evoke behaviours from the observer such as staring in order to make them more familiar with the stimuli. An interesting finding in this study was that while persons with facial disfigurement were rated more negatively than persons without facial
disfigurement, the longer viewers stared at a photo, the more positively they rated the person in the photo.

4.4 Study Limitations

4.4.1 Selection of Photos

There were a limited number of photographs to represent each type of treatment. Even with the same treatment plan outcomes will vary. The four photographs chosen by no means represent all cases of implants or canine substitution. The four cases per treatment option that were chosen met the inclusion criteria, and were considered to be the most esthetic of the seven possible choices employed in the pilot study. The number of cases was chosen as a good compromise because a greater number of photos may have led participants become fatigued or bored.

Other studies attempt to limit confounding variables by using a single photograph and then digitally manipulating one aspect of it (Kokich et al. 1999, Hunt et al. 2002, Geron and Atalia 2005, Heravi et al. 2011, Bothung et al. 2014, Espana et al. 2014) then letting raters judge which they prefer. An alternative method was allowing the raters change one aspect of the smile with a “slider” to the degree of their liking (Ker et al. 2008, Springer et al. 2011, Chang et al. 2011, McLeod et al. 2011). Very few studies use unaltered photographs (Flores-Mir et al. 2004, Krishnan et al. 2008). Studies using highly altered photos are well designed to eliminate or minimize confounders. However this comes at the cost of losing clinical significance or real-world application because it is not often that one can truly only change one parameter of a smile without affecting any other aspects. The difficulty with using unaltered clinical photographs is that many confounding variables may be contributing to what was studied. A comparison of different treatment plans (space opening vs space closure) was the aim, but many other things differ such as the shade of the teeth and soft tissues that frame the teeth.

In the current study tooth shade was a frequently and consistently cited factor in how laypeople assigned esthetic scores. It was not specific as to which teeth had unesthetic coloration, however it seemed that the shade referred to all teeth in general. There were no specific comments regarding the shade of the “second tooth”. Since tooth
shade is a known factor in smile esthetics, it appears possibly advantageous to eliminate this factor by use of Photoshop to make the shade of teeth consistent. Janson and co-workers (2011) suggests that conversion of color photographs to black and white is important for studies that compare the smiles of different subjects, because this procedure evens the skin shades for the sample and reduces the number of confounding factors. It was elected to not alter the shade of all the teeth because the shade of the canine tooth is a clinical consideration when deciding whether canine substitution is a suitable option for a patient (Brough et al. 2010).

The photographs in the current study were obtained from different clinicians, so the settings and resolution of the images varied. While none of the viewers commented that difference in image quality affected their evaluation of the smile, standardized conditions for the photographs would minimize the effect of photo quality as a possible confounder.

4.4.2 Selection of Participants

Laypersons are the most common type of raters in smile esthetics studies, with the term ‘laypersons’ or ‘laypeople’ applied to people recruited on a college campus (Chang et al. 2011), first year social science students (Hunt et al. 2002), friends or family of patients (Flores-Mir et al. 2004, Krishnan et al. 2008, Schabel et al. 2009), patients (Geron and Atalia 2005, Heravi et al. 2011), military men (Van der Geld 2007) and not specifically defined (Ker et al. 2008, McLeod et al. 2011, Parekh et al. 2006). Most studies specify that they try to avoid laypersons with any dental affiliations. While this exclusion criteria may seem reasonable, our choice of first year dental students was justified by the fact that the first-year dental school curriculum does not include the study of smile esthetics and the course on orthodontics begins in second year. In fact, a study by Espana et al. (2014) shows that dental students do not develop their ability to detect alterations in smile esthetics over the entire course of dental school training. The dental students in the current study demonstrated some dental knowledge in their comments, including FDI tooth numbers, description of midlines and even the term ‘golden ratio’. Their novice status was demonstrated by some comments including the lack of familiarity with physiological pigmentation of gingiva and comments that were contradictory. While
having some knowledge and interest in dentistry, dental students were selected for ease of recruitment. Even though dental students may have some dental knowledge beyond that of the general public, patients and their parents must not be underestimated because they have greater access to health care information, including orthodontic treatment, from the Internet. Since participation was voluntary, there may be participation bias whereby the laypersons who participated are more keen and may be treat the study as an educational exercise. It is worth noting that there are more studies on the layperson’s perspective than the dental professional’s perspective in esthetic studies. This makes sense, because these laypersons are meant to reflect how patients and the "outside world" perceive dental esthetics.

It was expected that the group of raters consisting of certified orthodontists in Canada to be relatively homogenous due to similar education and training. This group of raters is similar to that of several other studies on factors influencing smile esthetics (Bothung et al. 2014, Parekh et al. 2006, Schabel et al. 2009). A systematic review by Andrade (2012) claimed that the type of environment one practices in, isolated or interdisciplinary, leads to a bias in choosing orthodontics alone or interdisciplinary treatment for managing cases of missing MLI. Orthodontists were not surveyed to determine the type of environment they practice in. Including other dental specialists as raters would provide a broader input from the clinician’s standpoint. Other studies (Krishnan et al. 2008, Bothung et al. 2014) included a greater range of dental professionals who may provide additional insight into the restorative aspect of treatment for missing MLI.

Krishnan and co-workers (2008) found there was a high correlation between dental specialists and laypersons in rating the overall appearance of smiles. Flores-Mir et al. (2004) stated that level of education in laypersons did not consistently influence the esthetic perception.

There are conflicting reports of who is more critical or sensitive to detecting alterations in smile characteristics, laypersons or dental professionals. In terms of detecting thresholds, Kokich et al. (1999) showed that orthodontists have the lowest threshold for detecting changes from the ideal for smile characteristics such as midline deviation and
occlusal cant, with dentists coming next, and laypersons being the least sensitive to changes. On the other hand, Schabel et al. (2009) reported that laypersons are more critical than dental professionals when assigning esthetic scores on a VAS, suggesting that this difference may be related to laypersons’ exposure to seemingly perfect smiles portrayed by celebrities and models, whereas dental professionals have insight into how natural smiles of patients look without any cosmetic alterations such as veneers or digital enhancement of photos by software programs such as Adobe Photoshop.

Ethnicity was not included as a selection criterion for raters. This poses two possible issues. Firstly, the accuracy and precision of eye tracking may be related to ethnicity in relation to the size of eyes (Blignaut et al. 2014). Secondly, own-race and other-race bias has been reported in facial esthetics studies (Collins 2012).

A specific proportion of male and females for raters was not selected for the photographs. Gender of the photographs was a factor in how raters perceive esthetics as demonstrated by a study (Geron and Atalia 2005) that had viewers judge a smile telling them the photo was “female” and then the same photos by another set of viewers telling them the photo was “male.” “Female” smile images were scored lower by both male and female evaluators, suggesting that higher attractiveness is expected from women than from men. Schabel (2009) found disagreement between male and female evaluators in what they consider “attractive” vs “unattractive”. An esthetic study on the influence of shape of anterior teeth (Heravi et al. 2011) found that male and female raters agreed on esthetic preference for rounded incisors.

4.4.3 Eye Tracking as the Measurement Tool

Eye tracking is a valuable tool in marketing research that allows one to determine what attracts attention on a billboard or website as indicated by first fixations and longest fixations in defined areas of interest. When applied to how one looks at a smile, it is limited by the fact that people may not look at a smile on a tooth-by-tooth basis, but rather take in the smile as a whole. Judgment on whether the smile is attractive or not may only require a quick glance rather than visual attention focused on small parts of the smile, such as the lateral incisors. While it would have been favorable to have the eye-tracking measures corroborate the esthetic ratings that was simply not the case.
The esthetic ratings showed that orthodontists considered extra-oral control images most esthetic, with implants second and canine substitution least esthetic. Eye-tracking measures showed that orthodontists gave the most visual attention to the AOIs in the canine substitution photos, and that visual attention to the AOIs in the implant and control photos was not significantly different from each other. Laypersons gave controls the highest ratings and similar ratings to both substitution and implant photos. In contrast, eye-tracking measures showed that laypersons had similar AOI dwell time and AOI fixation count across all three treatment groups.

Attention is composed of both involuntary and voluntary components, so humans can voluntarily dissociate attention from the direction of gaze. The voluntary component of vision may be thought of as a covert component that is not easily detectable by external observation. This is a well-known problem for eye-tracking research. An eye tracker can only track the overt movements of the eyes, however, it cannot track the covert component of visual attention. Thus in all eye-tracking work, an important assumption is usually accepted: we assume that attention is linked to gaze direction (Corbetta et al. 1998), but at the same time we acknowledge that this may not always be the case (Duchowski, 2007).

### 4.4.4 Duration of Viewing

The study by Hickman et al. (2010) only gave viewers six seconds per photograph before they had to rate it. This approach with shorter viewing time could arguably provide two advantages: a greater number of images and simulation of real-world social interactions in which one only has a short period of time to look at one’s smile. On the other hand, in our study by giving viewers an unspecified amount of time, the viewing duration could be considered a reflection of how the rater felt about the photograph.

### 4.4.5 Study Design

In designing the study again, I would use a prospective approach in choosing patients with bilaterally missing maxillary lateral incisors. The patients who were treated by canine substitution would all be photographed one month after removal of orthodontic appliances. The patients who were treated by lateral incisor implants would all be
photographed one month after completion of the implant. All photos would be taken by the same photographer using the same settings and under the same conditions. I would also use different equipment, mainly a monitor and wireless keyboard and wireless mouse. The ideal range is 60 to 80 cm between viewer and eye tracker, this is a bit close in comparison to how someone would look at a smile in a social interaction. Also the photo is large and hence the focus of attention is solely on the smile. Eye-tracking studies on facial esthetics have shown that the mouth draws less than ten percent of viewing attention (Hickman et al. 2010). Patients with missing MLI comprised two-thirds of the photos in the current study. Since the prevalence of missing MLI in the general population is merely two percent, it may have been suitable to include a greater proportion of control photos. Some of the orthodontists were sensitized to notice canine substitution after seeing one such photo.

4.5 Future Directions

Stability of orthodontic treatment is a challenge in cases where all teeth are present and especially when teeth are missing. Cases of canine substitution may be prone to spaces opening where the main factor in stability is retention. In contrast, dental implants are prone to marginal bone loss and recession. There are also numerous variables that may affect how the implants hold up in the long term, including systemic factors, bone quantity and quality, emergence and contour of the implant crown. The same study could be repeated on the same patients in 5 or 10 years to see whether esthetics or perceived esthetics change over time. In the next few years, it can be expected that literature reporting on the longevity of dental implants beyond 10 to 15 year follow-up periods to provide more support for the option of space opening or give further credence to canine substitution.

According to the systematic review by Andrade (2013), to qualify to be part of a systematic review, the study should have more than one post-treatment assessment. This study could be strengthened by recalling patients to have photos taken again. However, due to the fact that the patients finished their treatment at different times, the amount of time since completing treatment would vary.
4.6 Clinical Significance

Several studies have attempted to quantify smile esthetics because this is an area that interests not only clinicians, but all people, especially those seeking orthodontic treatment. As other authors have noted, smile esthetics is an evolving topic and fertile ground for more research as likely there will not be a consensus for smile esthetics, rather it may vary according to the environment. Armed with information about what the general public and orthodontists consider to be an esthetically pleasing smile, clinicians can aim for treatment outcomes that meet esthetic standards of the times. From this study, orthodontists can be confident that canine substitution, a camouflage option that seems to go unnoticed by laypersons, provides an esthetic outcome in the eyes of their patients and colleagues for patients with missing maxillary lateral incisors.

4.7 Conclusion

It was found that for patients with missing MLI, orthodontists consider the outcome of space opening/implants to be more esthetic than space closing/canine substitution. In contrast, laypersons do not perceive any esthetic differences between the two treatment options.

From eye-tracking data, it was found that laypersons did not look at the photos of patients with missing MLI differently as demonstrated by the AOI fixation count and AOI dwell time percentage. Orthodontists were keen to notice canine substitution and spent a greater percentage of time looking at the second and third teeth for canine substitution photos compared to the control or implant photos.

To relate the esthetic ratings and eye-tracking measures, it was found that staring at the photo for longer (quantified by viewing duration and fixation count) was correlated with lower esthetic ratings.

Scan paths varied among all observers, orthodontists and laypersons. Qualitatively, there was greater variability in how laypersons analyzed smiles compared to orthodontists.
References


53. ODA Suggested Fee Guide for General Practitioners 2015

54. ODA Suggested Fee Guide for Periodontists 2015

55. ODA Suggested Fee Guide for Prosthodontists 2015


Appendices

Appendix A: Operational Definitions

*Fixation*
Visual attention of greater than 80 milliseconds (ms).

*Fixation Count*
The number of fixations over the entire photo over the entire duration of view. The potential range for this measurement is 0 to infinity. The range for this measurement in this particular study was 13 to 245 fixations.

*AOI Fixation Count*
The number of fixations in the given AOI (either ‘center AOI’ or ‘L+R AOI’). The potential range for this measurement is 0 to infinity. The range for this measurement in this particular study was 0 to 78 fixations.

*AOI Dwell Time (%)*
The percentage of time spent by the rater looking in the given AOI (either ‘center AOI’ or ‘L+R AOI’). This is a percentage of the duration of view. The potential range for this measurement is 0 to 100%. The range for this measurement for this study was 0 to 52%.

*Duration/Duration of View/Viewing Duration*
The amount of time (milliseconds) spent by the rater looking at a photograph. The potential range for this measurement is 0 to infinity. The range for this measurement in this study was 2105ms to 132915ms for laypersons and 2336ms to 99563ms for orthodontists.

*Esthetic Rating*
The esthetic rating assigned by the rater on a scale from 0 to 10 (where 0 represents extremely poor esthetics and 10 represents excellent esthetics).