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INFUENCE OF DIFFERENCE IN LIGHTNESS OF A SINGLE ANTERIOR TOOTH IN SMILE ATTRACTIVENESS AND COLOR PERCEPTION AMONG DENTISTS AND LAYPERSON

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To my Parents

To my Sister & Brother

To my Teachers

ΕΘΝΙΚΟΝ ΚΑΙ ΚΑΠΟΔΙΣΤΡΙΑΚΟΝ ΠΑΝΕΠΙΣΤΗΜΙΟΝ ΑΘΗΝΩΝ

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Στην Αδερφή μου & τον Αδερφό μου

Στους Δασκάλους & και τους Καθηγητές μου

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PART A

REVIEW OF THE LITERATURE

Chapter 1

COLOR: AN OVERVIEW

1.1 The nature of color

Light is radiation in the form of electromagnetic waves that make vision possible to humans and other creatures with visual systems. Electromagnetic spectrum is a continuum of electromagnetic waves. These waves consist of different wavelengths and frequencies. Sensation of color is produced by a variety of different wavelengths.[1] For many centuries, humans have been quite interested in color. However, the scientific study of color only goes back to Newton, when he performed his classical experiment with a prism. Colors produced by a prism are called spectrally pure or monochromatic. The perception of red is generated by the longest wavelengths and the shortest ones generate the perception of violet.[1]

Any color has to be specified by specific parameters, i.e., hue, luminance(lightness) saturation (or chroma). Different spectrally pure colors are said to have a different hue, that is related to the wavelength. Not all colors in nature are spectrally pure, as they can be a mix of them.[1] Orange component with a wavelength of 600.0 nm, can be produced with a combination a red with a wavelength of 700.0 nm, and a yellow with a wavelength of 580.0 nm, light beams.

Lightness is the perceived level of emitted light relative to light from a region that appears white. Saturation is the perceived difference between a color and white, regardless of lightness.[2] The degree of saturation is called the *chroma*. In this manner, a mixture of red and white produces a pink color that goes from pure red (100% saturated) to white (0% saturated), depending on the relative amounts of red and white. All of these colors obtained by mixing a spectrally pure color with white are said to have the same *hue* but different *saturation*. There also other parameters that can be used for color analysis.

1.2 Color models – spaces

Color space, also known as the color model or color system, is a specific organization of colors. Actually, it is an abstract mathematical model which describes the range of colors, as tuples of numbers, typically as 3 or 4 values or color components. A range of colors can be created by the primary colors. Color space allows for reproducible representation of color, in both analog and digital representations. It represents what a camera can see, a monitor can display or a printer can print etc. It is also a useful method in order someone, to understand the nature of color. There are a variety of color spaces, such as RGB, CIELAB, CMY, HSV, HIS. The most common of them are described in more detail.[3]

The Munsell color space consists of three independent properties of color which serve as a framework for specifying a surface color: hue (H, measured by degrees around horizontal circles), chroma (C, measured radially outward from the neutral (gray) vertical axis), and value (V, measured vertically on the core cylinder from 0 (black) to 10 (white).[4] Each color is identified by a 3-part code. Munsell determined the spacing of colors along these dimensions by taking measurements of human visual responses. So, these color codes are supposed to be identical to human eyes under standard observation condition (daylight illumination). Munsell color space is perceptually uniform. This means equal size steps in Munsell hue have the same perceptual distance across color space.[3,4] Perceptual distance refers to the perceived difference between two colors. Uniform perceptual distance means that equal distances between colors in a space are perceived by human observers to have the same color difference. This color space was the first which separates hue, value, and chroma into perceptually uniform and independent dimensions. Also is the first which illustrates the colors systematically in three-dimensional space.

Another common color space is the RGB color Space. It is usually used in television screens and computer monitors. In RGB Color Space three phosphors, red phosphors, green phosphors and blue phosphors, are used to produce colors. The trichromatic coordinates of these three phosphors form a triangle. Any of the colors inside this triangle can be reproduced. However, the colors on the outside of the triangle cannot be produced. This means that, the larger the triangle, the larger the color gamut.[1,5] The RGB responses of a device are unique to that device. This means that the colors with the same RGB coordinates will not look the same when displayed, for example, on different computer monitors.[6] The RGB Color Space is not perceptually uniform. Nowadays, the majority of monitors adopt RGB color space because it is a convenient color model for computer graphics and the human visual system works in a similar way. Currently the most popular RGB color spaces are sRGB and Adobe RGB. Colorimetry laws state that many colors can be matched in a color completely, using additive mixtures of three fixed primary colors, whose wavelengths have been suitable adjusted.[3] The choice of three primary colors can be very wide, but it is not arbitrary. According to this theory, none of the primary colors, can be color matched, by a mixture of the other 2 colors.

The first color spaces that have been defined as quantitative links among the distributions of wavelengths in the electromagnetic visible spectrum and the physiologically perceived by human color vision colors, was the CIE 1931 color spaces. These color spaces are defined by mathematical relationships. They are essential tools for color management in many applications, as color of an ink, calibtation of a dispay etc. [1-7]

The human eye with normal vision, has three different types of cells. In order to sense light, they provide three different peaks of spectral sensitivity. (short 420 nm – 440 nm, middle 530 nm – 540 nm, and long 560 nm – 580 nm). The aforementioned cone cells, are responsible for color perception in conditions of medium and high brightness. During conditions with low-brightness, rod cell become effective and as a result a more monochromatic perception of the color prevails. The total light power spectrum, that are weighted for each of thhe three kinds of cone cells, renders three effective values of stimulus. These three values compose a tristimulus specification of the objective color of the light spectrum.[4-7]

The tristimulus values associated with a color space can be analysed, as amounts of three primary colors in a tri-chromatic, additive color model. In some spaces. Like XYZ, the primary colors that are implemented, are colors that are not real as they cannot be generated in any light spectrum. CIE XYZ color space can encompass, all the color sensation, that are visible by humans with an average eyesight. The tristimulus values derived from CIE XYZ color space, are device-invariant. As a result they can serve as a standard reference.[4-7]

CIE (L* a* b*) space is the transformation of the CIE (X, Y, Z) and it is approximately perceptually uniform. Perceptual uniformity is an important property for estimating color differences in terms of perceptual differences. In CIE (L* a* b*) space, a* is the conversion of X and Y; and b* is the conversion of Y and Z.[5] The lightness of the color is a conversion of Y. *L** = 0 yields black and *L** = 100 indicates diffuse white, negative values of a* indicate green while positive values indicate magenta, and negative values of b* indicates blue and positive values indicate yellow. The CIE values of a color are called device-independent, they are not tied to a device, but to human vision.[6,7] The CIE 1976 L*a*b* color space, sometimes also referred as the CIELAB color space, is the most widely used method for measuring object color. It is routinely employed throughout the world by those controlling the color of inks, paints, textiles plastics, paper, printed materials, and other. CIE lab is the most commonly used color space in dental research.

1.3 Color harmony

More recently, experimental psychologists have sought to ground theories of color harmony in the empirical study of responses to single and paired colored samples by subjects. However, this empirical work has done little to either substantiate or replace any of the traditional theories.[8] For example, based on categorical-judgement data for Chinese observers, a quantitative model of color harmony was developed for two-color combinations.[9] Ou and Luo's quantitative model can be used to derive several rules for color harmony including: 1. Two colors that differ only in lightness will appear harmonious 2. Small lightness differences between two colors may reduce the harmony of the pair 3. The higher the lightness of each component in a binary pair, the more likely it is that they will appear harmonious 4. Blue is the most likely hue to create harmony in a two-color combination, with red least likely to the others. The latter point may indicate a confusion between color harmony and color preference (many studies report that blue is more preferred than red). The last hundred years have seen a divergence in view between artists and scientists on the topic of color aesthetics. This trend needs to be reversed if significant progress is to be made in terms of understanding color harmony.[10]

1.4 Color vision – perception

Color vision is formed when light passes through lens and falls on the retina of the eye. The retina is covered by sensitive in light receptors with a variance of spectral sensitivity. Individuals with normal color vision have three types of specialized cells in their retina to help them to perceive colors. Each type o cell is maximally responsive to a different wavelength, representing the colors red, green and blue as described above. This condition is called trichromacy for conveying color information.[11]

Normal human color vision is trichromatic. This means that any color can be reproduced by a mixture of three properly chosen primary colors. The physiological substrate of color vision is the cone photoreceptor. There are three different classes of the blue, green, and red cones also known as the short, medium, and long wavelength sensitive cones, respectively.[12] The different categories of the cone contain different types of photopigment molecules comprising two components: first, a heptahelical protein component (opsin) and second, 11–cis retinal (a derivative of dietary vitamin A). These photopigments are responsible for absorbing light. This is the process which forms the first stage of a signal transduction cascade on which vision is dependent.[13,14]

The different classes of cone respond to light over a large range of wavelengths. As a result, they have overlapping sensitivity curves, but they are most responsive to light of a specific wavelength. Each cone can only signal the rate at which light is absorbed and cannot alone convey information about wavelength. This also is called as the principle of the univariance. Blue cones are maximally responsive to light with a wavelength of 419 nm (violet). Green cones are maximally sensitive to light with a wavelength of 531 nm (green). Red-cones are maximally sensitive to light with a wavelength of 558 nm (yellow-green).[15] The visual system derives trichromatic color vision by comparing the responses of the three different classes of cone. Such comparisons are thought to be made initially at the level of tertiary neurons. Midget ganglion cells appear to be specialized for comparing red and green cone responses.

At least four distinct ganglion cell types appear to be specialized for comparing blue cone responses to those of the red and green cones. Within the central retina, midget cells are thought to draw inputs into the center of their receptive fields from single cones. There is still controversy as to whether the surround is normally drawn in a precise manner from cones of a different class or indiscriminately from adjacent cones. The receptive fields of ganglion cells conveying blue cone signals are larger than those of the midget cells and thus support an inferior level of spatial resolution.[12-14]

1.5 Color deficiency

People with color vision deficiency (also called and color blindness), lack of or have decreased ability to recognize a certain color or to perceive color difference properly under normal lighting conditions.[16] Humans with unregular cones will perceive colors differently.[17] The condition with only two types of cone receptors, that means this organism lack of ability to see a specific section of the light spectrum is called dichromacy. Achromatism or Monochromatism, is a rare condition, which allows no color perception at all. In this situation, person will see no color at all and their world consists of different shades of grey ranging from black to white. Congenital, physical or chemical damage to the eye can cause color vision deficiency.[18] Furthermore, color vision may degrade with age. Especially in midlife, the risk of acquiring color vision defects increases due to ocular and systemic changes that may occur.[19-21]

People with color vision deficiency can easily cope with most everyday situations.[22] Both anomalous trichromacy and dichromacy do not affect other abilities of the vision than color perception, such as visual acuity (visual acuity is the measurement of one's ability to resolve detail) and night vision are unaffected. However, little effort has been put into improving the visual condition for both people with normal vision and people with color deficiency.[23]

1.6 Test of color vision

Color vision testing methods have greatly evolved since their emergence in the 1800s. Historically, the development of color vision tests was driven by two major demands. The first was the need for vocational tests to ensure accurate color vision in professions and industries, such as textiles, electrical, railway, navy, and armed forces. The second was to create accurate clinical assessments to screen for congenital color deficiencies and to diagnose acquired color defects.[24-26]

The current standard clinical tests use either pseudoisochromatic plates or hue discrimination. However, each of these methods has possible pitfalls for clinicians in administration, recording and interpretation of test's results.

Pseudoisochromatic color vision tests have a long-standing acceptance both in research and clinical practice. These tests consist of plates with a central test figure, such as a number, symbol, picture or pattern that can be traced by an illiterate subject. The test shapes and their background are composed of variably sized dots in a random place.[27] The test figure is delineated from the background by color and can be readily detected by a person with normal color vision. For people with abnormal color perception, the testing plate, which will correspond to their particular color deficiency will appear isochromatic and therefore, the test figure will either be invisible or confused.[28]

The most known pseudoisochromatic plate test is the Ishihara.[29] Several editions of this test have been published. Ishihara is used as a quick and reliable screening test, for accurate identification of congenital red–green color deficiencies.[27,30] Although there are some short-comings of the test, arising predominantly through administration under non-optimal conditions or misinterpretation of results Ishihara remains the most common used color vision test.[31]

In all color vision tests appropriate illumination is essential for the correct and consistent display of colors. The majority of pseudoisochromatic plate manufacturers recommend that the test plates must be well illuminated by daylight or by using a daylight lighting with a color temperature close to 6740° Kelvin. Likewise, other testing

parameters such as testing distance should also be kept consistent. The Ishihara test manufacturers recommend a testing distance of 75cm, 2/3m or 1 arm length to be used, with the plates held at a right angle to the line of vision.[29,32]

With the widespread use of high-resolution color monitors and the evolution of the computer technology, digital vision color assessments are an inevitable and valuable step in the evolution of color vision testing. However, standardization of these digital tests is essential to ensure their compatibility with current clinical standards. Continued investigation into their validity and reliability, will inevitably result in consistent and robust digital color vision tests.[33,34]

1.7 Cultural difference

Interpretation of color is varied across cultures. Studies generally have focused on the effects of language on color memory. A correlation exists between codability of a color and participants' ability to recognize colors. The more codable colors were remembered better since they could easily be coded linguistically and stored in memory.[35] Many African languages provide good opportunity for the cross-cultural study of color, since they use a single color term to indicate a region of color space that other Western languages including English encode using two or more terms.[36] Infants responded to colors from the same category as they are the same, suggesting that prelinguistic infants perceive colors categorically. Four-month-old infants looked more at a new color if it came from a different color category compared to the same category as the habituation color. Although both colors were physically equidistant from the habituation color, in wave length terms.[37]

1.8 Categorization and color categories

Categorization is the process, in which things that are discriminable but, in some way, related, are grouped together and are responded to as equivalent.[38] The main scope of categorization is to reduce the complexity of the environment. One of the advantages of categorization is that it reduces the complexity of the environment.

Even if humans are capable to discriminate a lot of colors, the number of color terms in every language is comparatively small.[39] Many colors are grouped together and distinct categories such as red, green, or blue are formed.[40] Some members of a category are better representatives of that category than others, as it is stated The prototype theory of natural categories states that by the prototype theory of natural categories.[41,42] According to this theory, a color is perceived as a member of a category or not, on the basis of how much it resembles a prototype color.[43,44] The prototypical nature of color categories has led to the development of important theories and empirical studies that contributed to the linguistic relativity debate.[43,45,46]

Chapter 2

COLOR IN DENTISTRY

2.1 Introduction

Color as a field of interest has continually raised the concern of dentists. It is apparent that a growing number of scientists involved in restorative dentistry are occupied with color and its implications in clinical application, research and education.[47] The success of each restoration is heavily determined by the uniformity and color resemblance, that they have while opposed to the adjacent teeth or restorations.[48] Visual judgment remains the most commonly used method of evaluating color in dentistry. Therefore, a knowledge of the perceptual limits of color is crucial both in clinical dentistry and dental research.[49]

2.2 Tooth color

Optical properties of human teeth are uniquely influenced by their anatomy and polymorphism, increasing the complexity of color matching in dentistry. Tooth color is predominantly light white, yellowish and slightly reddish. Teeth have a relatively small size, they are curved and exhibit color transitions from the gingival to the incisal-occlusal, from the mesial to the distal, and the labial/buccal to the lingual surfaces. These transitions are derived from differences in thickness of enamel and dentin. An additional complexity in tooth color matching, communication and reproduction, is added by local characteristics, such as enamel cracks and craze lines, enamel hypoplasia, tetracycline staining, or incisal halo.[50]

A large amount of research has been occupied with tooth's color, including both color ranges and distribution.[51-63] The mean L*, C*, and h° values of natural teeth to be 74.5 (6.3), 21.0 (5.8), and 92.3 (5.8), respectively. In general, darker teeth are more chromatic (higher C*) and less red (higher h°), while it is the opposite with lighter teeth. The ranges of lightness, chroma, and hue of human teeth, encompasses approximately only 0.015% of the entire color space.

Color differences in tooth's color are reported to be associated with sex, oral hygiene, habits, and bleaching. In the oral environment, extrinsic factors, such as changes in the supporting periodontal tissues and wear facets, affect the overall tooth appearance. Smokers' teeth are darker, redder, and more chromatic than nonsmokers' teeth. Finally, bleached teeth are lighter, less red, and less chromatic than nonbleached teeth.[64]

When attempting to create a natural-looking restoration, it is important to note that tooth structure varies and tooth color changes throughout life. As teeth age, enamel is reduced and dentin becomes more exposed. Also, there is wear on the incisal edge, causing the alteration of tooth's shape, to more tapered and triangular. In adolescence, the surface characteristics are accentuated and the surface appears rough. As people age, their surface texture becomes shinier and smoother because of continuous abrasion and attrition. Aging affects the color of teeth in the following ways:

- More visible dentin, through the thinner, more translucent enamel.
- Lower translucency of the enamel, due to calcification that is taken place over the years.
- Changing the color from an opaque light color to a more translucent dark color, as the diffusion of light through dentin decreases with age.
- With age teeth's color changes from the high-value whitish color of the young people, to a low-value orange-brownish color.[64,65]

2.3 Light from the environment

Human vision route requires three essentials, the light, the object and the receiver. Assuming that the receiver is functioning properly, (no chromatic perception pathology exists), influence of light in the measurement of color is major. The nature of the light source in the clinic is essential. Light's spectrum can influence chromatic appreciation in a critical way. The ideal light for color assessment, is that which is closest to the light spectrum of daytime sunlight. This is not always possible because not all clinics, have access to this ideal natural light, and because at certain hours of the day, or at certain seasons of the year, daylight is insufficient. In this case artificial light sources have to be utilized. Incandescent and common halogen light bulbs must be avoided, as they can alter chromatic appreciation, since they emit a spectrum with a greater proportion of colors close to red or blue-green respectively.[66] The use of light sources known as day light sources is recommended for proper lighting of the clinic.

A system created in 1931 by the Commission Internationale de l'Éclairage (CIE; translates to International Commission on Illumination) classified illuminants based on their effect on color perception. (International 1971) This system was developed with the aim to allow manufacturers of products such as paints and inks to specify and communicate the colors of their products.[67] According to the CIE standard illuminant, the corrected fluorescent light sources with color temperatures between 5,000° and 6,500°K are suggested.[64] These lights are suitable for all processes that require a correct chromatic perception. On the market, D65 and D55 light sources are available for this purpose, to provide ideal observation conditions. Given to its relatively low cost and ease of use, this type of lamps are available for a great number of professionals.[64,68] Dental professionals have long relied, on so-called color-corrected lighting when evaluating tooth
shade. However, the use of lights with that particular designation does not ensure accurate color matching. The reason for this is twofold: (1) conflicts in lighting and (2) metamerism.[64]

2.4 Lighting conflicts

Dental workplace is not free from conflicts in lighting. Environmental light coming in through windows, is usually mixed with the fluorescent light coming from the halls and the color-corrected lighting in the main clinic. These various lighting conflicts, can make it difficult for the clinician, to determine an accurate shade match. The following tips will aid in that process:[65,69]

- Shade matching is better to take place at 10 am or 2 pm on a clear, bright day when the ideal color temperature of 6,500 K or 5,500 K is present.
- Color-corrected lighting tubes that burn at about 6,500 K or 5,500 K (D65 and D55 illuminants, respectively) should be used, when there is not natural light.
- A color temperature meter should be used periodically, to verify that the recommended color temperature is achieved in the shade-matching area
- Dust and dirt should be cleaned routinely from lighting tubes and diffusers because the presence of dust may alter the quantity and quality of emitted light.[39,70,71]

2.5 Metamerism

Metamerism occurs when restorations match in one light but display a different color in other light conditions.[72] The color seen depends on the nature of the light source illuminating the object. The color of an opaque object is the sum of the wavelengths that reflect off it. Porcelain might reflect light from its surface exactly as enamel in one part of the spectrum, but under dissimilar illumination, two objects that previously looked identical might look different. The closer the curves of the two materials to be matched, the more successful the color match will be.[73] Use of opaque surface stains for porcelain teeth to correct mismatches will increase metamerism.[39]

In dentistry, metamerism occurs frequently, and mistakes can often be glaring, resulting in a return visit, an unhappy patient, and unproductive chair time. Color-corrected lighting is designed to match the wavelengths and relative quantity of visible light coming from the sun. However, a person's smile will be viewed under a number of different lighting conditions. This cause restorations to appear different in terms of hue, value, and chroma.[71] Traditional shade tabs will appear also different when viewed under various lighting conditions, creating difficulties in shade matching.[74]

The only sure way to avoid metamerism is to achieve a spectral curve match. Isomers are pairs of colored objects that have the same spectral curve that will always match regardless of the light in which they are viewed (spectral or unconditional match). Advanced technology in dentistry has greatly increased the chances of achieving a spectral curve match. Although some manufacturers have tried to combat metamerism by developing materials that exhibit a chameleon effect by taking on the color of their surroundings, metamerism continues to be a problem in the dental operatory. Metamerism complicates shade selection and, on the whole, can only be recognized and explained. With all variables being equal, there is often no solution to it. However, because some degree of metamerism is generally unavoidable, the clinician should explain to the patient that it is natural for the color of restorations to vary slightly under different lighting conditions.[73]

2.6 Appearance attributes

There are several factors that can influence the dental professional's color assessment. When using traditional shade-matching techniques, there are several variables that the dental professional should consider.

Appearance attributes (optical propertied) of the enamel and dentin, including translucency/opacity, fluorescence, opalescence, and gloss, can influence the perception of color. Translucency is not a color dimension, but this appearance attribute is closely related to the color of teeth and dental restorations and is perhaps one of the most critical factors for an aesthetic restoration. The incisal edges of natural teeth are translucent, and accurate translucency determination is vital to a restoration's aesthetic success. A huge difference in translucency between natural teeth and a restoration might greatly compromise its appearance and aesthetic outcome in general.[75,76] It is important to note that although the correct restorative material and shade may be selected, there is still the possibility for error due to inconsistencies and variations in the materials, which is difficult to control.[77-81]

Gloss is an attribute of visual appearance that corresponds to the amount of light reflected from a surface in specular direction. It is an important parameter used to describe the visual appearance of an object. The gloss depends on the angle of incident light and the surface roughness and refractive index of the teeth and restorative material. Glossy areas mask the color of teeth and restorations, both during visual shade matching and on digital images used for communication and documentation.

Fluorescence is an important physical property for clinicians who practice esthetic restorative dentistry. By their very nature, teeth (more specially, dentin) are fluorescent because they emit visible light when exposed to ultraviolet light. Fluorescence adds to the natural look of a restoration and minimizes the metameric effect.

Opalescence is the ability of a translucent material to appear bluish in reflected light and reddish-orange in transmitted light. The opalescent effect is based on the behavior of translucency of natural teeth.[81]

2.7 Shade-matching

Shade selection usually is carried out subjectively, using prefabricated shade guides subjectively by comparing and matching them with dental structures or dental materials under non-controlled light conditions, leading to errors in color selection.[82] These shade guides often are made from ceramic with different optical properties compared to composite resins.[83] Also, there are differences in composite's color, for the same shade among commercial brands or even batch numbers.

Application and light curing of composite resin masses (buttons) directly on the corresponding regions of a sound tooth's surface, might be a reliable technique for shade selection.[82,84] However, with this technique the influence of the stratification and composite's color change due to hydration cannot be estimated.[85]

Construction of custom-made shade guides with different composite shade combinations in various thicknesses, can be a viable option. However, these shade guides are prone to color change over time. Nonetheless these techniques remain subjective, as shade selection is still highly dependent on visual perception, which depends on the clinical experience of the operator.[82,86]

A recommended distance between the eye and the shade tab for the shade matching procedure should be about 30–40 cm. The shade tab must be held parallel to the patients' tooth and as close to the gingiva as possible. The dental practitioner has to focus his/her attention on the central area of the shade tab while trying to mask out other portions of the tab. If different shades are required for cervical, central, and incisal areas, the shade matching procedure has to be repeated and done separately for each of these areas. It is also important to make a decision in a short period of time (normally less than 10 s) since dehydration of the tooth might occur as well as other phenomena, as eye fatigue, for example. If a satisfactory match is not achieved in this period of time, it is recommended to rest and look to a grey area for about 20 s to wash away any eye fatigue or visual chromatic adaptations.[49]

2.8 Color perception

Each individual perceives color differently. There are several factors that can influence the dental professional's color assessment. When using traditional shade-matching techniques, there are several variables that the dental professional should consider. When tooth shade is selected properly, it gives efficient results and satisfaction to dentists and patients both. Different clinicians may vary in their ability to detect small differences in color between two objects.[87-89] Contemporary instrumental color measurement in dentistry helps in shade selection using intra oral optical electronic determination of a target color during fabrication of a restoration.[90] Color perception also might differ for the same person under different conditions.[91-92] However, sometimes it happens that observers detect a color difference between two objects; their opinions might differ to some extent.[93] Clinicians were more serious of crowns in which color differed in redness as opposed to in yellow color.[87]

2.9 Quantify color in dentistry

In the CIELab color system, each color is integrated into space according to three axes.[47] Axis L value ranges from 0-100 (0 black, 100 white) while axes a and b values range between -128 and +127. Negative values of axis a illustrate color green and the positive ones color red, while for axis b color blue and color yellow for the positive and negative values respectively.[67] According to this color space a quantitate representation of the perceived color difference between a pair of colored specimens, can be assessed under a given set of experimental conditions, using the following formula: $\Delta E= [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{½}$.[67]

2.10 Color Difference Thresholds in Dentistry - Interpretation of color differences

It emerges as urgent, on a clinical level not only to determine how different in terms of color 2 distinct surfaces are, but to set the values within which the differences could be perceived (perceptibility threshold) and could be acceptable (acceptability threshold).[47] Perceptibility threshold (PT) refers to the smallest color difference that can be detected by an observer. A 50:50% perceptibility threshold refers to the situation in which 50% of observers notice a difference in color between two objects while the other 50% notice no difference. Similarly, the difference in color that is acceptable for 50% of observers corresponds to a 50:50% acceptability threshold (AT).[50]

Despite there exists a sizeable literature on the perceptibility and/or acceptability of dental color differences, there is an inconsistency not only in their findings but most importantly in the way of them being carried out. Therefore, no apparent unanimity within the dentists' scientific community on such values dictates a more controlled study on the issue under scrutiny.[94] In a recent review paper, values for PT and AT were set at 1.2 and 2.7 ΔE units respectively.[94]

An experiment conducted by Kuehni and Marcus, account for the perceptibility threshold and designate its value to ΔE=1 for the 50% of the observers using dentist materials.[95] Seghi et al, have found that for ΔE=2 100% of the observers could perceive the color difference when watching closely monochromatic porcelain dental plates.[96] They also stated that when: ΔE>1: there is very high probability for detection and correct judgment of the difference and when: ΔE<1 the probability of incorrect judgment is increased. Ghinea et al. also argue that for ΔE= 1,8 50% of the observers actually perceived the color differences when observing ceramic dental plates.[97] Utilizing semitransparent porcelain dental plates Ragain and Johnston concluded that in those showcasing differences of ΔE=2.72, 50% of the observers rejected any color difference.[98]

Ghinea et al noticed that for ΔE=3.46, 50% of the observers evaluated such color differences as unacceptable.[93,97] It is to be stated that Douglas and Brewer et al instead of using monochromatic samples they employed to the trial metal ceramic dental crowns resulting to the acceptability threshold being different in values between axes a, b depending on the axis upon which color differences are made.[92] More specifically, for axis a values ranged between 0,5- 1,5 while for axis b they were between 1,7- 2,7 clearly indicating that acceptability thresholds are –additionally- heavily depended on the axis of color change and it emerged as a robust finding that changes of axis a (green/ red) are more easily perceivable.[92] However, the spectrophotometer used is this study provided inaccurate measurements and the color samples were not precisely confined to any one direction in CIELab system.
In the vast literature there are a few articles which evaluate color differences between natural teeth and restorations that are already placed in the oral cavity. In Johnston and Kao clinical trials it was found that perceptibility threshold ΔE was 3,7 while acceptability's ΔE was 6,8 when contrastively comparing natural teeth and composite resin veneers with a color meter[93] It is also to be stated that in this specific research

only two observers were evaluating the color differences, which could have led to incorrect thresholds. Ishikawa- Nagai et al, while comparing all ceramic crowns consisted of zirconia coping and layered porcelain with intact contralateral incisor, reached to the conclusion that when $\Delta E<1,6$ a color difference cannot be perceived.[99] In the same study while comparing contralateral natural teeth the difference was $\Delta E=0,9$. The main objective of this study was to determine and define only the perceptibility threshold and not that of acceptability and it is to be noted that the study concluding remarks could be attributed to the limited sample. Moreover, Douglas et al uttered the proposition that 50% of the observers could detect color change when $\Delta E= 2,60\%$ while 50% of the observers would replace the restoration when $\Delta E=5,5$.[91] In the aforementioned study ,the researchers used a test denture that allowed the left upper incisor to be interchanged with teeth with various shades .However ,this study might be considered biased because the dentists/observers were informed that with this denture the researchers could change the teeth at ease. Furthermore, Lindsey and Wee using Photoshop processed the portrait of two models (one African-American and one Caucasian) and altered the value of L axis towards darker or lighter directions. The findings revealed that changes on lightness axis L of the Caucasian race group members are statistically more difficult to be noticed contrastively to any other combination and color change axis.[100,101]

Difference in the methodology, between the studies may be the probable cause of this diversity. Color perception it is claimed that changes between observers, their age, their experience in tooth shade taking and emotional state.[93,98] Study design, as regard to the methodologies employed to test color perception; full portrait, smile view, specimens of dental materials or an artificial digital set up, seems to be responsible for the variance in threshold color differences.[47,100,101] It is claimed by a considerable number of scholars that color perception does not only variates and changes between observers but also changes for the same observer when the variables of lighting, object and its material are altered.[93,98] Moreover, the position of an object and its lighting and observer's fatigue and emotional state are determining variables that may differentiate the outcome of an observation. As Takasaki, Smith et al have emphasized, color and the backdrop in which we examine color changes could be considered a possible parameter of leading to differentiated outcomes (Takasaki H 1966, Smith 2000). The luminance of the background in which the evaluation of color difference is made, facial complexion, smile aesthetics and gum color can indeed affect the final judgment.[47,100,102] Finally, according to Haralur , it is to be affirmed that color perception is not solely governed by eyesight (the ability to see); it is psychological state and observers' personality that is definitive in the process of color perception.[103]

2.11 Computer-aided image manipulation in color research

Over the years, computer-aided image manipulation has been utilized to investigate the impact of specific changes in dental appearance, leaving unchanged the rest of the facial/smile characteristics. This technique is considered a reliable option which is closer to the reality, than estimating the color difference on dental materials.[101,104,105] Also in the age of social media, people unconsciously assess smile esthetics using a digital screen.[106] However based to the knowledge of the authors only 2 studies, written in the English language, have been utilized the digital image manipulation in order assess color perception in dentistry.[101,107] None of the studies have used this technique , in order to investigate color perceptibility and acceptability thresholds.

2.12 Smile attractiveness

The emphasis on dentoalveolar esthetics has increased, among both dental professionals and patients in the recent years.[108] Improvement of smile esthetics is one of the main reasons for patients seeking dental care.[109,110] Facial expressions via the smile is one of the most important nonverbal parameter of communication.[111] The smile is an important method of influencing people.[112] An attractive smile is considered, as an important tool to influence people. According to surveys, smiling people seem to be trusted more than non-smiling ones.[113] Smile attractiveness contribute significantly in facial attractiveness, influencing job recruitments, and other social interactions.[109,113] Attractive people often are judged more positively than unattractive ones, considered to be of a higher social standing, more interesting, and more intelligent.[113,114] Also they tend to earn higher incomes and have a more successful life outcome.[115,116] Established standards for facial and dental appearance do not differ widely, among the cultures.[117-118] Mainly eyes and the mouth assemble social attention during face to face social communications.[119] Smile attractiveness except other people's perceptions, influence also the psychosocial wellbeing of the individual, as well as their behavior and character. The social and entertainment media have gradually established esthetics standards, exposing the viewers to beautiful smiles.[120] Self-perception of an attractive smile is strongly relate to a high self- esteem, low neuroticism and dominance.[121]

In our modern, beauty-conscious society, facial attractiveness cannot be underestimated. In the face, the eyes and the mouth were found to be the most important factors in a hierarchy of characteristics for determining esthetic perceptions.[122] On the other hand, overall facial attractiveness does not depend on a single feature: cheeks, chin, eyes, hair, lips, nose, skin, and teeth contribute equally.[122] Nevertheless, most Americans believe that dental appearance is "very important" in social interactions.[123] A smile plays a major role in the assessment of facial attractiveness and in the overall evaluation of a smiling person.[124] Several studies have shown that poor dental esthetics is considered to be less attractive overall, including social attractiveness.[125-127]

2.13 Perception of smile attractiveness

Perception is defined as a cognitive process involving interpretation of a stimulus and recognition of the object producing a sensation.[128] This process is based on earlier experience, and it represents the instrument by which one becomes acquainted with the environment.[129] Perception's basis is psychological, therefore is not simple to connect perception with sensation.[130] The perceptions of others can produce an environment that might affect a person's social and intellectual development. It has also been confirmed that others' perceptions can influence the way a person acts and even result in long term developmental changes and varying levels of achievement.[121,131,132]

Person perception in smile esthetics has been a fundamental part in the research concerning smile attractiveness. Observer's experience seems to play a significant role in how the smile attractiveness is perceived.[133] As it regards facial appearance, the mouth and the eyes constitute the most crucial factors in a hierarchy of characteristics for determining esthetic perceptions. Often there is a difference between laypeople and professional's opinions in relation to dental esthetics. Clinicians have to understand that their patients, might be less attentive to dental esthetic factor than they are. So, it is important to find out the thresholds of esthetic acceptability for facial and dental attractiveness.[128,134]

Over the years, several studies have utilized computer-aided image manipulation to investigate the impact of specific changes in dental appearance, without altering other facial/smile characteristics in smile atractiveness. These studies have demonstrated that people are perceived more favorably when they have healthy dentition as opposed to abnormal tooth color (caused by caries or severe dental fluorosis) or teeth alignment.[135-138] The presence of apparently healthy, straight teeth are considered critical positive factors in the perception of smile attractiveness.[139-140] Symmetrical smiles are considered more esthetically pleasant.[125] Maxillary central incisors have a major role in determining smile esthetics, followed by the canines, whereas lateral incisors have less visual weight.[125]

2.14 Quantification of smile attractiveness

As a mean to 'quantify' smile attractiveness and subsequently 'calculate' the influence of different of specific changes in dental appearance a variety of tests have been used. Generic point scales, questionnaires, rank ordering and Visual Analog Scale studies, are the most common tests that have been used in the literature. Visual analog scale is one of the most common ways in order to assess smile attractiveness. A Visual Analogue Scale (VAS) is a measurement instrument that tries to measure a characteristic or attitude that is believed to range across a continuum of values and cannot easily be directly measured. It is often used in epidemiologic and clinical research to measure the intensity or frequency of various symptoms. Visual analogue scale (VAS) usually consists of a 100 mm line anchored at each end by descriptors. Patients place a mark on the scale that corresponds to their smile attractiveness perception. The distance (usually in mm) from the lower end of the scale is then measured and recorded.[141]

2.15 Influence of color in smile attractiveness

Tooth shade seems to be the most important factor in predicting smile attractiveness.[135] Tooth lightness influences the perception of social appeal, with computer generated darkened smiles receiving significantly poorer scores than natural color smiles and the later ones being also worse than lightened smiles.[136] A major predictor of social appeal is tooth lightness. A perceptible change in teeth lightness is the strongest factor associated with the dental attractiveness stereotype, affecting significantly Happiness, Social Relations and Academic Performance traits assessed.[136] A brighter tooth shade significantly affected smile attractiveness, independently from skin tone.[137]

There seems to be a tendency in the literature for laypersons to judge smiles/faces with brighter teeth as more attractive compared to dentists.[125,138] However, this was not always observed.[137] The effect of gender and age of observers in perceived smile attractiveness has been investigated, but results in the literature are inconclusive.[136-138] In all the aforementioned studies brighter or darker teeth color referred to dentition as a total, i.e. to all the teeth appearing when smiling. When perception and evaluation of single anterior tooth color and their influence on overall facial attractiveness were investigated participants did not consciously notice the discoloration of a maxillary lateral incisor and attractiveness judgments were not influenced by tooth color. However, the degree of the discoloration was arbitrary and there were only three degrees of lightness (bright vs. dark vs. control) for one maxillary lateral incisor. Moreover, the effect of the discoloration of other tooth types (central incisor, canine) on the overall facial attractiveness was not investigated.

2.16 References for chapters 1 and 2

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PART B – RESEARCH PROJECTS

Chapter 3

INFLUENCE OF LIGHTNESS DIFFERENCE OF SINGLE ANTERIOR TOOTH TO SMILE ATTRACTIVENESS

3.1 Introduction

In our modern, beauty-conscious society, facial attractiveness cannot be underestimated. In the face, the eyes and the mouth were found to be the most important factors in a hierarchy of characteristics for determining esthetic perceptions.[1] On the other hand, overall facial attractiveness does not depend on a single feature: cheeks, chin, eyes, hair, lips, nose, skin, and teeth contribute equally.[2] Nevertheless, most Americans believe that dental appearance is "very important" in social interactions.[3] A smile plays a major role in the assessment of facial attractiveness and in the overall evaluation of a smiling person.[4] Several studies have shown that poor dental esthetics is considered to be less attractive overall, including social attractiveness.[5-7]

Over the years, several studies have utilized computer-aided image manipulation to investigate the impact of specific changes in dental appearance, without altering other facial/smile characteristics. These studies have demonstrated that people are perceived more favorably when they have healthy dentition as opposed to abnormal tooth color (caused by caries or severe dental fluorosis) or teeth alignment.[8-11] The presence of apparently healthy, straight teeth are considered critical positive factors in the perception of smile attractiveness.[6,12,13] Symmetrical smiles are considered more esthetically pleasant.[14] Maxillary central incisors have a major role in determining smile esthetics, followed by the canines, whereas lateral incisors have less visual weight.[14]

Tooth shade seems to be the most important factor in predicting smile attractiveness.[15] Tooth lightness influences the perception of social appeal, with computer generated darkened smiles receiving significantly poorer scores than natural color smiles and the later ones being also worse than lightened smiles.[16] A major predictor of social appeal is tooth lightness. A perceptible change in teeth lightness is the strongest factor associated with the dental attractiveness stereotype, affecting significantly Happiness, Social Relations and Academic Performance traits assesed.[16] A brighter tooth shade significantly affected smile attractiveness, independently from skin tone.[17]

There seems to be a tendency in the literature for laypersons to judge smiles/faces with brighter teeth as more attractive compared todentists.[14,18,19] However, this was not always observed.[17] The effect of gender and age of observers in perceived smile attractiveness has been investigated, but results in the literature are inconclusive.[16-18] In all the aforementioned studies brighter or darker teeth color referred to dentition as a total, that is, to all the teeth appearing when smiling. When perception and evaluation of single anterior tooth color and their influence on overall facial attractiveness were investigated participants did not consciously notice the discoloration of a maxillary lateral incisor and attractiveness judgments were not influenced by tooth color.[20] However, the degree of the discoloration was arbitrary(not measured) and there were only three degrees of lightness (bright vs dark vs control) for one maxillary lateral incisor. Moreover, the effect of the discoloration of other tooth types (central incisor, canine) on the overall facial attractiveness was not investigated. So far, the influence of various lightness difference values of a single maxillary anterior tooth on smile attractiveness has not been fully studied.

The null hypotheses of the present study were that there is no difference in smile attractiveness for various lightness differences of maxillary anterior teeth:

- Irrespective of the direction of lightness difference (lighter vs darker) of a single maxillary central incisor, lateral incisor or canine.
- Between dentists and laypersons
- Between males and females
- Between younger and older observers.

Finally, that there is no correlation between smile attractiveness and change in lightness.

3.2 Material & methods

This cross-sectional study was designed and conducted in a Dental School environment, between March and June 2019. All observers were subjected to Ishihara's test for color deficiency. Power analysis indicated that a sample size of 160 participants was necessary (P= .8). Half of them (n = 80) were patients or staff of the School of Dentistry and the remaining half were faculty members.

A 25-year-old Caucasian male was selected as a model for the study, with a smile exhibiting good teeth alignment and tooth size symmetry. A frontal view full-portrait image, with the smile showing lips and teeth was captured with a digital camera (EOS80D, Canon) and a 100 mm macro camera lens (Canon IS USM) in RAW image format. The initial image was digitally modified (Adobe Photoshop CS 2015, Adobe), for the color of the teeth to be close to the average measurements obtained in a diverse population.21Asecond digital manipulation created a series of images with varying lightness (L) for the maxillary central incisor, lateral incisor and canine. The lightness (L) of one maxillary central incisor, lateral incisor and canine was digitally modified individually by 1ΔE unit (ΔL=ΔE= 1). For each one of the three anterior teeth the shade was modified, to create 15 different images per tooth (14 digitally modified and 1 initial that served as the control) half with increased and half with decreased lightness (−7,−6,−5,−4,−3,−2,−1, 0, +1, +2, +3, +4, +5, +6, +7).

Lightness differences were calculated using Color Picker software (macOS). In total, 45 images were displayed in random order to the observers. An example of the extreme values of ΔL modification in lightness difference com-pared to control is presented in Figure 1 for the maxillary central incisor. The modification of the lightness of one anterior tooth simulated clinical situations, like discoloration of a single anterior tooth due to a trauma or endodontic therapy, or mismatch in the color of a tooth or implant supported restoration.

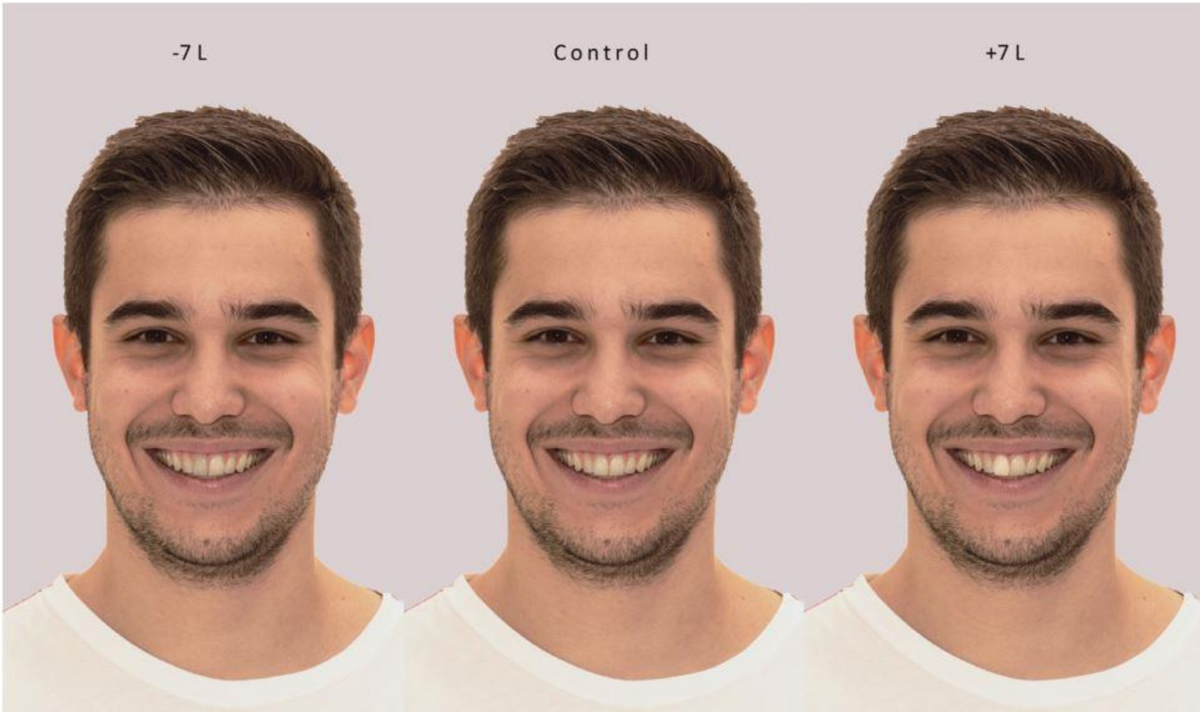

Figure 1. Maximum and minimum modification of lightness in central incisor compared to control

At the beginning of the interview, the examiner recorded age and gender of the participant. The images were viewed in a digitally calibrated monitor (LCD Dell 21″ HD) adjusted in portrait format, so as to achieve a full-face smile, to its real dimensions. Observations were carried out during midday (11:00AM–13:00PM), while in the test room the artificial lighting conditions were standardized and the room and the monitor were not directly exposed to sunlight. Seat height was adjusted for each individual observer, to align the eye level of the observer to that of the monitor model. The distance between the observer and the monitor was consistently 60 cm, which stands for the typical distance between persons during social contact. The observation of each of the modified images for 10 sec was followed by a 4 sec viewing of a uniform grey screen with a black cross as a fixation point in the center. Observers completed the test in two appointments with an interval of 3 weeks between the two half parts of the test. The images appeared in a random sequence for all participants. They rated the images without conferring with others.

Participants were asked to evaluate the attractiveness of the smiles and were not informed about the digital manipulations of the images. Particularly, they were asked to fill out a Visual Analogue Scale VAS (0–100) questionnaire for every image recording the attractiveness of the smile. VAS consisted of a 100 mm horizontal line from point 0 = extremely unattractive to point 100 = extremely attractive. Every participant was asked to mark a vertical line on the horizontal line answering to the question “How attractive do you consider this smile?”

3.3 Statistical analysis

For each of the modified anterior tooth the differences in VAS in the evaluation between the control and each of the 14 color changed images were recorded and analyzed. In addition, the pairwise differences of images with the same magnitude but different sign in the 14-level digitally simulated scale were similarly treated for all three tooth categories. The preliminary analysis (normal probability plots and Anderson-Darling test for normality) indicated a significant deviation from normality, due to the presence of outliers for the majority of the above defined variables. Therefore, nonparametric statistics were used for the analysis of our data. The median was used as the descriptive measure of central tendency while non-parametric confidence intervals and hypothesis testing for the median differences were used for statistical inference. Wilcoxon signed rank test was used to determine whether the median of a sample differed significantly from the control, while the Kruskal-Wallis test was used to determine whether the medians of gender and age groups differ.

3.4 Results

The total number of participants was 160, where 80 (50%) of them were dentists and 80 (50%) were layperson. The overall response rate was 91.2% for the dentists and 84.3% for the layperson. The male (46.3%) and female (53.7%) individuals were aged from 18 to 75 years. The mean age was 38.22 years for the dentists and 43.81 years for the layperson. Subjects were divided into two age groups: 18 to 35 and 36 years old or over.

Central incisor: The difference in perceived smile attractiveness score between the control and each altered image (each increment of ΔL), for both dentists and laypersons is presented in Figure 2. Lightness differenceΔL≥1 affects smile attractiveness both for dentists and layperson ($P< .001$,$P= 0.023$ respectively). Dentists perceived decreased smile attractiveness when aΔL≥5 was originated from lighter tooth alteration compared to darker ($P= .024$). Laypersons did not perceive a significant difference in smile attractiveness in respect of the direction (darker or lighter) of lightness difference. No difference between male and female evaluators in perceived smile attractiveness score was observed for the dentists group. In laypersons' group, female participants seem to perceive smiles with lightness difference as significantly less attractive compared to male participants especially for the lighter teeth ($P= .034$). Dentist's age did not significantly affect smile attractiveness perception in relation to the light-ness difference. Younger laypersons perceived darker central incisor color, as less attractive for the smile than older participants ($P= .019$).

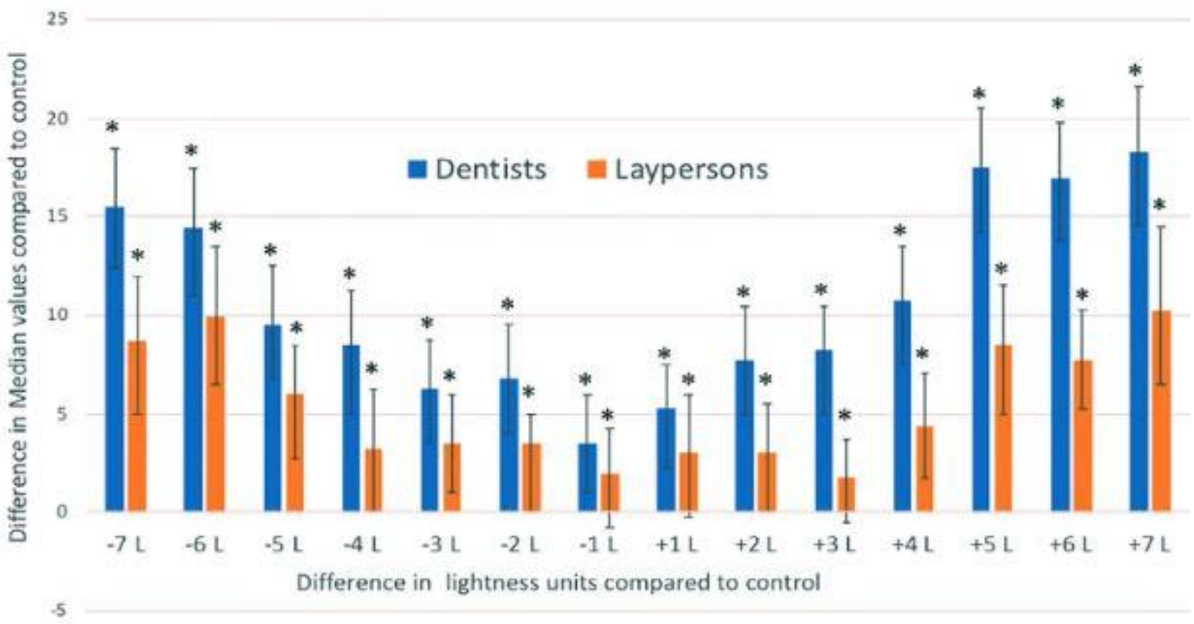

Figure 2. Difference in perceived smile attractiveness score of altered images compared to control for the central incisor. The symbol * denotes significant difference from the control

Lateral incisor: The difference in smile attractiveness scores between the control and each altered image (each increment of ΔL) for both dentists and laypersons is presented in Figure 3. Both groups perceived smiles with lightness difference ΔL≥1 from decrease in lightness as significantly less attractive than control smile (P< .001,P< .001). For lightness differences derived from increase in lightness, both dentists and laypersons did not perceive a difference in smile attractiveness, compared to control up to 6 ΔL units. Both dentists and layperson perceived darker color alterations, as less attractive compared to lighter equivalents (P< .001, P< .001). No difference between males and females was observed in the dentists' group. In laypersons' group, women perceived lightness difference in the darker teeth as significantly less attractive compared to males (P= .007). Dentist's age did not significantly affect smile perception. Younger layperson perceived smiles with darker laterals as less attractive compared to older ones (P< .05).

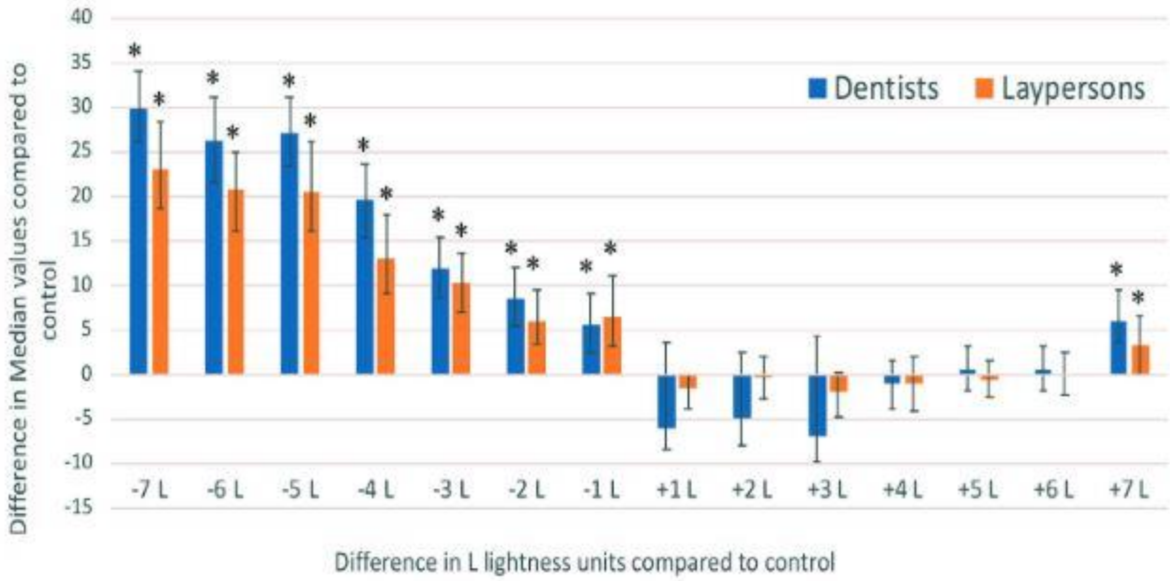

Figure 3. Difference in perceived smile attractiveness score of altered images compared to control for the lateral incisor. The symbol * denotes significant difference from the control

Canine: The difference from the control for each evaluated ΔL difference in smile attractiveness score between the control and each altered image (each increment of ΔE) is presented in Figure 4, for both dentists and layperson. Regarding lightness difference derived from darker canine alteration, both dentists and layperson perceived smiles with ΔL≥6assig-nificantly less attractive compared to control smile ($P< .001$,$P= .019$). For lightness difference derived from lighter canine alteration, dentists and laypersons perceived full face smile of 2≤ΔL≥3, as significantly less attractive than control smile ($P= .002$,$P= .004$).

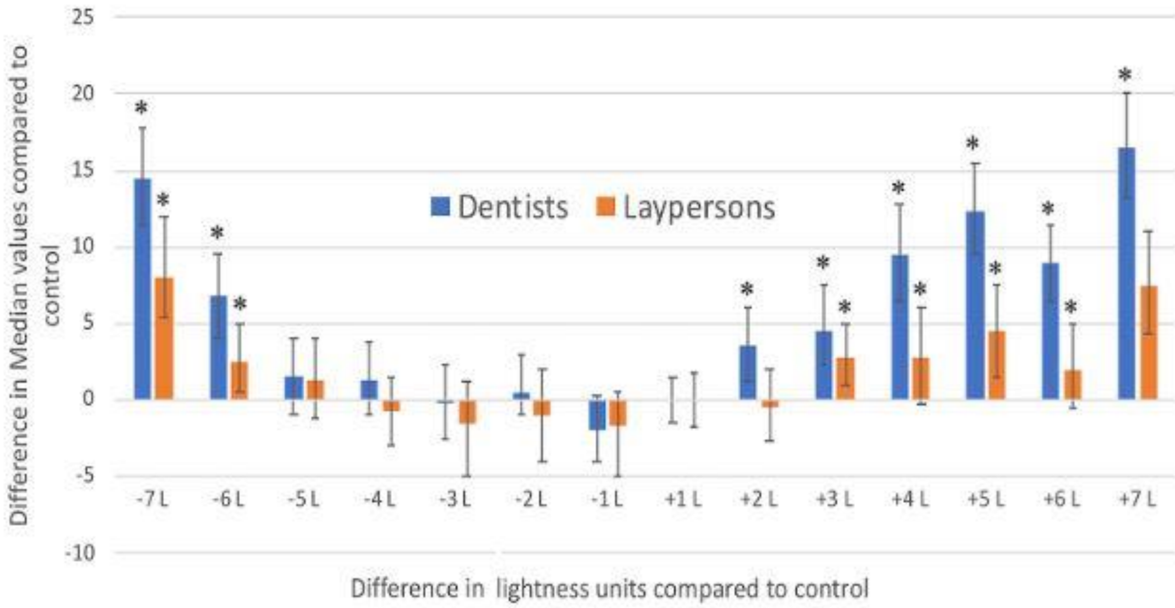

Figure 4. Difference in perceived smile attractiveness score of altered images compared to control for the canine. The symbol * denotes significant difference from the control

The correlation of attractiveness score for each anterior tooth to lightness difference is presented in Figure 5 for the dentists and in Figure 6 for the laypersons. The trendline follows a polynomial relation. The pattern of the trendlines is similar, with a steeper inclination in dentists' group. For the dentists' group, and for the central incisor and canine, as lightness difference increases, VAS decreases. On the contrary, for the lateral incisor increase of the lightness' difference, increases VAS.

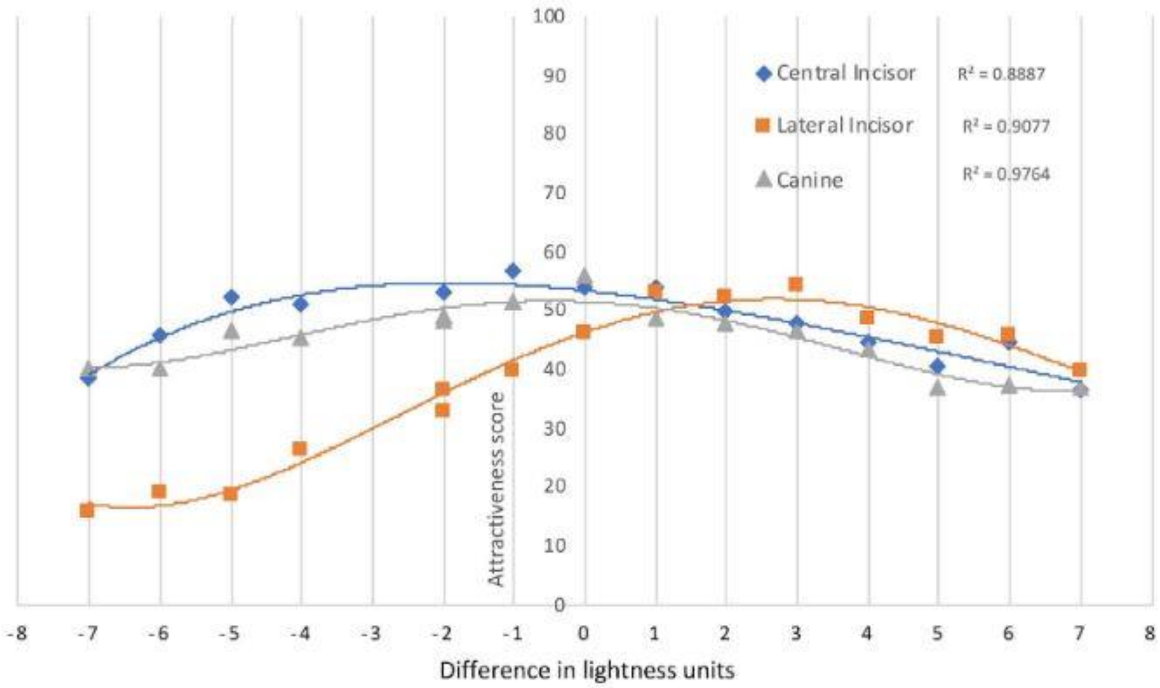

Figure 5. Attractiveness score based on Visual Analogue Scale (VAS) test correlated to difference in lightness units (dentists)

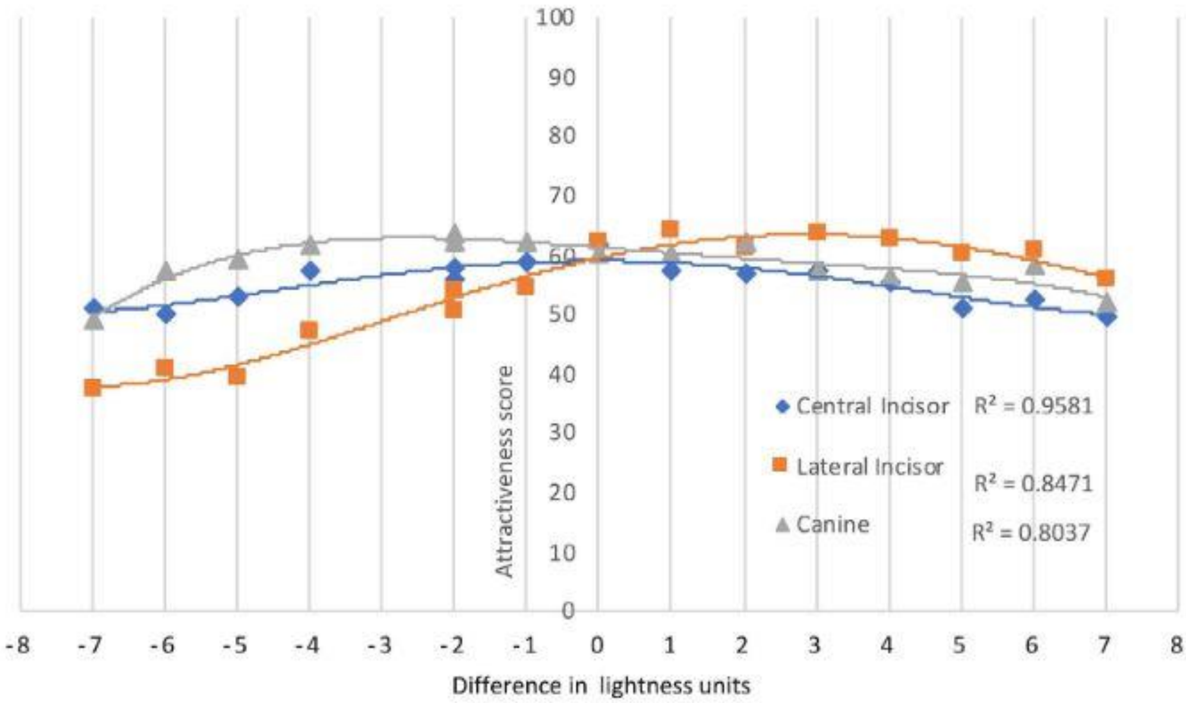

Figure 6. Attractiveness score based on Visual Analogue Scale (VAS) test correlated to difference in lightness units (laypersons)

Dentists considered smile attractiveness significantly decreased when the lightness difference was lower than 6 units and originated from lighter, compared to darker tooth color alteration ($P< .01$). Lay-persons did not perceive a difference in smile attractiveness when lightness difference derived from lighter compared to darker tooth, shades and vice versa, for all ΔL steps. No difference was observed for both dentists and laypersons between males and females. Dentist's and laypersons' age significantly affected smile perception ($P= .049$, $P= .034$), with younger participants perceiving smiles with darker canines as less attractive compared to older ones.

3.5 Discussion

The results of the present study contribute to a better appreciation of the influence of lightness difference of a single anterior tooth on the overall facial attractiveness. Changes in the lightness of even one tooth seem to improve or worsen the overall facial attractiveness, as judged both by experienced dentists and layperson. The null hypotheses of the present study were all rejected because there was significant difference in perceived smile attractiveness for various lightness differences of a single maxillary central incisor, lateral incisor or canine, there was difference in perceived smile attractiveness irrespective of the direction of lightness difference (lighter vs darker),there was difference in perceived smile attractiveness between dentists and laypersons, between males and females and finally, between younger and older observers, for various lightness differences of maxillary anterior teeth.

In a previous study evaluating the color difference and its impact on smile esthetics of a maxillary lateral incisor, but in this study color modification was arbitrary.[20] In the present study, the influence of seven steps of increased and seven steps of decreased lightness, equally distributed, for maxillary central, lateral and canine, was examined. In that study,[20] a lighter single maxillary lateral incisor seemed to be judged in a more positive way, but did not improve participants' assessment. The darker alteration was hardly noticed. In general, tooth alteration did not influence overall facial attractiveness acrossparticipants.[20] On the contrary, the present study indicated that smile attractiveness is significantly influenced from lightness changes at a different degree and threshold level for central vs lateral vs canine.

Results about the lightness perceptibility/acceptability threshold have been previously published in literature.[22,23] Based on these studies, one could argue that smaller lightness difference should have been used and at a range of no more than 2–3 L units, since that exceeds the acceptability level. However, in these studies, results were obtained using very crude approximations to human dentition: two simulated teeth with their cervical portions embedded in a highly schematic depiction of reddish upper gingiva[22] and a digital image of teeth and a shade-guide tab cropped to reveal the oral cavity and gum area but excluding the lips.[23] Previous studies have shown that detection thresholds for luminance and color differences depend upon background luminance and hue.[24] Likewise, the perception of supra-threshold color differences depends on the structure of the viewing scene. A "crispening effect" has been reported when stimuli consisted of simple targets presented on uniform backgrounds.[25] However, in more complex, naturally occurring scenes, the relationship between surface color perception and background contrast is more complex.[26] These classic findings, along with a more recent study, underscore the potential usefulness of naturalistic simulations of clinically relevant stimuli in the study of dental color differences.[27]They used high-quality, image-processed,[2] the clinical assessment of colordifferences.[27] In that study one central incisor was digitally altered in5 steps of 1 ΔE units along the +L, +a, or + b directions of CIELAB color space. Since the color was altered in 3 dimensions it was not clear which color parameter (L vs a, vs b) affected more the results. Additionally, changes in the opposite direction (ie, -L meaning darker teeth) were not examined.

The kind of questions the observers are asked is very important. In a previous study participants were asked whether they perceive a difference in whiteness between the shade tab and the teeth.[23] In another study subjects were asked whether they perceive any color difference between the two teeth examined and were explicitly asked to judge acceptability on the basis of whether they would want a crown of a given color difference cemented in their mouth.[22] In the present study participants were asked to evaluate the attractiveness of the smile using a VAS questionnaire while they were looking at the face of the patient. The question did not imply that a change of tooth color was present. Our aim was to investigate whether an existing (and perhaps "easily" perceptible) lightness difference would influence the participants perceived smile attractiveness.

For all the aforementioned reasons we chose to investigate the influence of increased or decreased lightness over 1 unit in perceived smile attractiveness. Based on our results, it is evident that $\Delta L > 3$ units was needed in some cases to have an effect in perceived smile attractiveness. More specifically, for lateral incisor, both dentists and laypersons did not perceive a difference in smile attractiveness, compared to control up to 6 ΔE units. Regarding color difference derived from darker canine alteration, both dentists and layperson perceived smiles with $\Delta E \geq 6$ as significantly less attractive compared to control smile.

Especially, for the central incisor, changes in lightness as small as 1 ΔL, affected smile attractiveness. For the lateral incisor, increase of lightness tooth was perceived less, compared to decrease. On the contrary, for the canine, darker tooth alterations were perceived as more preferable compared to lighter equivalents. This difference between the incisor and the canine can probably be explained by the fact that people, are used to darker canine shade compared to theincisors.[21] The focus on the smile goes first to the maxillary central incisors and then canines, whereas lateral incisors seem to have less visual weight.[14] Maybe this is the reason that a lighter lateral was perceived as less attractive than a darker one clearly shown on Figure 5. As we move away from the dental midline, the difference in the light-ness of a single tooth color is less perceptible, because the distance from one tooth to its counterpart is increased and the visible proportion of the tooth is decreased, making the direct comparison moredifficult.[28]

The clinical relevance of our results is applicable in everyday restorative and prosthetic dentistry. It will help dentists to make evidence-based decisions when they have to perform bleaching of single discolored tooth or a single anterior restoration on a natural tooth or an implant. When one of the centrals is restored, lightness matching should be accurate; otherwise it negatively affects smile attractiveness. On the other hand, there seems to be a higher tolerance for lightness mismatch when one lateral incisor is lighter or when a canine is darker than the other anterior teeth. What is really important to understand is that a lightness difference may be perceptible and not acceptable based on published values, but still the smile attractiveness might not be significantly different, therefore, may not warrant restorative intervention.

Perceived smile attractiveness scores and lightness differences exhibited high correlation values for each tooth type, for both dentists and laypersons. As lightness difference increased, VAS scores decreased. Future study will define the perceptibility and acceptability threshold for lightness differences for this type of experimental setup and will examine the relation to facial attractiveness.

Regarding the gender, in the laypersons' group, females were more influenced by the darker modifications of the central incisor and the lighter modifications of the lateral. However, there was no difference between males and females in the dentists' group. In a previous study, as tooth brightness decreased men were more critical in theirratings.[18] Another study has also shown that women tend to give higher scores of attractiveness than men do.[9] Labban et al[29] evaluated 48 images of smiles and found out that gender had an influence on the perception of tooth shades: women participants preferred lighter shades if compared to men participants. On the other hand, in anotherstudy,[17] gender did not affect significantly VAS values: lighter tooth shades were always preferred, irrespective of the sex of the participants (dentist and laypeople).

There are two different issues to be addressed here: whether, there is a difference between men and women in the perception of color and whether there is a difference between men and women in the perception of smile/face attractiveness. Results from the literature are rather inconclusive: Regarding color perception, in one study, men showed borderline more uniform shade selection than women, even though the difference was small and only slightly significant.[30] In another study, females achieved significantly better shade matching results than males, indicating that gender plays an important role in shade matching,[31] whereas, in a third study, males tended to be more successful in discriminating the shades.[32] In other studies, however, no difference is observed between the genders in the perception ofcolors.[33,34] The perception of facial esthetics is a complex phenome-non influenced by biopsychosocial factors.[35] In the literature, the perception of facial esthetics was found to be related to the gender of the participants, but again, in an inconclusive way. More specifically, in one study women gave generally lower grades for the esthetics of every male and female profile than did men in the same social context of evaluation,[35] while in another study females were more tolerant of upper gingival exposure compared to men.[36] Similarly, when the observer was female, the odds ratio of perceiving positive values in perceived social appeal increased significantly.[17]

In the present study results indicated that for the dentists' groupage did not significantly affect smile perception while for the laypeople group, younger participants perceived smiles with a darker tooth as less attractive compared to older ones. This suggests that as sub-jects grow older, they become more accepting of darker teeth or of teeth with lightness differences. This agrees with the findings of Sabherwal et al, where attractiveness ratings increased with the age ofparticipants.[18] However, in the study of di Murro et al no statistically significant differences based on participants' age were found.[17] A possible explanation for these findings could be that older people may have been less critical in their ratings as they see changes in their own tooth color with age. This does not apply for the dentists' group, how-ever, probably because knowledge, experience and education play an important role.

The perception of tooth color is subjective and many factors can influence it, as the type of illumination, the position of the object, the viewing angle, the surrounding environment and, of course, the chromatic perception of the observer.[18,37] In the current study the use of high quality, image processed full face portraits, presented in real dimensions, on a calibrated high definition display aimed to simulate as close as possible the real life circumstances and to standardize the way that each participant accessed the presented faces. The required color differences were achieved by modifications in lightness (L) only. The reason was that human eye is probably more sensitive to differences in lightness, compared to differences in saturation and hue. The present research design, aimed to bridge the gap between in vitro and in vivo, as color judgments are made in a more realistic manner that the in vitro studies.

A certain advantage of the current survey is the blinded nature of the participants and the randomization in order to eliminate bias. However, even if a standardized, experimental environment was rendered, an experimental setting for shade determination cannot totally simulate all real-life lighting situations, being a possible limitation of this study. Moreover, laypersons group included dental patients recruited from the waiting room of the dental school, that were probably more likely to be currently focused on the dental/smile appearance compared to the general population. To eliminate this bias larger sample from laypeople coming from different environments would need to be studied.

Another limitation of the present survey is problems arising from the process of answering the questionnaire, such as the alertness of the participants or their subconscious tendency to avoid answering something that may be unpleasant or impolite. The study did not attempt to measure the intra-rater reliability for the observers, as the experimental design did not include a retesting of the same judgments at different times. The reliability within dentists and laypeople overtime should be evaluated in future studies.

Various rating methods have been used to assess esthetic preferences related with dentofacial structures and appearance, each with its own inherent advantages and disadvantages. The visual analog scale (VAS) has been used extensively to evaluate opinions regarding various aspects of dentofacial appearance.[38] The VAS has also been used to investigate facial esthetic preferences of alternate photo-graphic views of the same subject.[17] A VAS is a convenient, simple, economical, and rapid method of obtaining value judgments.[39] How-ever, it still exhibits weaknesses or limitations. Raters tend to spread their responses over the entire scale and avoid the ends at the anchor points, independently of the actual preferences.[40] Moreover, raters might be incapable of making equally discriminative judgments at each level of a scale.[41]

The present study showed that dentists and laypeople find faces less attractive due to the presence of a darker or lighter single anterior tooth. This is in accordance with the findings of a previous study that unsatisfactory tooth shade, especially of a single tooth, is a dominant factor in motivating patients for dental treatment.[42] Color research has extensively investigated perceptibility and acceptability color difference thresholds.[43] However, so far, in these studies the participants are prejudiced, because they were asked if they observe a color difference in a certain tooth and whether this difference is acceptable. In the present study, however, the question did not imply that a change of tooth color was present. Lindsey and Wee showed that when individuals are presented with the difficult task of judging small color differences, the demands of the task may bias them toward responding "yes, there is a color difference "or even" the match between crown and adjacent incisor is unacceptable, "even when the two simulated "teeth" are calorimetrically identical.[22]

In the study of Lindsey and Wee,[27] the influence of tooth color difference on perceptibility and acceptability was investigated in realistic full-face male Caucasian and female African-American portraits. L* thresholds were found to be higher for the male Caucasian than for the female African-American face. It is possible that perceived smile attractiveness would also be affected by the type of the model. In our study the model was an independent variable, in order to evaluate the influence of change of tooth lightness on smile attractiveness, without other possible confounding factors. In future study the effect of the model gender, age, race and percent of tooth length that appears in the smile, on facial attractiveness, should be examined.

3.6 Conclusions

In the tested conditions and within the limitations of the study, results of the present study clearly indicate that even minor changes in the lightness of a single anterior tooth can influence the perceived smile attractiveness, both for dentists and laypersons. Central incisors are the teeth that most profoundly affect smile esthetics; therefore, accurate lightness matching of direct or indirect restoration is critical. There seems to be a higher tolerance for lightness mismatch when one lateral incisor is lighter than the other anterior teeth and the same applies when the canine is darker. In the dentists' group age and gender did not significantly affect smile perception while for the laypeople, younger participants perceived smiles with a darker tooth as less attractive compared to older ones

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Chapter 4

Lightness difference thresholds, associated with smile attractiveness, of a maxillary central incisor in digital simulated facial portraits

4.1 Introduction

The success of each restoration is heavily determined by the uniformity and color resemblance, that they have while opposed to the adjacent teeth or restorations.[1,2] Color difference among the anterior, visible to the smile teeth can significantly decrease smile attractiveness.[3] Visual judgment remains the most commonly used method of evaluating color in dentistry. Therefore, a knowledge of the perceptual limits of color is crucial both in clinical dentistry and dental research.[4]

The perception of color in the space related to dentistry, is a complex phenomenon that involves three factors: the observer, the illuminant and the object.[5,6] It is well established that dentistry employs mathematic equations as a mean to 'quantify' color and subsequently 'calculate' the color difference between two distinct surfaces.

According to this color space a quantitate representation of color difference between a pair of colored specimens, can be assessed, using the following formula: $\Delta E= [(\Delta L)2 + (\Delta a)2 + (\Delta b)2]½$.[7] It emerges as urgent, then, on a clinical level not just to determine how different in terms of color 2 distinct objects are, but ostensibly set the values within which the differences could be perceived (perceptibility threshold) and could be acceptable (acceptability threshold).[1,8] Perceptibility threshold (PT) refers to the smallest color difference that can be detected by an observer. A 50:50% perceptibility threshold refers to the situation in which 50% of observers notice a difference in color between two objects while the other 50% notice no difference. Analogously, the difference in color that is acceptable for 50% of observers corresponds to a 50:50% acceptability threshold (AT).[9]

There exists a sizeable literature on the perceptibility and/or acceptability of dental color differences, however, there is an inconsistency in their findings and most importantly in the way of them being carried out. Therefore, no apparent unanimity within the dentists' scientific community on such values dictates a more controlled study on the issue under scrutiny.[1,10] Methodological diversity between the studies may be the probable cause of this diversity. Color perception is claimed that changes between observers, their age, their experience in tooth shade taking and emotional state.[11,12] The luminance of the background in which the evaluation of color difference is made, facial complexion, smile aesthetics and gum color can indeed affect the final judgment.[1,13,14] Study design, as regard to the methodologies employed to test color perception; full portrait, smile view, specimens of dental materials or an artificial digital set up, seem to be responsible for the variance in threshold color differences.[1,14,15] In a recent review paper, values for PT and AT were set at 1.2 and 2.7 ΔE units respectively.[1]

Over the years, computer-aided image manipulation has been utilized to investigate the impact of specific changes in dental appearance, leaving unchanged the rest of the facial/smile characteristics. This technique is considered a reliable option which is closer to the reality, than estimating the color difference on dental materials.[15-17] Also in the age of social media, people unconsciously assess smile esthetics using a digital screen.[18] However based to the knowledge of the authors only 2 studies, written in the English language, have been utilized the digital image manipulation in order assess color perception in dentistry.[15,19] None of the studies have used this technique, in order to investigate color perceptibility and acceptability thresholds.

Despite the importance of perceptibility and acceptability thresholds, considering color difference, the influence of the difference in the attractiveness of the face is also significant.[3] Perceptibility and acceptability frequencies, as well as the influence of smile attractiveness, have been investigated by various studies. However, their possible association, still has not been evaluated.

The purpose of this study was to assess the visual perceptibility and acceptability thresholds, for lightness differences of a single maxillary central incisor, using the CIELAB system on digital facial portraits and to investigate possible differences in these thresholds between the type (i.e. dentists vs laypersons), the gender, the age or the smile self-perception of the observers. In order to estimate the boundaries within which a singled restoration prosthesis can remain undetectable or with an acceptable difference compared to the remaining teeth of the smile. In addition, the association between the attractiveness of the smile and perceptibility and acceptability frequencies would be investigated.

The null hypotheses of the present study were that:

- There are no differences in 50% perceptibility or 50% acceptability visual thresholds for lightness differences of a single central incisor:
    - irrespective of the direction of lightness difference (lighter vs darker),
    - irrespective of the type of observer (dentists vs laypersons)
    - between males and females
    - between younger and older observers
- There is not a correlation between smile attractiveness score and perceptibility frequencies
- There is not a correlation between smile attractiveness score and acceptability frequencies

4.2 Material & Methods

The present cross-sectional study was designed and carried out in a Dental School environment, between March and August 2019. All participants were screened using Ishihara's test for color deficiency, in order to ensure judgements validity, regarding the color changes. Power Analysis was conducted before the initiation of the study. A sample size of 160 participants was necessary. Half of the observers (n=80) were patients or staff of the Dental School and the remaining half were faculty members.

A model for the study, a 25-year-old Caucasian male was selected. His smile was exhibiting good teeth alignment and an adequate tooth size symmetry. A frontal view full-portrait image, with the smile showing lips and teeth was captured. Initially the color of the teeth, was digitally modified (Adobe Photoshop CS 2015, Adobe), in order to be close to the average measurements, of a diverse population.[20] Through a second digital manipulation, a series of images with varying lightness (L) for the maxillary central incisor was created. The lightness (L) of the central incisor was digitally modified by 1 ΔE unit (ΔL=ΔE=1). In total, 15 images were displayed in a random order to the observers; 7 images with increased lightness, 7 images with decreased lightness and the original image that served as the control. (Figure 1.)

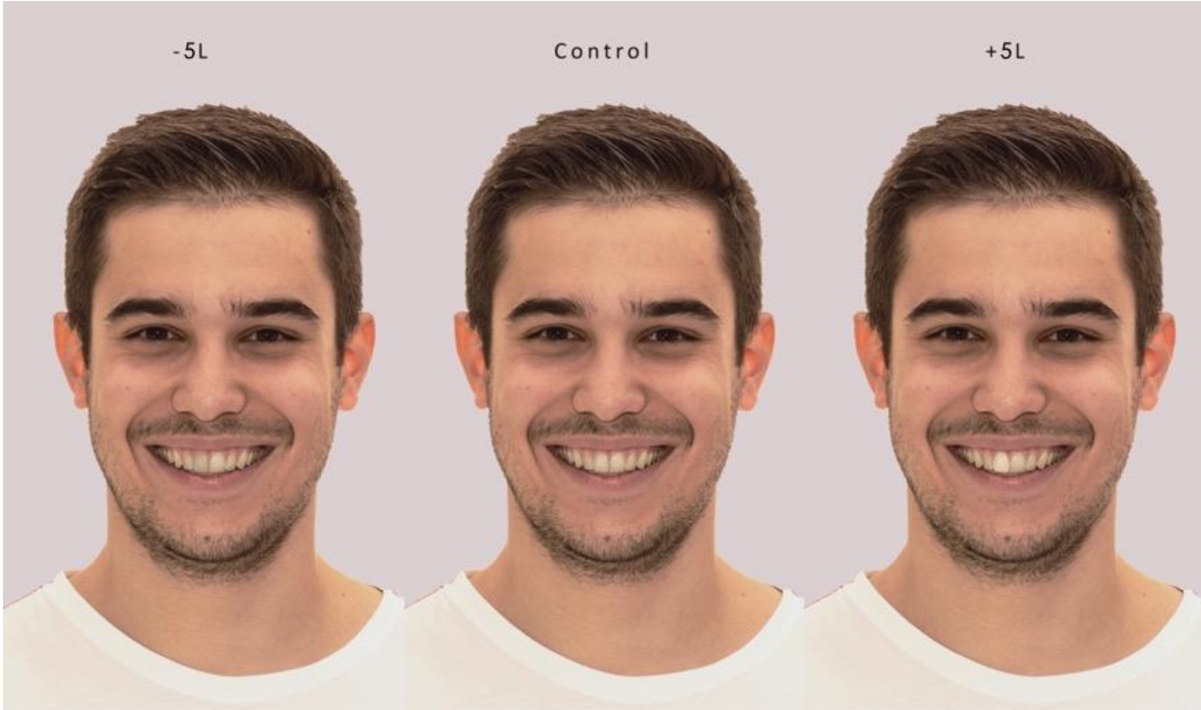

Figure 1. Modification of lightness compared to control (Central Incisor)

The images were presented in a random order to the observers, in a digitally calibrated monitor adjusted in portrait format, as it has been described in a previous article. The typical distance between persons during social contact (60cm), was preserved, between the observer and the monitor.

In a second appointment, each participant was instructed to answer positively or negatively to whether a difference between the central incisors was apparent, for every image. Subsequently, those observers were asked to state whether they would opt for a dental intervention in color if those unevenly colored teeth were their own ones. The attractiveness score of the smile for each image, as it was estimated by Ntovas et al was also used in the presented study, for further interpretation of the results.

4.3 Statistical analysis

The acceptability and perceptibility percentage for every modified image (% of participant answered "yes") were calculated. False rate was calculated for each group based on the percentage of participants, that they answer yes in the image which served as control ($\Delta L=0$). Chi-square test of independence was performed in order to evaluate the statistical significance of differences in false rate between the type and the gender of the observer. Acceptability and perceptibility frequencies were regressed with difference in lightness (ΔL) in order to estimate the best curve (R^2), implementing "curve estimation" function in SPSS software. (SPSS 23, IBM) The 50% perceptibility and acceptability thresholds for each type of observer gender and age group, along with their 95% confidence intervals (CI, 95 % Lower Confidence Limit. 95 %Upper Confidence Limit) were calculated, using SPSS software and statistical functions in Excel software (2020, Microsoft). Correlation among attractiveness score and perceptibility and acceptability frequencies, were assessed using Spearman correlation. Significant difference among the evaluated parameters, was estimated at a=0.05.

4.4 Results

The total number of the participants in the present study was 160 (80 dentist and 80 layperson), with a response rate of 91.2% for the dentists and 84.3% for the layperson group. From them 50% were dentists and 50% layperson, with a percentage of 46.3% for the male and 53.7% for female individuals respectively. Their age ranged from 18 to 75 years old, with a mean age of 38.22 years old for the dentists and 43.81 years old for the layperson. Based on their age, participants were divided in two age groups: 18 to 35 and >35 years old.

Scatter plots representing the overall perceptibility, acceptability frequencies,, regarding the simulated L* differences, with their trendlines are presented in Figure 2. for the dentists and in Figure 3. for the laypersons.

Cubic equation was the curve that represented the best fit, with the regression of perceptibility and acceptability frequencies, when CIELAB color difference formula was used. As a result, this type of curve was used in order to estimate 50% PT and 50% AT values. 50% PT values were significant smaller compared to 50% AT values, regarding difference in lightness derived both from an increase or a decrease in the lightness of the central incisor. 50% PT values in the group of dentists were significant smaller than the corresponding values in the group of laypersons. There was not found a significant difference regarding the 50% AT values, between the 2 type of observers. For both groups, 50% AT were smaller, when difference in L was derived from a decrease in lightness. False perception rate was significant higher in dentist group (55,7%) compared to layperson group (22,8%) (p<.0.05). False perception rate was significant higher for the female compared to male dentists and for dentists <35 compared to dentist >35 years old. In the layperson group there was not a significant difference in false rate, regarding the gender of the participants. The 50% PT and AT along with their 95% confidence intervals, for both type of observers, for an increase or a decrease in the lightness of a single incisor are presented in Table 1.

Thresholds	Observer (n)	ΔL Origin	
		Decrease in L	Increase in L
Perceptibility (PT)	Dentists (80)	- 0,86 [a] [-1,05 – - 0,47]	1,1 [a] [0,71-1,45]
	Laypersons (80)	- 2,36 [b] [- 2,97 – - 1,74]	1,71 [a,b] [1,1 – 2,32]
Acceptability (AT)	Dentists (80)	- 3,6 [c] [- 4,09 – -3,11]	2,51 [b,d] [2,02 – 2,99]
	Laypersons (80)	- 4,24 [c,d] [- 4,73 – - 3,75]	3,29 [d] [2,74 – 3,85]

Table 1. 50:50 perceptibility (PT) and acceptability (AT) thresholds and the 95% confidence interval values, followed by the statistical grouping for each observer type. Same superscript letters in the same column or row, show no statistical difference. ($p < 0.05$).

Regarding the gender of the observers, 50% PT was significant different between male and female, for ΔL delivered from a decrease in the lightness of the central incisor in the dentist group. For a ΔL derived from an increase in L, 50% PT was decreased in male compared to female laypersons. 50% AT was significant lower in dentist group, as regard female compared to male participants, when the ΔL was derived from a decrease in lightness. The 50% PT and AT along with their 95% confidence intervals, based on gender, for an increase or a decrease in the lightness of a single incisor are presented in Table 2.

Thresholds	Observer (n)	Gender	ΔL Origin	
			Decrease in L	Increase in L
Perceptibility (PT)	Dentists (80)	Male	-1 [a] [0,36 – 0,74]	1,2 [a,b,c,d,h] [-1,33– 3,83]
		Female	-0,23 [b] [-0,71 – 0,35]	0,58 [a] [0,27 – 0,89]
	Laypersons (80)	Male	-2,7 [b] [-3,18 – -2,22]	1,31 [a] [0,79 – 1,84]
		Female	-2,73 [b] [-3,34 – -2,12]	2,75 [b,c,d] [2,16 – 3,35]
Acceptability (AT)	Dentists (80)	Male	-4,07 [c,e] [-4,51 – -3,62]	2,78 [d] [2,33 – 3,22]
		Female	-3,16 [d] [- 3,59 – -2,74]	2,4 [d] [2,02 – 2,76]
	Laypersons (80)	Male	-4,88 [e,h] [-5,34 – -3,62]	4,23 [h] [3,71 – 4,75]
		Female	-4,19 [e] [-4,36 – -4,03]	2,69 [d] [2,12 – 2,79]

Table 2. 50:50 perceptibility (PT) and acceptability (AT) thresholds and the 95% confidence interval values, followed by the statistical grouping based on gender. Same superscript letters in the same column or row, show no statistical difference. ($p < 0.05$)

50% PT thresholds were significant different between the 2 different age groups for laypersons. 50% AT thresholds were significant different between the different age group, for both type of obsrvers, independent from the source of ΔL. The 50% PT and AT along with their 95% confidence intervals, based on age group, for an increase or a decrease in the lightness of a single incisor are presented in Table 3.

Thresholds	Observer (n)	Age Group	ΔL Origin	
			Decrease in L	Increase in L
Perceptibility (PT)	Dentists (80)	≤ 35	-0,79 [a] [-1,73 – 0,19]	0,66 [a] [-0,19 – 1,51]
		> 35	- 1 [a, b] [- 1,43 – 0,57]	0,96 [a] [0.59 – 1,33]
	Laypersons (80)	≤ 35	- 2,97 [c] [- 3,47 – - 2,47]	0,93 [a] [0,58 – 1,31]
		> 35	-1,71 [b] [- 2,19 – - 1,22]	2,85 [b,c] [2,21 – 3,49]
Acceptability (AT)	Dentists (80)	≤ 35	- 2,99 [c] [- 3,43 – - 2,54]	2,20 [c] [1,80 – 2,59]
		> 35	- 4,11 [d,f] [- 4,54 – - 3,69]	3,08 [b] [2,71 – 3,45]
	Laypersons (80)	≤ 35	-4,70 [d,e] [-5,10 – -4,30]	2,41 [c] [2,14 – 2,69]
		> 35	- 3,79 [f] [- 4,26 – - 3,33]	3,86 [b,f] [3,21 – 4,50]

Table 3. 50:50 perceptibility (PT) and acceptability (AT) thresholds and the 95% confidence interval values, followed by the statistical grouping for each observer based on age group. Same superscript letters in the same column or row, show no statistical difference. ($p < 0.05$)

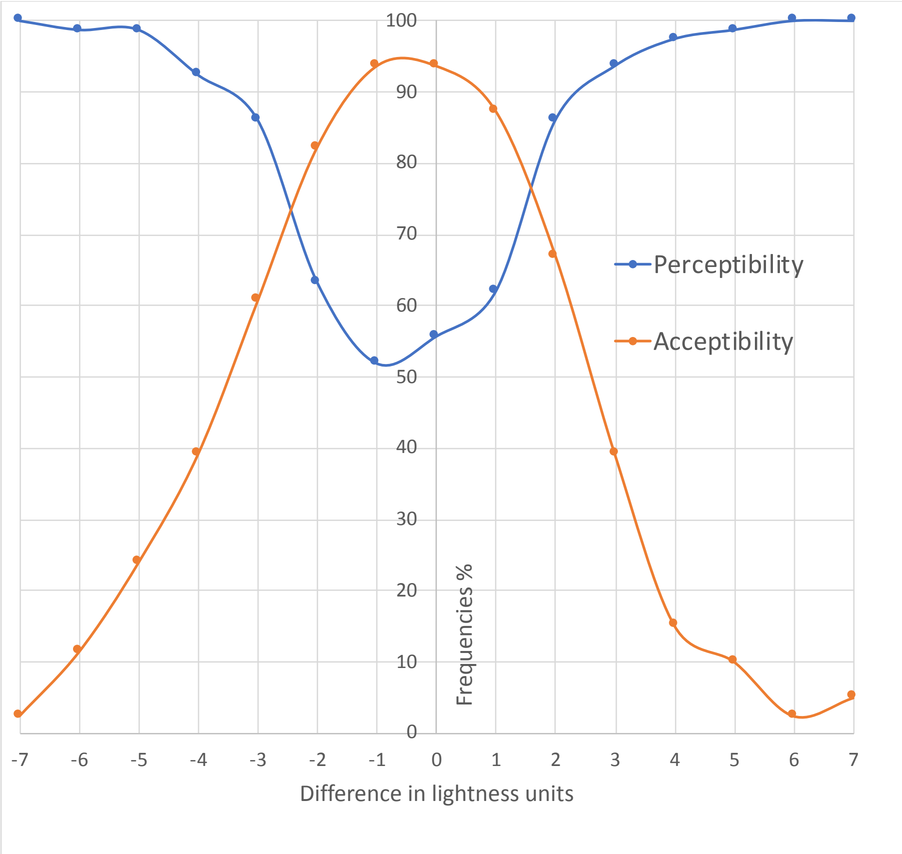

Figure 2. Perceptibility-acceptability frequencies, correlated to difference in lightness units. (dentists)

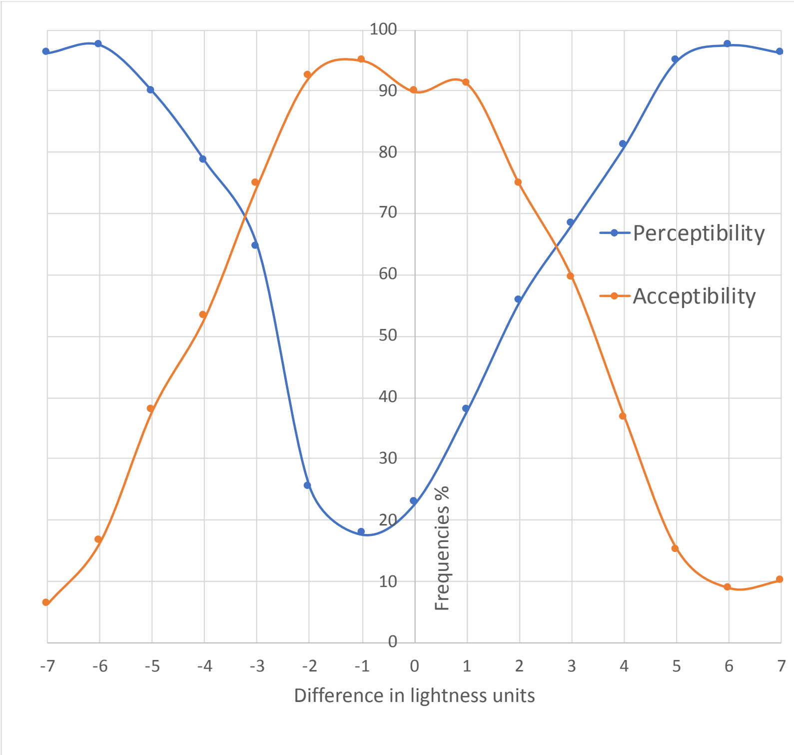

Figure 3. Perceptibility-acceptability frequencies, correlated to difference in lightness units. (laypersons)

There was a negative relationship between smile attractiveness score and perceptibility frequencies for both dentists and laypersons and a positive relationship between smile attractiveness score and acceptability frequencies for dentists. ($p<0.05$) The attractiveness scores along with the perceptibility frequencies and acceptability frequencies, for the dentists and laypersons, regarding simulated L* differences are presented in Figure 4 and 5 respectively.

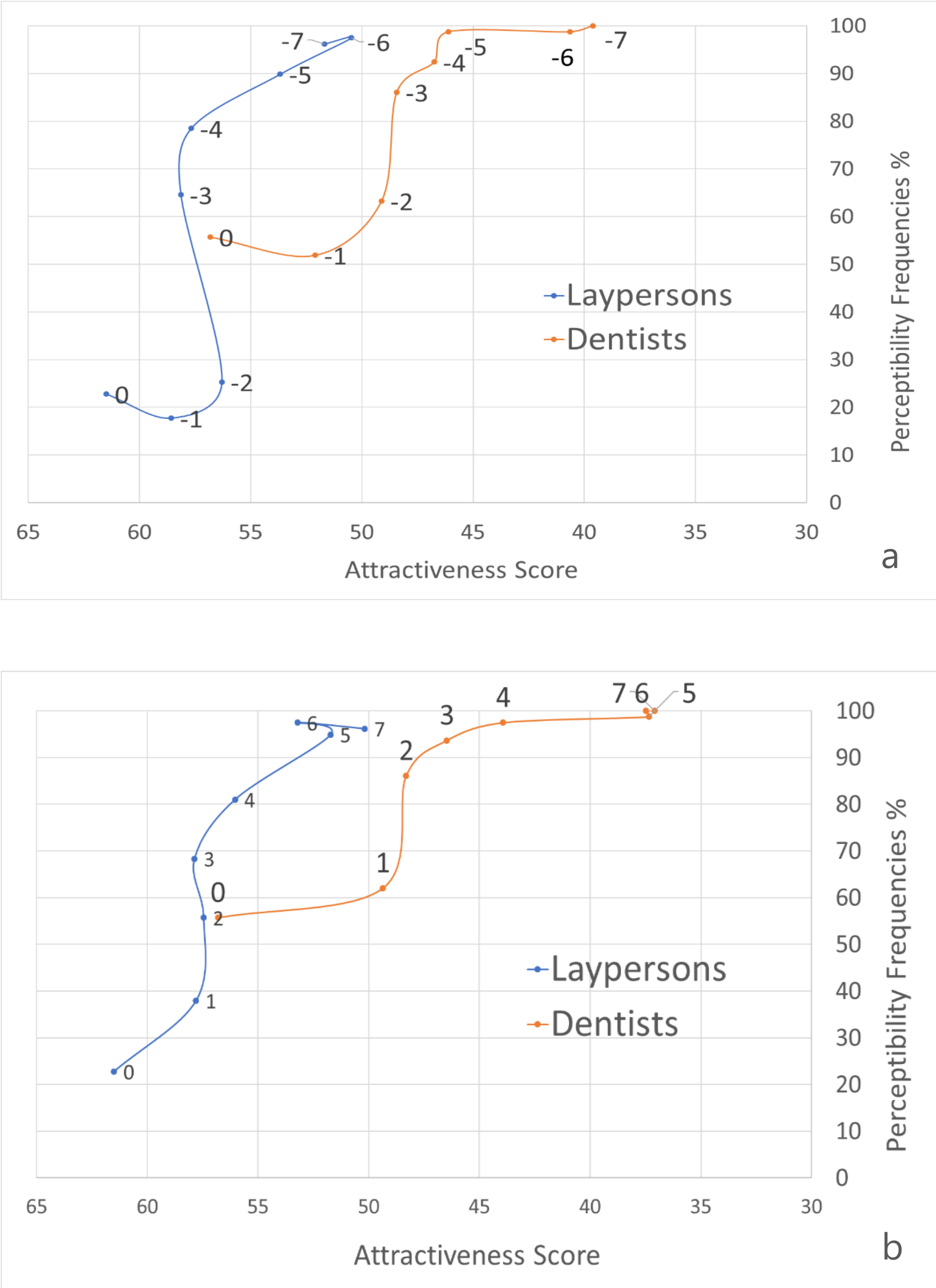

Figure 4. Scatter plots representing the overall perceptibility versus attractiveness score for the dentists and laypersons, regarding the simulated L* differences for a: -7 to 0, b: 0 to 7 L*.

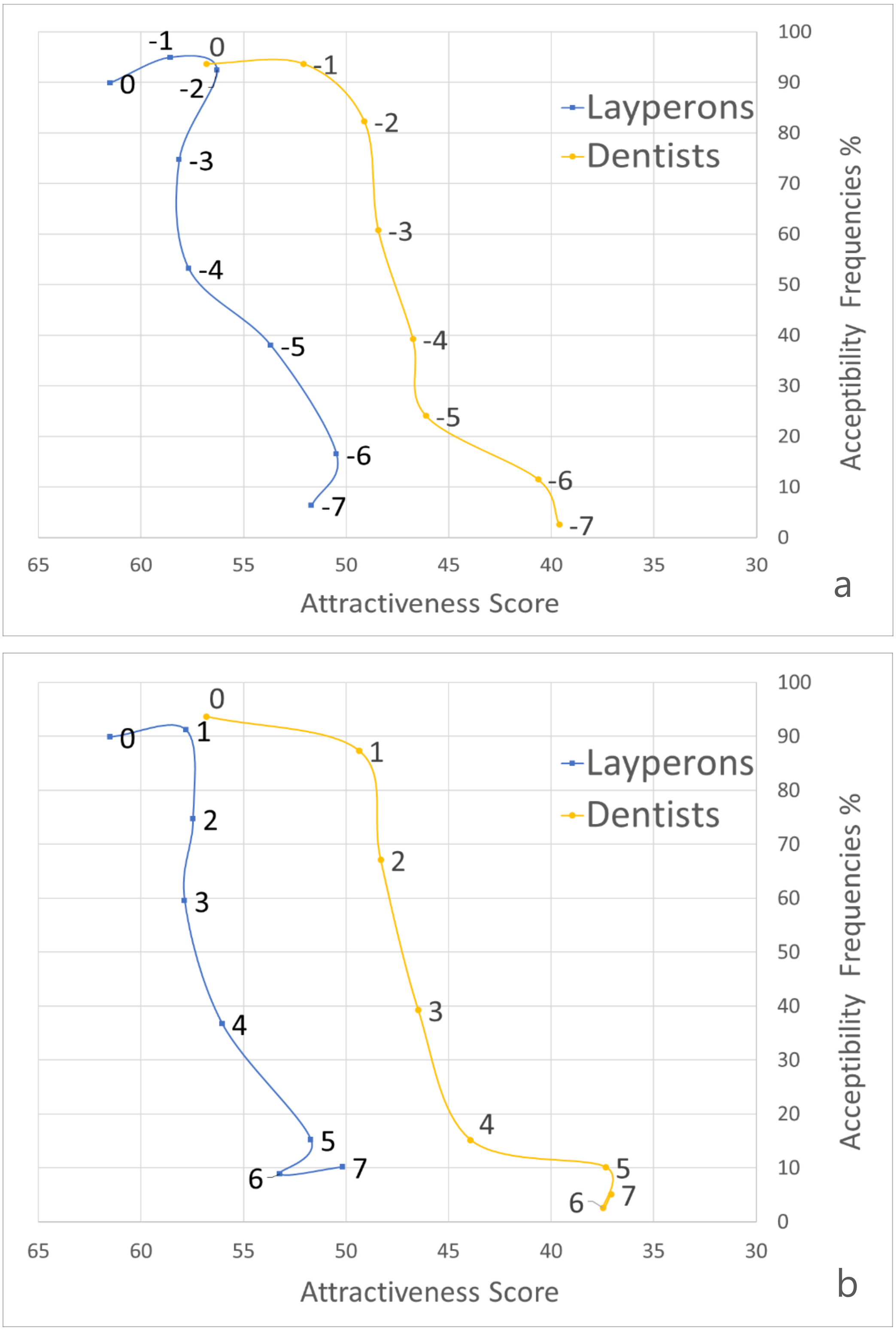

Figure 5. Scatter plots representing the overall acceptability versus attractiveness score for the dentists and laypersons, regarding the simulated L* differences for a: -7 to 0, b: 0 to 7 L*.

4.5 Discussion

The importance of visual thresholds, have been extensively described in scientific literature. Thresholds of color can serve as a tool for the quality control and a guide for the evaluation and selection of dental materials both in direct and indirect restorations, the assessment of their clinical performance, the interpretation of research findings and standardization of color in the dental field.[1]

Considering the direction of lightness difference, null research hypothesis was confirmed, as there was not a significant difference among 50% PT and 50% AT, when the difference was derived from an increase in lightness of the single incisor compared to a decrease. This was the first study that investigated PT and AT thresholds using darker as well as lighter compared to control, lightness differences, in a single tooth. Another research has been reported that lightness difference thresholds, were independent from the direction of the lightness difference.[21] In this study close-up images of the maxillary anterior tooth, with lips retracted have been used and lightness has been altered in the half three of the anterior teeth.

Perceptibility thresholds were different compared to acceptability thresholds for both type of observers. This is in accordance with the findings of previous studies that investigate PT and AT thresholds have hound a significant deference between them.[1,9,22-25] In the contrary some studies have reported no significant different between perceptibility and acceptability thresholds.[14,15] It must be highlighted that in this studies, contrary to similar studies that utilize a sequential judgment method, an independent judgment method was used in order to assess perceptibility and acceptability. Sequential methods may render perceptibility and acceptability judgments statistically dependent, as the acceptability threshold can never be smaller than perceptibility threshold.

The hypothesis of no difference between the type of observers was partially rejected as 50% PT were significant lower for the dentists compared to layperson for a decrease in lightness but not for a similar increase in lightness. This difference among the groups can possibly be explained, by the different training of the groups, as training can improve the ability to differentiate color.[1,9] Contrariwise there was not a significant difference for 50% AT. Waller et all. reported a difference both in PT and AT between dentists and layperson.[23,24] The difference was that in this clinical study different clinical cases of single restorations in the anterior teeth have been investigated without the homogeneity, that a digital simulated study provides between the different groups for light difference in a single central incisor. Also, the sample on that study for each group of observers was lower.[24] In the study of Thomas et al. there was not a significant in thresholds in lightness difference. It is possible that the magnification and focus of the close-up retracted images, in combination with the expanding area of difference in three teeth, lead to a mitigation in the difference of perception between the different type of observers.[21]

The age of the observer seems to play an important role both for PT and AT thresholds both for layperson but not for the dentists Older laypersons (>35) were more sensitive to a darker single incisor. In the opposite younger laypersons (≤ 35) realized more a lighter single incisor. It has to be noticed that younger dentists presented a significant higher false rate compared to older dentists.

In respect of the gender, in layperson group female participants presented a lower PT and AT compared to male observers, when the lightness of a single central incisor was increased. The present study is the first study, utilizing full portrait images in order to compare PT and AT values in gender perspective. In the dentist group a lower PT and AT was found in female compared to male participants, when the difference in color was derived from a decrease in lightness. The lower PT and AT values for female participants maybe can also explain the better shade matching performance from female participants.[26]

An increased percentage of false alarm answers was found in dentists compared to layperson, especially regarding perceptibility. This outcome come in contrast with the study of Lindsey et all, who reported a not significant difference in false alarm rates between the type of observers.[14] In the present study false alarm rates for the perceptibility were significant lower compared to the acceptability. In other studies, the opposite has been described.[14,25] This difference maybe can be explained by the different in the design of these studies, compared to current study. It must be noted that female dentists presented the highest false positive answers even when the 2 central incisors were identical in color. Also, young dentists presented a higher false rate compared to older. This high false alarm rate in dentists and especially in youngers, maybe also can be explained by their subconscious tendency to show their ability to discriminate even minor color differences. The design of the studies that assess perceptibility and acceptability thresholds, that is widespread in the literature, seems to create noise and fluctuation, to the observers, even if the same stimuli is presented. It seems that their decision to answer, is not based only to the observer comparison stimuli but also from his ability to realize if the sensory signals arise from the same color or from different colors. It seems that individual's ability to determine how large a difference between the sensory signals must be in order to perceive them is unique.[14,27]

The impact of smile esthetics in the attractiveness of the smile has been evaluated by a high number of articles, using various scales.[28] The most usually applied scale in the literature, is the visual analog scale (VAS test) The impact of the difference in the lightness among the anterior teeth, has also been reported.[3] The present study is the first study in the literature, which has been implemented both an assessment of smile attractiveness and of perceptibility and acceptability threshold, using exactly the same environment, the same observers and the same differences in the lightness of a central incisor. This gives as the opportunity to see how the perceptibility and acceptability frequencies are correlated with the attractiveness of the smile. A high correlation between attractiveness score and perceptibility was found for both type of observers. For the laypersons there was a correlation between attractiveness score and perceptibility frequencies. Taking into account these findings, it can be assumed that laypersons are realizing difference in lightness between the same incisors in the same way that this difference is becoming perceptible in their eyes. In the other hand dentists' observers perceive difference in lightness acutely, while the attractiveness continues to decrease. These results indicate the importance of calculating directly the influence of differences in color in the attractiveness of the smile and not only though perceptibility thresholds.

It seems that in both groups and especially in dentist group, the questionnaire, as it is performed in the assessment of perceptibility, make them prejudiced, as they have to know that they have to check the portrait for a color difference in a certain tooth.[3] In the evaluation of smile attractiveness observers are unaware of what they have to check in the portrait. It must not be forgotten that one of the aims of dental interventions, is to make a smile to be perceived attractive by ensuring a harmony between their structures.[28] The problem is not only the difference between the teeth or the restorations, but the negative influence of this difference in the esthetics of the smile. Taking also this into account, smile attractiveness has to be further implemented, when color in dentistry is investigated, as it helps overcoming the bias that the questions in perceptibility and acceptability evaluation by their nature create, and also help avoid the problems that high false alarm rates, especially in the dentists' participants create.

The present study enhances the evidence, that computer simulated of teeth colors, can be used for the estimation of perceptibility and acceptability thresholds as well as of smile attractiveness. The use of an electronic computer to reproduce the modified portrait seems to be a more reliable method, which is closer in reality compared to the assessment using dental materials. Presenting high quality, image processed, full-face portraits on a calibrated display, seems to be a promising technique for the assessment of color difference. A significant difference between digital images and judgment in real life, is the effect that different psychological and perceptual factors can create. Nowadays with the extended use of social media, digital images constitute a significant part of social interactions. Taken this into account, the use of digital images is both a simulation of the in vivo social interaction and a representation of the communication via social media.

Digital simulation in this study, was a limitation in order to expand the results in the clinical reality but an advantage for the interpretation of the results in the era of social media. Another limitation was that only one-color difference formula has been applied. Also, the experimental design in the present study didn’t include a second judgment with the same pictures for the same participants in order to assess their intra-examiner reliability. Especially the reliability between the type of observers (layperson, dentists) would be of great interest to be evaluated. The present study evaluated color difference derived only from a difference in lightness. More research is needed utilizing the presented scientific method, in order to assess the relationship between facial attractiveness and perceptibility and acceptability thresholds. The influence of type of the model in the portraits, is something that have to be tested in the research projects as regard color thresholds, as it has been reported to lead to significant differences in the smile attractiveness. Nevertheless, the impact of gender and age has to be assessed by more studies, including, not only the lightness but also more color parameters. Except from color parameters that influence significant the optical properties of teeth and their restorations such as surface texture, luster, translucency etc, have to been further investigated.

4.6 Conclusions

Digital simulation of differences in the color of the teeth on human portraits, constitute a significant tool in order to assess color difference thresholds. Difference in lightness between the two central incisors, is tolerated with various degrees among dentists and laypersons. The age and the gender of the observer plays an important role in the perception of differences in lightness. Perceptibility thresholds were significantly lower than acceptability thresholds. Dentist group presented a high false rate compared to layperson. The Assessment of smile attractiveness complement the perceptibility and acceptability estimation, assisting in a better interpretation, of the influence of color difference in clinical reality, overcoming problems, as high false alarm rates and the bias that is created when the observers are informed that they have to assess a difference in color.

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5.

Abstract

Introduction: A smile plays a major role in the assessment of facial attractiveness and in the overall evaluation of a smiling person. Several studies have shown that poor dental esthetics is considered to be less attractive overall, including social attractiveness. The success of each restoration is heavily determined by the uniformity and color resemblance, that they have while opposed to the adjacent teeth or restorations. The perception of color in the space related to dentistry, is a complex phenomenon that involves three factors: the observer, the illuminant and the object. It is well established that dentistry employs mathematic equations, as a mean to 'quantify' color and subsequently 'calculate' the color difference between two distinct surfaces. Digital technology, using the computer-aided image manipulation, has been used in order to investigate the impact of specific changes in dental appearance, without altering other facial or smile characteristics. In order to interpret, color difference, usually perceptibility and acceptability thresholds are estimated. Perceptibility threshold refers to the smallest color difference, that can be detected by an observer. A 50:50% perceptibility threshold, refers to the situation in which 50% of observers notice a difference in color, between two objects while the other 50% notice no difference. Accordingly, the difference in color that is acceptable for 50% of observers corresponds to a 50:50% acceptability threshold. Except from these thresholds, the influence of color difference in smile attractiveness is an important factor. However, the effect of the discoloration of tooth types (central incisor, canine) on the overall facial attractiveness, has not yet been investigated. Moreover, the association between perceptibility and acceptability frequencies and smile attractiveness, still has not been evaluated.

Objectives. The first purpose of this study, was to evaluate the influence of lightness difference, of a single anterior maxillary tooth on smile attractiveness, using the CIELAB system on digital simulated facial portraits. The second aim was to assess the visual perceptibility and acceptability thresholds, for lightness differences of a single maxillary central incisor, and to investigate possible differences in these thresholds between the type (i.e. dentists vs laypersons), the gender and the age, in order to estimate the boundaries, within which a singled restoration prosthesis can remain undetectable or with an acceptable difference compared to the remaining teeth of the smile. The third purpose was to investigate the association between the attractiveness of the smile and perceptibility and acceptability frequencies would be investigated.

Material & Methods: A series of images with varying lightness (L), were created by altering the anterior teeth of a male Caucasian, on a frontal view of full-portrait image. For each one of the three anterior teeth the shade was modified, to create 15 different images, one image serving as the control and half with increased and half with decreased lightness, were created by modifying digitally in each step 1 ΔL unit ($\Delta L=\Delta E=1$). The images were presented in random order in a digital calibrated monitor. 160 participants (80 dentists, 80 laypersons) were instructed to fill out a questionnaire, giving a score using a Visual Analog Scale and evaluating every image for a perceptibly or an acceptable mismatch of central incisor color. All participants were screened using Ishihara's test for color deficiency, in order to ensure judgements validity in the perceptibility and acceptability questions regarding the color changes.

Results: For central incisors difference in lightness, $\Delta L\geq 1$ negatively affected attractiveness. There was a higher tolerance for lightness mismatch, when one lateral incisor is lighter and the same applies when the canine was darker. Difference in lightness affected smile attractiveness, both for dentists and laypersons. No difference between males and females was observed for the dentists. For laypersons, females perceived smiles with lightness difference, as significantly less attractive compared to males. Dentist's age did not affect perception of smile attractiveness. Younger laypersons perceived darker color, as less attractive. 50% perceptibility thresholds were significant lower in dentists compared to laypersons. There was found a significant difference, regarding 50% acceptability thresholds between the type of observer. Dentist group presented a high false rate compared to layperson. Smile attractiveness score presented a different curve, compared to perceptibility and acceptability frequencies.

Conclusion: Changes in lightness of a single anterior tooth significantly affected smile attractiveness in a different way for the central vs lateral vs canine. For the dentists, age and gender did not significantly affect smile perception, in contrast to laypeople. Difference in lightness between the two central incisors, is tolerated with various degrees among dentists and laypersons. The age and the gender of the observer plays an important role in the perception of differences in lightness. Perceptibility thresholds were significantly lower than acceptability thresholds. The assessment of smile attractiveness complement the perceptibility and acceptability estimation, assisting in a better interpretation, of the influence of color difference in clinical reality, overcoming problems, as high false alarm rates and the bias that is created when the observers are informed that they have to assess a difference in color. Digital simulation of differences in the color of the teeth on human portraits, constitute a significant tool in order to assess color difference thresholds, especially in the era of social media, where a major part of communication is performed via digital images. However, image simulation, is a technique that presents also limitations compared to in vivo circumstances, when the results has to be expanded in the clinical reality.

Clinical significance: Lightness differences of a single anterior tooth affects smile attractiveness, in an individualized way for each tooth. The assessment of smile attractiveness complements the perceptibility and acceptability estimation of visual thresholds, assisting in a better interpretation, of the influence of color difference in clinical reality

6.

Περίληψη

Εισαγωγή: Το χαμόγελο διαδραματίζει κυρίαρχο ρόλο, στην εκτίμηση της αισθητικής του προσώπου και γενικότερα του ατόμου που χαμογελά. Σημαντικός αριθμός ερευνών έχει δείξει ότι χαμηλή αισθητική των δοντιών, οδηγεί σε υποβάθμιση της αισθητικής του ατόμου, όπως αυτή γίνεται αντιληπτή, κατά τις κοινωνικές συναναστροφές. Η επιτυχία κάθε αποκατάστασης, καθορίζεται σε μεγάλο βαθμό και από την χρωματική της ομοιομορφία, με τις παρακείμενες οδοντικές επιφάνειες ή αποκαταστάσεις. Η αντίληψη του χρώματος στο χώρο της οδοντιατρικής, αποτελεί ένα σύνθετο φαινόμενο, το οποίο εμπεριέχει 3 παράγοντες: τον παρατηρητή, το φως και το αντικείμενο που κάποιος παρατηρεί. Είναι σαφώς εδραιωμένο, ότι στην οδοντιατρική χρησιμοποιούνται μαθηματικοί τύποι, ως ένα μέσο για την ποσοτικοποίηση του χρώματος, και πιο συγκεκριμένα της διαφοράς του χρώματος μεταξύ 2 ξεχωριστών επιφανειών. Η ψηφιακή τεχνολογία, με τις υπολογιστικές παραμετροποιήσεις τις οποίες μπορεί προσφέρει, για την αλλαγή συγκεκριμένων χαρακτηριστικών των δομών που συνθέτους το χαμόγελο, έχει χρησιμοποιηθεί για την έρευνα της επίδρασης, αλλαγών στην εμφάνιση του χαμόγελου. Για τη καλύτερη κατανόηση της σημασίας της διαφοράς του χρώματος, συχνά ΄υπολογίζονται τα όρια αντίληψης και αποδοχής. Το όριο της αντίληψης, αναφέρεται στη μικρότερη δυνατή διαφορά χρώματος η οποία μπορεί να γίνει αντιληπτή από έναν παρατηρητή. Το 50:50% όριο αντίληψης, χρησιμοποιείται για να δείξει τη διαφορά χρώματος, η οποία γίνεται αντιληπτή από το 50% των παρατηρητών, αλλά όχι από το υπόλοιπο 50%. Αντίστοιχα, η διαφορά του χρώματος η οποία είναι αποδεκτή από το 50% των παρατηρητών, ορίζεται ως 50:50% όριο αποδοχής. Εκτός όμως από τα προαναφερθείσα όρια, η επίδραση της διαφοράς χρώματος στην αισθητική του χαμόγελου είναι ένα σημαντικός παράγοντας. Παρόλα αυτά η επίδραση, της διαφοράς χρώματος μεταξύ των πρόσθιων δοντιών, στην αισθητική του χαμόγελου δεν έχει ακόμα μελετηθεί. Επιπλέον, η συσχέτιση μεταξύ των όριων αντίληψης και αποδοχής, και της αισθητικής του χαμόγελου δεν έχει εξεταστεί.

Σκοπός: Πρωταρχικός σκοπός της μελέτης, ήταν ο έλεγχος της επίδρασης της διαφοράς χρώματος, σε ένα πρόσθιο δόντι της άνω γνάθου στην αισθητική του χαμόγελου, με βάση το χρωματικό μοντέλο CIELAB, χρησιμοποιώντας ψηφιακά προσομοιωμένα χαμόγελα. Ο δεύτερος στόχος, ήταν η μελέτη των ορίων αντίληψης και αποδοχής, για διαφορές χρώματος στο κεντρικό τομέα της άνω γνάθου, και ο ανεύρεση πιθανών διαφορών σε αυτά τα όρια μεταξύ των τύπο των παρατηρητών(οδοντίατροι ή μη σχετική με την οδοντιατρική), το φύλο και την ηλικία, ώστε να υπολογιστούν τα όρια, μέσα στα οποία μία μονήρη αποκατάσταση μπορεί να παραμείνει απαρατήρητη ή με μία αποδεχτή διαφορά, έναντι των υπόλοιπων δοντιών του χαμόγελου. Τρίτος σκοπός, ήταν η αξιολόγηση της συσχέτισης, μεταξύ της αισθητικής του χαμόγελου, και των συχνοτήτων αντίληψης και αποδοχής.

Μέθοδος & Υλικά: Μια σειρά από εικόνες πορτραίτου, με διαφορετική φωτεινότητα των δοντιών δημιουργήθηκε, παραλλάσσοντας τα πρόσθια δόντια ενός άντρα καυκάσια φυλής. Για κάθε ένα από τα τρία πρόσθια δόντια, το χρώμα μεταβλήθηκε, ώστε να δημιουργηθούν 15 διαφορετικές εικόνες. Μία από τις οποίες χρησιμοποιήθηκε ως εικόνα ελέγχου. Οι μισές από τις υπόλοιπες εικόνες, είχαν χαμηλότερη, και οι άλλες μισές υψηλότερη φωτεινότητα, παραλλάσσοντας ψηφιακά κάθε μία με βήμα 1 μονάδας ΔL (ΔL=ΔE=1). Οι εικόνες παρουσιάστηκαν, με τυχαία σειρά, σε ψηφιακά καλιμπραρισμένη οθόνη. Δόθηκαν οδηγίες σε 160 συμμετέχοντες (80 οδοντίατροι και 80 ασθενείς), να συμπληρώσουν ένα ερωτηματολόγιο, δίδοντας μία βαθμολογία μέσω κλίμακας οπτικού ανάλογού, και εξετάζοντας κάθε εικόνα για αντιληπτή ή αποδεκτή διαφορά μεταξύ του χρώματος των κεντρικών τομέων. Όλοι οι συμμετέχοντες, εξετάστηκαν με τη βοήθεια της δοκιμασίας Ishihara, για διαταραχές της έγχρωμης όρασης, ώστε να εξασφαλιστεί η εγκυρότητα, των απαντήσεων, στις ερωτήσεις αντίληψής και αποδοχής, σχετικά με τη διαφορές στο χρώμα.

Αποτελέσματα: Για το κεντρικό τομέα διαφορά στη φωτεινότητα ΔL≥1, επηρεάσε αρνητική την αισθητική του χαμόγελου. Υπάρχει μεγαλύτερη ανεκτικότητα στη μη σύμπτωση του χρώματος, για πιο φωτεινό πλάγιο τομέα και πιο σκοτεινό κυνόδοντα. Η διαφορά στη φωτεινότητα επηρεάσε τόσο τους οδοντιάτρους όσο και τους μη σχετικούς με την οδοντιατρική επιστήμη. Για τους τελευταίους, οι γυναίκες αντιλήφθηκαν τα χαμόγελα στα οποία υπήρχε διαφορά στη φωτεινότητα, ως λιγότερο αισθητικά σε σχέση με τους άντρες. Η ηλικία των οδοντιάτρων δεν επηρέασε, το πως αντιλαμβάνονται τις διαφορές της φωτεινότητας ενός πρόσθιου δοντιού, στην αισθητική του προσώπου. Οι ασθενείς μικρότερη ηλικίας, αντιλήφθηκαν της πιο σκοτεινές αλλαγές στη φωτεινότητα, ως λιγότερο αισθητικές. Το 50% όριο αντίληψης ήταν σημαντικά μικρότερο στους οδοντιάτρους. Υπήρξε σημαντική διαφορά στο όριο αποδοχής, μεταξύ του τύπου των παρατηρητών. Οι οδοντίατροι παρατηρητές, εμφάνισαν αυξημένο ποσοστό ψευδών αληθών απαντήσεων, έναντι των ασθενών. Η βαθμολογία της αισθητική του χαμόγελου εμφάνισε διαφορετική καμπύλη, σε σχέση με τις συχνότητες αντίληψης και αποδοχής.

Συμπεράσματα: Διαφορές στη φωτεινότητα προσθίων δοντιών, επηρεάζουν σημαντικά την αισθητική του χαμόγελου, με διαφορετικό τρόπο στο κεντρικό, το πλάγιο ή το κυνόδοντα. Για τους οδοντιάτρους, η ηλικία και το φύλο δεν επηρεάζουν σημαντικά την αισθητική του χαμόγελου, ενώ το αντίθετο συμβαίνει στους μη σχετιζόμενους με τη οδοντιατρική παρατηρητές. Διαφορές στη φωτεινότητα, μεταξύ των δύο κεντρικών, γίνεται ανεκτή σε διαφορετικό βαθμό μεταξύ οδοντιάτρων και ασθενών. Η ηλικία και το φύλο των παρατηρητών, παίζει σημαντικό ρόλο, στην αντίληψη της διαφοράς στη φωτεινότητα.

Κλινική σημασία: Η διαφορά στο χρώμα ενός πρόσθιου δοντιού ,επηρεάζει την αισθητική του χαμόγελου, με διαφορετικό τρόπο για κάθε δόντι. Η αξιολόγηση της αισθητικής του χαμόγελου, συμπληρώνει την εκτίμηση την οποία προσδίδουν, τα όρια αντίληψης και αποδοχής, βοηθώντας στην καλύτερη αντίληψη και ερμηνεία, τη διαφοράς του χρώματος, στη κλινική πραγματικότητα. Τα όρια αντίληψης, ήταν σημαντικά μικρότερα από τα όρια αποδοχής. Η αξιολόγηση της αισθητικής του χαμόγελου, συμπληρώνει την εκτίμηση που προσφέρουν τα όρια αντίληψης και αποδοχής, βοηθώντας στη καλύτερη ερμηνεία, της επίδρασης της διαφοράς χρώματος στη κλινική πραγματικότητα. Με αυτό το τρόπο μπορούν, να αντιμετωπισθούν προβλήματα, όπως η μεγάλη συχνότητα, ψευδών αληθών απαντήσεων και το συστηματικό σφάλμα που δημιουργείται, όταν οι παρατηρητές γίνονται ενήμεροι, για διαφορά στο χρώμα των δομών που εξετάζουν. Η ψηφιακή προσομοίωση, διαφορών στο χρώμα των δοντιών, σε ανθρώπινα πορτραίτα, αποτελεί ένα σημαντικό μηχανισμό, για την αξιολόγηση των οριακών τιμών στη διαφορά του χρώματος, ιδιαίτερα στην εποχή των μέσων κοινωνικής δικτύωσης, όπου σημαντικό μέρος της επικοινωνίας πραγματοποιείται μέσω ψηφιακών εικόνων. Παρ΄ όλα αυτά, η ψηφιακή προσομοίωση, είναι μια τεχνική που παρουσιάζει, περιορισμούς, έναντι των κλινικών συνθηκών, όταν τα αποτελέσματα πρέπει να επεκταθούν στη κλινική πραγματικότητα.

7.

Appendices

Publication of the first research part, in the Journal of Esthetic and Restorative Dentistry:

Ntovas P, Diamantopoulou S, Gogolas N, Sarri V, Papandreou A, Sakellaridi E, Petrakos G, Papazoglou E. **Influence of lightness difference of single anterior tooth to smile attractiveness.** J Esthet Restor Dent. 2020 Dec 2. doi: 10.1111/jerd.12678. Epub ahead of print. PMID: 33264491.

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RESEARCH ARTICLE

WILEY

Influence of lightness difference of single anterior tooth to smile attractiveness

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Abstract

Objectives: To evaluate the influence of lightness difference of a single anterior maxillary tooth on difference smile attractiveness.

Methods: A frontal view full-portrait image of a smiling male Caucasian, was digitally modified altering a single tooth, creating a series of images with varying lightness (ΔL) for the maxillary central, lateral and canine. A total of 160 participants (80 dentists, 80 laypersons) were asked to fill out a Visual Analog Scale questionnaire for every image recording smile attractiveness.

Results: For central incisors $\Delta L \geq 1$ negatively affected attractiveness. There was a higher tolerance for lightness mismatch when one lateral incisor is lighter and the same applies when the canine was darker. Difference in lightness affected smile attractiveness both for dentists and laypersons. No difference between males and females was observed for the dentists. For laypersons, females perceived smiles with lightness difference as significantly less attractive compared to males. Dentist's age did not affect smile attractiveness perception. Younger laypersons perceived darker color, as less attractive.

Conclusions: Changes in lightness of a single anterior tooth significantly affected smile attractiveness in a different way for the central vs lateral vs canine. For the dentists, age and gender did not significantly affect smile perception, in contrast to laypeople.

Clinical significance: Lightness differences of a single anterior tooth affects smile attractiveness.

KEYWORDS
color difference, color science, lightness difference, single anterior tooth, smile attractiveness

1 | INTRODUCTION

In our modern, beauty-conscious society, facial attractiveness cannot be underestimated. In the face, the eyes and the mouth were found to be the most important factors in a hierarchy of characteristics for determining esthetic perceptions.[1] On the other hand, overall facial attractiveness does not depend on a single feature: cheeks, chin, eyes, hair, lips, nose, skin, and teeth contribute equally.[2] Nevertheless, most Americans believe that dental appearance is “very important” in social interactions.[3] A smile plays a major role in the assessment of facial attractiveness and in the overall evaluation of a smiling person.[4] Several studies have shown that poor dental esthetics is considered to be less attractive overall, including social attractiveness.[5-7]

Over the years, several studies have utilized computer-aided image manipulation to investigate the impact of specific changes in dental appearance, without altering other facial/smile characteristics. These studies have demonstrated that people are perceived more favorably when they have healthy dentition as opposed to abnormal tooth color (caused by caries or severe dental fluorosis) or teeth alignment.[8-11] The presence of apparently healthy,[12,13] straight teeth[6] are considered critical positive factors in the perception of smile attractiveness. Symmetrical smiles are considered more esthetically pleasant.[14] Maxillary central incisors have a major role in determining smile esthetics, followed by the canines, whereas lateral incisors have less visual weight.[14]

Tooth shade seems to be the most important factor in predicting smile attractiveness.[15] Tooth lightness influences the perception of social appeal, with computer generated darkened smiles receiving significantly poorer scores than natural color smiles and the later ones being also worse than lightened smiles.[16] A major predictor of social appeal is tooth lightness. A perceptible change in teeth lightness is the strongest factor associated with the *dental attractiveness stereotype*, affecting significantly *Happiness*, *Social Relations* and *Academic Performance* traits assesed.[16] A brighter tooth shade significantly affected smile attractiveness, independently from skin tone.[17]

There seems to be a tendency in the literature for laypersons to judge smiles/faces with brighter teeth as more attractive compared to dentists.[14,18,19] However, this was not always observed.[17] The effect of gender and age of observers in perceived smile attractiveness has been investigated, but results in the literature are inconclusive.[16-18]

In all the aforementioned studies brighter or darker teeth color referred to dentition as a total, that is, to all the teeth appearing when smiling. When perception and evaluation of single anterior tooth color and their influence on overall facial attractiveness were investigated participants did not consciously notice the discoloration of a maxillary lateral incisor and attractiveness judgments were not influenced by tooth color.[20] However, the degree of the discoloration was arbitrary (not measured) and there were only three degrees of lightness (bright vs dark vs control) for one maxillary lateral incisor. Moreover, the effect of the discoloration of other tooth types (central incisor, canine) on the overall facial attractiveness was not investigated.

So far, the influence of various lightness difference values of a single maxillary anterior tooth on smile attractiveness has not been fully studied.

The null hypotheses of the present study were that there is no difference in smile attractiveness for various lightness differences of maxillary anterior teeth:

- Irrespective of the direction of lightness difference (lighter vs darker) of a single maxillary central incisor, lateral incisor or canine,
- Between dentists and laypersons,
- Between males and females,
- Between younger and older observers.

Finally, that there is no correlation between smile attractiveness and change in lightness.

2 | MATERIAL AND METHODS

This cross-sectional study was designed and conducted in a Dental School environment, between March and June 2019. All observers were subjected to Ishihara's test for color deficiency. Power analysis indicated that a sample size of 160 participants was necessary ($P = .8$). Half of them (n = 80) were patients or staff of the School of Dentistry and the remaining half were faculty members.

A 25-year-old Caucasian male was selected as a model for the study, with a smile exhibiting good teeth alignment and tooth size symmetry. A frontal view full-portrait image, with the smile showing lips and teeth was captured with a digital camera (EOS 80D, Canon) and a 100 mm macro camera lens (Canon IS USM) in RAW image format. The initial image was digitally modified (Adobe Photoshop CS 2015, Adobe), for the color of the teeth to be close to the average measurements obtained in a diverse population.[21] A second digital manipulation created a series of images with varying lightness (L) for the maxillary central incisor, lateral incisor and canine. The lightness (L) of one maxillary central incisor, lateral incisor and canine was digitally modified individually by 1 ΔE unit ($\Delta L = \Delta E = 1$). For each one of the three anterior teeth the shade was modified, to create 15 different images per tooth (14 digitally modified and 1 initial that served as the control) half with increased and half with decreased lightness (−7, −6, −5, −4, −3, −2, −1, 0, +1, +2, +3, +4, +5, +6, +7). Lightness differences were calculated using Color Picker software (macOS). In total, 45 images were displayed in random order to the observers. An example of the extreme values of ΔL modification in lightness difference compared to control is presented in Figure 1 for the maxillary central incisor. The modification of the lightness of one anterior tooth simulated clinical situations, like discoloration of a single anterior tooth due to a trauma or endodontic therapy, or mismatch in the color of a tooth or implant supported restoration.

At the beginning of the interview, the examiner recorded age and gender of the participant. The images were viewed in a digitally calibrated monitor (LCD Dell 21" HD) adjusted in portrait format, so as to achieve a full-face smile, to its real dimensions. Observations were carried out during midday (11:00 AM–13:00 PM), while in the test room the artificial lighting conditions were standardized and the room and the monitor were not directly exposed to sunlight. Seat height was adjusted for each individual observer, to align the eye level of the observer to that of the monitor model. The distance between the observer and the monitor was consistently 60 cm, which stands for the typical distance between persons during social contact. The observation of each of the modified images for 10 sec was followed by a 4 sec viewing of a uniform gray screen with a black cross as a fixation point in the center. Observers completed the test in two appointments with an interval of 3 weeks between the two half parts of the test. The images appeared in a random sequence for all participants. They rated the images without conferring with others.

Participants were asked to evaluate the attractiveness of the smiles and were not informed about the digital manipulations of the images. Particularly, they were asked to fill out a Visual Analogue Scale VAS (0–100) questionnaire for every image recording the attractiveness of the smile. VAS consisted of a 100 mm horizontal line from point 0 = extremely unattractive to point 100 = extremely attractive. Every participant was asked to mark a vertical line on the horizontal

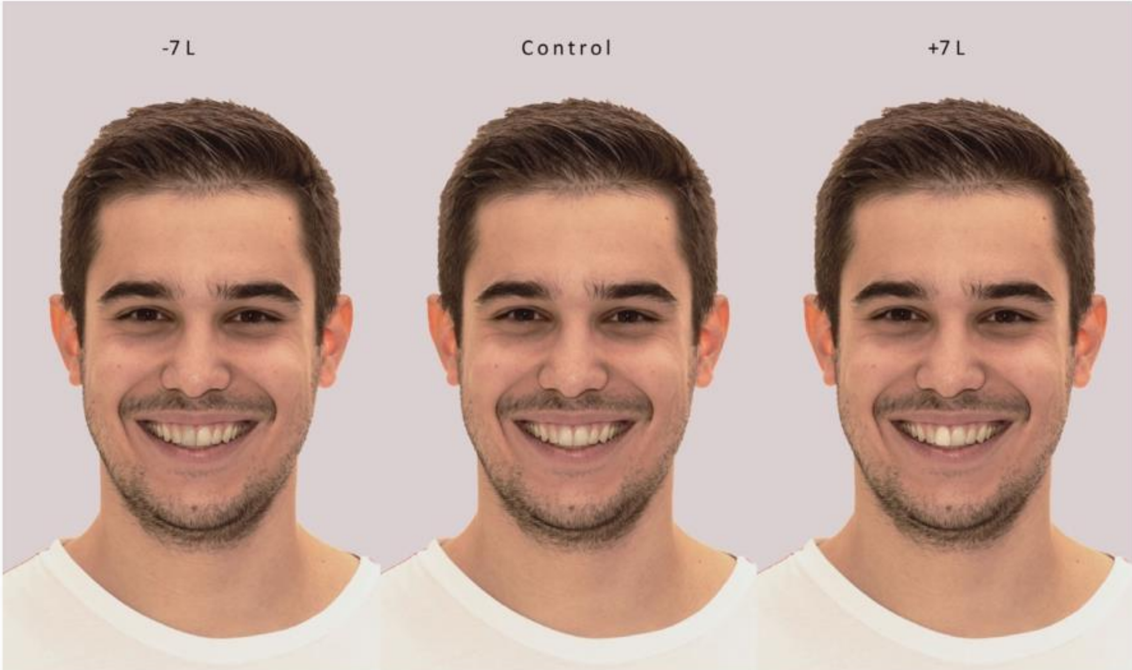

FIGURE 1 Maximum and minimum modification of lightness in central incisor compared to control

line answering to the question "How attractive do you consider this smile?"

3 | STATISTICAL ANALYSIS

For each of the modified anterior tooth the differences in VAS in the evaluation between the control and each of the 14 color changed images were recorded and analyzed. In addition, the pairwise differences of images with the same magnitude but different sign in the 14-level digitally simulated scale were similarly treated for all three tooth categories. The preliminary analysis (normal probability plots and Anderson-Darling test for normality) indicated a significant deviation from normality, due to the presence of outliers for the majority of the above defined variables. Therefore, nonparametric statistics were used for the analysis of our data. The median was used as the descriptive measure of central tendency while nonparametric confidence intervals and hypothesis testing for the median differences were used for statistical inference. Wilcoxon signed rank test was used to determine whether the median of a sample differed significantly from the control, while the Kruskal-Wallis test was used to determine whether the medians of gender and age groups differ.

4 | RESULTS

The total number of participants was 160, where 80 (50%) of them were dentists and 80 (50%) were layperson. The overall response rate was 91.2% for the dentists and 84.3% for the layperson. The male (46.3%) and female (53.7%) individuals were aged from 18 to 75 years. The mean age was 38.22 years for the dentists and 43.81 years for the layperson. Subjects were divided into two age groups: 18 to 35 and 36 years old or over.

Central incisor: The difference in perceived smile attractiveness score between the control and each altered image (each increment of ΔL), for both dentists and laypersons is presented in Figure 2. Lightness difference ΔL≥1 affects smile attractiveness both for dentists and layperson ($P < .001$, $P = 0.023$ respectively). Dentists perceived decreased smile attractiveness when a ΔL≥5 was originated from lighter tooth alteration compared to darker ($P = .024$). Laypersons did not perceive a significant difference in smile attractiveness in respect of the direction (darker or lighter) of lightness difference. No difference between male and female evaluators in perceived smile attractiveness score was observed for the dentists' group. In laypersons' group, female participants seem to perceive smiles with lightness difference as significantly less attractive compared to male participants especially for the lighter teeth ($P = .034$). Dentist's age did not significantly affect smile attractiveness perception in relation to the lightness difference. Younger laypersons perceived darker central incisor color, as less attractive for the smile than older participants ($P = .019$).

Lateral incisor: The difference in smile attractiveness scores between the control and each altered image (each increment of ΔL) for both dentists and laypersons is presented in Figure 3. Both groups perceived smiles with lightness difference ΔL≥1 from decrease in lightness as significantly less attractive than control smile ($P < .001$, $P < .001$). For lightness differences derived from increase in lightness, both dentists and laypersons did not perceive a difference in smile attractiveness, compared to control up to 6 ΔL units. Both dentists and layperson perceived darker color alterations, as less attractive compared to lighter equivalents ($P < .001$, $P < .001$). No difference between males and females was observed in the dentists' group. In laypersons' group, women perceived lightness difference in the darker teeth as significantly less attractive

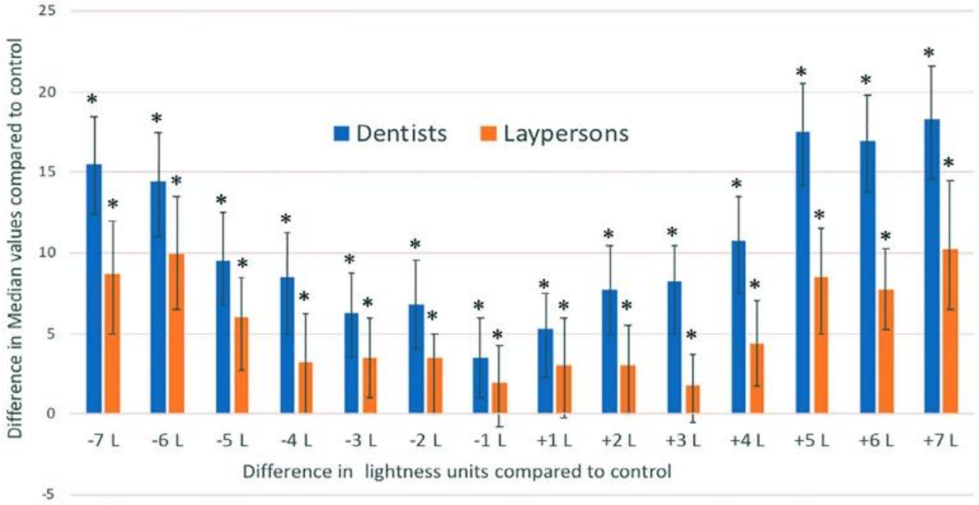

FIGURE 2 Difference in perceived smile attractiveness score of altered images compared to control for the central incisor. The symbol * denotes significant difference from the control

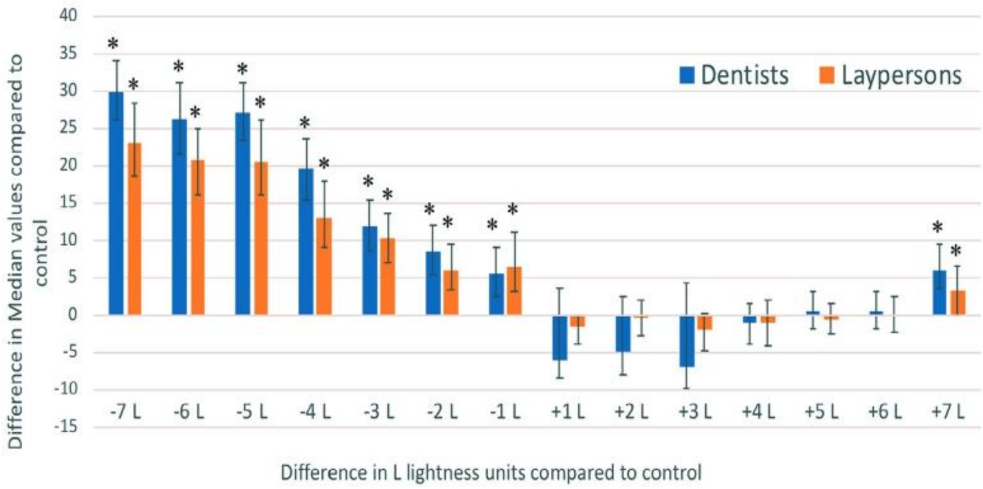

FIGURE 3 Difference in perceived smile attractiveness score of altered images compared to control for the lateral incisor. The symbol * denotes significant difference from the control

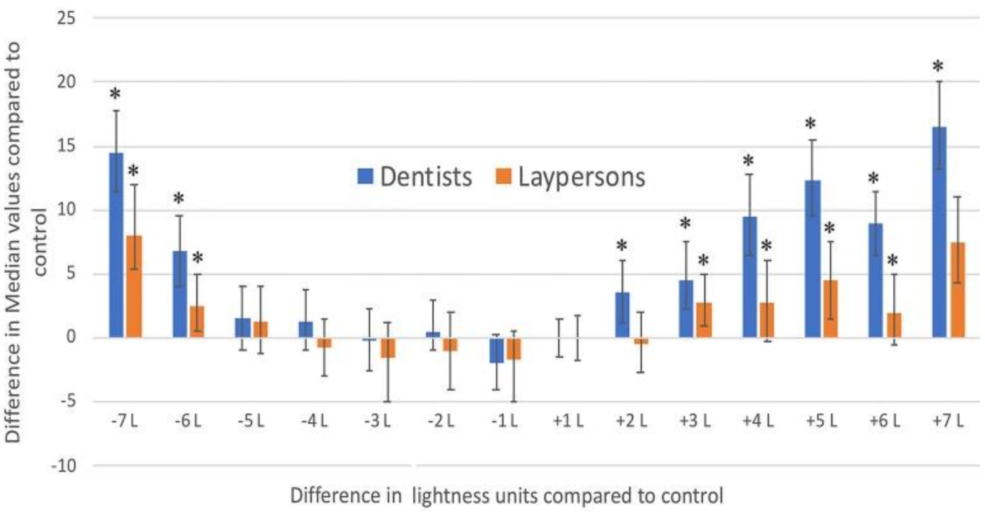

FIGURE 4 Difference in smile attractiveness score of altered images compared to control for the canine. The symbol * denotes significant difference from the control

compared to males (P = .007). Dentist's age did not significantly affect smile perception. Younger layperson perceived smiles with darker laterals as less attractive compared to older ones ($P < .05$).

Canine: The difference from the control for each evaluated ΔL difference in smile attractiveness score between the control and each altered image (each increment of ΔE) is presented in Figure 4, for both dentists and layperson. Regarding lightness difference derived from darker canine alteration, both dentists and layperson perceived smiles with ΔL≥6 as significantly less attractive compared to control smile ($P < .001$, $P = .019$). For lightness difference derived from lighter canine alteration, dentists and laypersons perceived full face smile of 2 ≤ ΔL ≥3, as significantly less attractive than control smile ($P = .002$, $P = .004$).

The correlation of attractiveness score for each anterior tooth to lightness difference is presented in Figure 5 for the dentists and in Figure 6 for the laypersons. The trendline follows a polynomial relation. The pattern of the trendlines is similar, with a more steep inclination in dentists' group. For the dentists group, and for the central incisor and canine, as lightness difference increases, VAS decreases. On the contrary, for the lateral incisor increase of the lightness' difference, increases VAS.

Dentists considered smile attractiveness significantly decreased when the lightness difference was lower than 6 units and originated from lighter, compared to darker tooth color alteration ($P < .01$). Laypersons did not perceive a difference in smile attractiveness when lightness difference derived from lighter compared to darker tooth

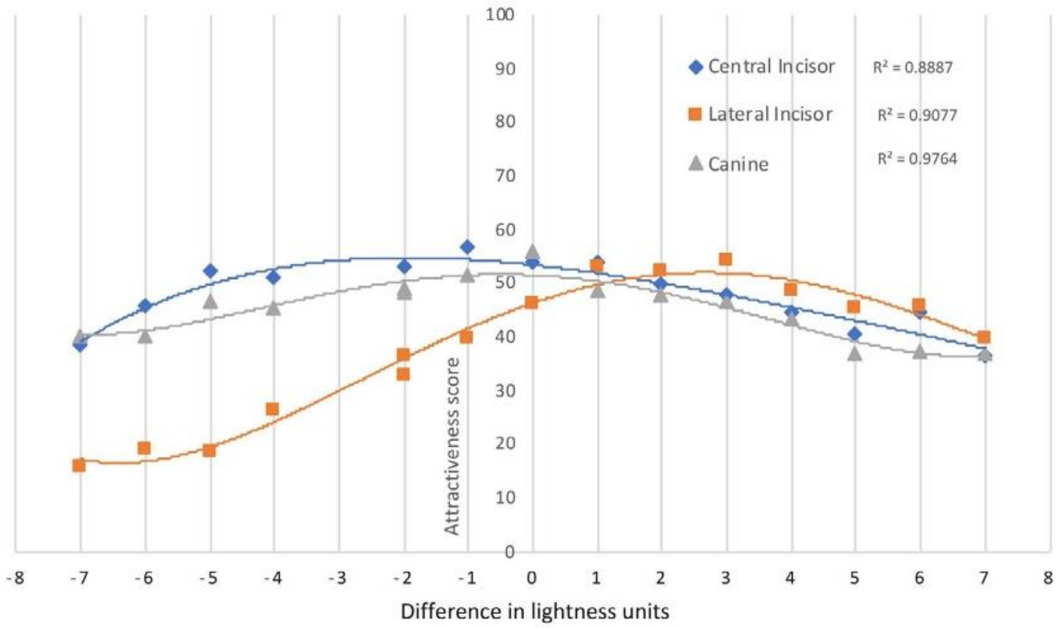

FIGURE 5 Attractiveness score based on Visual Analogue Scale (VAS) test correlated to difference in lightness units (dentists)

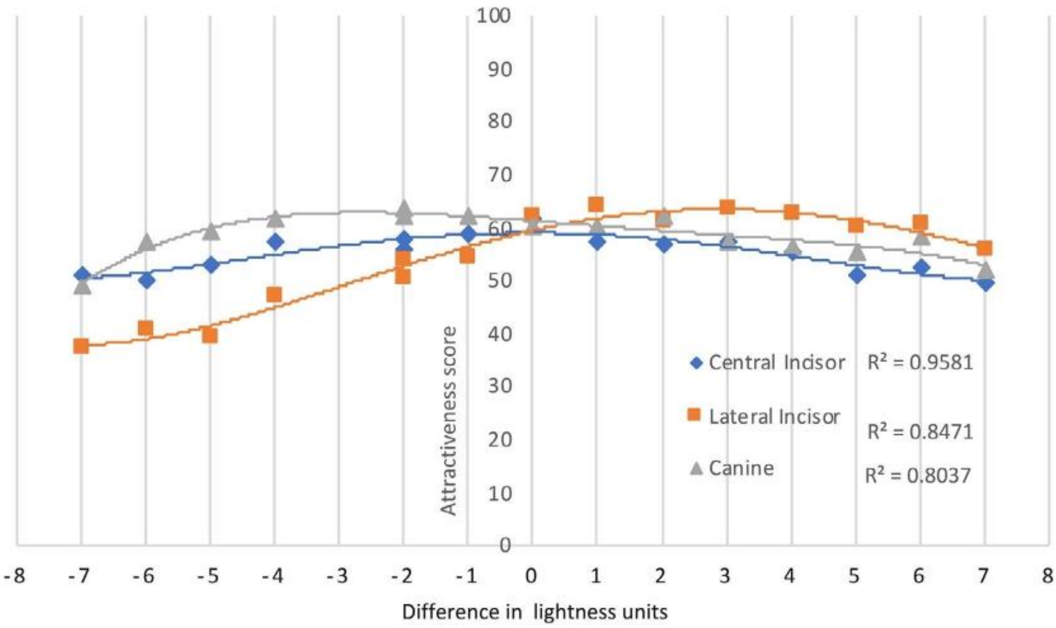

FIGURE 6 Attractiveness score based on Visual Analogue Scale (VAS) test correlated to difference in lightness units (laypersons)

shades and vice versa, for all ΔL steps. No difference was observed for both dentists and laypersons between males and females. Dentist's and laypersons' age significantly affected smile perception (P = .049, P = .034), with younger participants perceiving smiles with darker canines as less attractive compared to older ones.

5 | DISCUSSION

The results of the present study contribute to a better appreciation of the influence of lightness difference of a single anterior tooth on the overall facial attractiveness. Changes in the lightness of even one tooth seem to improve or worsen the overall facial attractiveness, as judged both by experienced dentists and layperson. The null hypotheses of the present study were all rejected because there was significant difference in perceived smile attractiveness for various lightness differences of a single maxillary central incisor, lateral incisor or canine, there was difference in perceived smile attractiveness irrespective of the direction of lightness difference (lighter vs darker), there was difference in perceived smile attractiveness between dentists and laypersons, between males and females and finally, between younger and older observers, for various lightness differences of maxillary anterior teeth.

In a previous study evaluating the color difference and its impact on smile esthetics of a maxillary lateral incisor, but in this study color modification was arbitrary.[20] In the present study, the influence of seven steps of increased and seven steps of decreased lightness, equally distributed, for maxillary central, lateral and canine, was examined. In that study,[20] a lighter single maxillary lateral incisor seemed to be judged in a more positive way, but did not improve participants' assessment. The darker alteration was hardly noticed. In general, tooth alteration did not influence overall facial attractiveness across participants.[20] On the contrary, the present study indicated that smile attractiveness is significantly influenced from lightness changes at a different degree and threshold level for central vs lateral vs canine.

Results about the lightness perceptibility/acceptability threshold have been previously published in literature.[22,23] Based on these studies, one could argue that smaller lightness difference should have been used and at a range of no more than 2–3 L units, since that exceeds the acceptability level. However, in these studies, results were obtained using very crude approximations to human dentition: two simulated teeth with their cervical portions embedded in a highly schematic depiction of reddish upper gingiva[22] and a digital image of teeth and a shade-guide tab cropped to reveal the oral cavity and gum area but excluding the lips.[23] Previous studies have shown that detection thresholds for luminance and color differences depend upon background luminance and hue.[24] Likewise, the perception of suprathreshold color differences depends on the structure of the viewing scene. A “crispening effect” has been reported when stimuli consisted of simple targets presented on uniform backgrounds.[25] However, in more complex, naturally occurring scenes, the relationship between surface color perception and background contrast is more complex.[26] These classic findings, along with a more recent study, underscore the potential usefulness of naturalistic simulations of clinically relevant stimuli in the study of dental color differences.[27] They used high-quality, image-processed, 2 real full-face portraits, presented on a calibrated computer color display, for the clinical assessment of color differences.[27] In that study one central incisor was digitally altered in 5 steps of 1ΔE units along the +L, +a, or + b directions of CIELAB color space. Since the color was altered in 3 dimensions it was not clear which color parameter (L vs a, vs b) affected more the results. Additionally, changes in the opposite direction (ie, -L meaning darker teeth) were not examined.

The kind of questions the observers are asked is very important. In a previous study participants were asked whether they perceive a difference in whiteness between the shade tab and the teeth.[23] In another study subjects were asked whether they perceive any color difference between the two teeth examined and were explicitly asked to judge acceptability on the basis of whether they would want a crown of a given color difference cemented in their mouth.[22] In the present study participants were asked to evaluate the attractiveness of the smile using a VAS questionnaire while they were looking at the face of the patient. The question did not imply that a change of tooth color was present. Our aim was to investigate whether an existing (and perhaps “easily” perceptible) lightness difference would influence the participants perceived smile attractiveness.

For all the aforementioned reasons we chose to investigate the influence of increased or decreased lightness over 1 unit in perceived smile attractiveness. Based on our results, it is evident that ΔL > 3 units was needed in some cases to have an effect in perceived smile attractiveness. More specifically, for lateral incisor, both dentists and laypersons did not perceive a difference in smile attractiveness, compared to control up to 6 ΔE units. Regarding color difference derived from darker canine alteration, both dentists and layperson perceived smiles with ΔE≥6 as significantly less attractive compared to control smile.

Especially for the central incisor, changes in lightness as small as 1 ΔL, affected smile attractiveness. For the lateral incisor, increase of lightness tooth was perceived less, compared to decrease. On the contrary, for the canine, darker tooth alterations were perceived as more preferable compared to lighter equivalents. This difference between the incisor and the canine can probably be explained by the fact that people, are used to darker canine shade compared to the incisors.[21] The focus on the smile goes first to the maxillary central incisors and then canines, whereas lateral incisors seem to have less visual weight.[14] Maybe this is the reason that a lighter lateral was perceived as less attractive than a darker one clearly shown on Figure 5. As we move away from the dental midline, the difference in the lightness of a single tooth color is less perceptible, because the distance from one tooth to its counterpart is increased and the visible proportion of the tooth is decreased, making the direct comparison more difficult.[28]

The clinical relevance of our results is applicable in everyday restorative and prosthetic dentistry. It will help dentists to make evidence-based decisions when they have to perform bleaching of single discolored tooth or a single anterior restoration on a natural tooth or an implant. When one of the centrals is restored, lightness matching should be accurate; otherwise it negatively affects smile attractiveness. On the other hand, there seems to be a higher tolerance for lightness mismatch when one lateral incisor is lighter or when a canine is darker than the other anterior teeth. What is really important to understand is that a lightness difference may be perceptible and not acceptable based on published values, but still the smile attractiveness might not be significantly different, therefore, may not warrant restorative intervention.

Perceived smile attractiveness scores and lightness differences exhibited high correlation values for each tooth type, for both dentists and laypersons. As lightness difference increased, VAS scores decreased. Future study will define the perceptibility and acceptability threshold for lightness differences for this type of experimental setup and will examine the relation to facial attractiveness.

Regarding the gender, in the laypersons' group, females were more influenced by the darker modifications of the central incisor and the lighter modifications of the lateral. However, there was no difference between males and females in the dentists' group. In a previous study, as tooth brightness decreased men were more critical in their ratings.[18] Another study has also shown that women tend to give higher scores of attractiveness than men do.[9] Labban et al[29] evaluated 48 images of smiles and found out that gender had an influence on the perception of tooth shades: women participants preferred lighter shades if compared to men participants. On the other hand, in another study,[17] gender did not affect significantly VAS values: lighter tooth shades were always preferred, irrespective of the sex of the participants (dentist and laypeople).

There are two different issues to be addressed here: whether there is a difference between men and women in the perception of color and whether there is a difference between men and women in the perception of smile/face attractiveness. Results from the literature are rather inconclusive: Regarding color perception, in one study, men showed borderline more uniform shade selection than women, even though the difference was small and only slightly significant.[30] In another study, females achieved significantly better shade matching results than males, indicating that gender plays an important role in shade matching,[31] whereas, in a third study, males tended to be more successful in discriminating the shades.[32] In other studies, however, no difference is observed between the genders in the perception of colors.[33,34] The perception of facial esthetics is a complex phenomenon influenced by biopsychosocial factors.[35] In the literature, the perception of facial esthetics was found to be related to the gender of the participants, but again, in an inconclusive way. More specifically, in one study women gave generally lower grades for the esthetics of every male and female profile than did men in the same social context of evaluation,[35] while in another study females were more tolerant of upper gingival exposure compared to men.[36] Similarly, when the observer was female, the odds ratio of perceiving positive values in perceived social appeal increased significantly.[17]

In the present study results indicated that for the dentists' group age did not significantly affect smile perception while for the laypeople group, younger participants perceived smiles with a darker tooth as less attractive compared to older ones. This suggests that as subjects grow older, they become more accepting of darker teeth or of teeth with lightness differences. This agrees with the findings of Sabherwal et al, where attractiveness ratings increased with the age of participants.[18] However, in the study of di Murro et al no statistically significant differences based on participants' age were found.[17] A possible explanation for these findings could be that older people may have been less critical in their ratings as they see changes in their own tooth color with age. This does not apply for the dentists' group, however, probably because knowledge, experience and education play an important role.

The perception of tooth color is subjective and many factors can influence it, as the type of illumination, the position of the object, the viewing angle, the surrounding environment and, of course, the chromatic perception of the observer.[18,37] In the current study the use of high quality, image processed full face portraits, presented in real dimensions, on a calibrated high definition display aimed to simulate as close as possible the real life circumstances and to standardize the way that each participant accessed the presented faces. The required color differences were achieved by modifications in lightness (L) only. The reason was that human eye is probably more sensitive to differences in lightness, compared to differences in saturation and hue. The present research design, aimed to bridge the gap between in vitro and in vivo, as color judgments are made in a more realistic manner that the in vitro studies.

A certain advantage of the current survey is the blinded nature of the participants and the randomization in order to eliminate bias. However, even if a standardized, experimental environment was rendered, an experimental setting for shade determination cannot totally simulate all real-life lighting situations, being a possible limitation of this study. Moreover, laypersons group included dental patients recruited from the waiting room of the dental school, that were probably more likely to be currently focused on the dental/smile appearance compared to the general population. To eliminate this bias larger sample from laypeople coming from different environments would need to be studied.

Another limitation of the present survey is problems arising from the process of answering the questionnaire, such as the alertness of the participants or their subconscious tendency to avoid answering something that may be unpleasant or impolite. The study did not attempt to measure the intra-rater reliability for the observers, as the experimental design did not include a retesting of the same judgments at different times. The reliability within dentists and laypeople over time should be evaluated in future studies.

Various rating methods have been used to assess esthetic preferences related with dentofacial structures and appearance, each with its own inherent advantages and disadvantages. The visual analog scale (VAS) has been used extensively to evaluate opinions regarding various aspects of dentofacial appearance.[38] The VAS has also been used to investigate facial esthetic preferences of alternate photographic views of the same subject.[17] A VAS is a convenient, simple, economical, and rapid method of obtaining value judgments.[39] However, it still exhibits weaknesses or limitations. Raters tend to spread their responses over the entire scale and avoid the ends at the anchor points, independently of the actual preferences.[40] Moreover, raters might be incapable of making equally discriminative judgments at each level of a scale.[41]

The present study showed that dentists and laypeople find faces less attractive due to the presence of a darker or lighter single anterior tooth. This is in accordance with the findings of a previous study that unsatisfactory tooth shade, especially of a single tooth, is a dominant factor in motivating patients for dental treatment.[42] Color research has extensively investigated perceptibility and acceptability color difference thresholds.[43] However, so far, in these studies the participants are prejudiced, because they were asked if they observe a color difference in a certain tooth and whether this difference is acceptable. In the present study, however, the question did not imply that a change of tooth color was present. Lindsey and Wee showed that when individuals are presented with the difficult task of judging small color differences, the demands of the task may bias them toward responding "yes, there is a color difference" or even "the match between crown and adjacent incisor is unacceptable," even when the two simulated "teeth" are colorimetrically identical.[22]

In the study of Lindsey and Wee,[27] the influence of tooth color difference on perceptibility and acceptability was investigated in realistic full-face male Caucasian and female African-American portraits. L* thresholds were found to be higher for the male Caucasian than for the female African-American face. It is possible that perceived smile attractiveness would also be affected by the type of the model. In our study the model was an independent variable, in order to evaluate the influence of change of tooth lightness on smile attractiveness, without other possible confounding factors. In future study the effect of the model gender, age, race and percent of tooth length that appears in the smile, on facial attractiveness, should be examined.

6 | CONCLUSIONS

In the tested conditions and within the limitations of the study, results of the present study clearly indicate that even minor changes in the lightness of a single anterior tooth can influence the perceived smile attractiveness, both for dentists and laypersons. Central incisors are the teeth that most profoundly affect smile esthetics; therefore accurate lightness matching of direct or indirect restoration is critical. There seems to be a higher tolerance for lightness mismatch when one lateral incisor is lighter than the other anterior teeth and the same applies when the canine is darker.

In the dentists' group age and gender did not significantly affect smile perception while for the laypeople, younger participants perceived smiles with a darker tooth as less attractive compared to older ones.

CONFLICT OF INTEREST

The authors do not have any financial interest in the companies whose materials are included in this article.

DATA AVAILABILITY STATEMENT

Research data not shared.

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