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Visual Complexity and Children's Art Engagement in Museum Settings: The Role of Audio Guidance

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Abstract

The present study examined whether visual complexity influences children's visual engagement with artworks, while assessing the moderating role of audio guidance. Visual complexity, a multifaceted aspect of perception and aesthetic appreciation, is often defined through various components, namely contrast, structural irregularity, and asymmetry. Additionally, audio guidance in museums serves as cognitive scaffolding, designed to direct attention and support affective responses. Using a mixed experimental design at the Kunstpalast Museum in Düsseldorf, 39 children (aged 5–13) viewed a curated selection of artworks while receiving either traditional audio guidance, a child-tailored audio guide (*Tonies*), or no guidance. Visual engagement was measured via eye-tracking metrics, including fixation count, saccade count, time to first fixation, and pupil dilation, and analyzed using Linear Mixed Models, to detect interactions between visual complexity and audio guidance. Results indicated that higher visual complexity, particularly RMS contrast (lightness and color variability) and 2D fractal dimension (structural complexity), increased visual engagement and exploratory patterns, whereas symmetric artworks elicited more focused but less active exploration. Although audio guidance generally sustained engagement, *Tonies* presented no significant advantage over the classic narrative-driven guides. These findings have practical implications for museum curators, informing child-friendly exhibition designs that manage cognitive load, while contributing to the empirical aesthetics literature by extending complexity research beyond artificial stimuli to real artworks and child populations.

Keywords: visual complexity, children, visual engagement, eye-tracking, museums

Lay Abstract

This study explored how the visual complexity of artworks influences the way children look at them, and whether audio guides can change this experience. Visual complexity refers to how detailed a picture appears, including elements such as changes in lightness, color, irregularity, and asymmetry, which all shape an image's final composition. To investigate this, 39 children aged 5 to 13 who were at the Kunstpalast Museum in Düsseldorf participated in the study. After being split into three groups, each group viewed the same three paintings either with a traditional museum audio guide, a child-friendly storytelling guide called *Tonies*, or no guide at all. While looking at the paintings, the children wore eye-tracking glasses, a device that measures visual engagement and attention, by analyzing where and for how long someone looks at specific points, how their eyes move, and how their pupils react. The results showed that artworks with higher visual complexity, in terms of lightness, color, and structure, made children look longer and explore more actively, while symmetric artworks led to less exploratory viewing. Both the traditional and *Tonies* guides helped maintain engagement, but the *Tonies* guide, although designed for children, was not more effective than the traditional one. These findings may help museums design more engaging experiences for young visitors by creating a balance between complexity and guidance, therefore supporting curiosity and art appreciation.

Introduction

Aesthetics and The Museum Experience

Aesthetics, derived from the Greek word *αισθητά*, refer to anything perceived by the senses (OED, 2009), and are co-determined by perception, emotion, and cognition (Chatterjee & Vartanian, 2014; Hekkert, 2006). According to Gibson's *Ecological Theory of Perception* (1979), action is perceived as the primary goal of perception, as individuals use their vision to explore visual arrays, dynamic environments full of visual information that afford potential actions. In that sense, art and museum spaces provide opportunities for aesthetic experiences and evaluations of the visual properties of artworks, which may or may not lead to affective enjoyment and intellectual satisfaction (Birkin, 2010; Rogers, 2012).

Aesthetic judgments represent the optimal cognitive aspect of our relationship with art, and it may be influenced by cultural or social norms, as well as personal and emotional responses (Chatterjee & Vartanian, 2014; Di Dio & Gallesse, 2009). As articulated in George Dickie's *Working Model of the Aesthetic* (Dickie, 1974), the aesthetic experience is shaped by the dynamics within the artworld, a triadic relationship consisting of the artist, the artwork, and the audience. In other words, the audience deciphers and interprets an artwork's perceptual properties, thereby influencing both art making and the creative act itself (Duchamp, 1957).

Art viewing is a multifaceted experience which involves a variety of cognitive processes (Bailey-Ross et al., 2019), while art museums function as informal educational institutions that provide valuable learning opportunities. For children especially, early exposure to art may support cognitive abilities, emotional growth and self-expression (Eisner, 2002; Heilig et al., 2010), while promoting joy and curiosity (Leder et al., 2006). Research shows that children themselves perceive museums as exciting and engaging spaces (Piscitelli & Anderson, 2001), where they can actively explore visual stimuli and develop perceptual and critical abilities (Tišliar, 2017; Walker et al., 2024). In fact, Gammon (2003) emphasizes that informal learning in museums, typically emerging through spontaneous interactions with exhibits, people and new ideas, facilitates both knowledge acquisition and emotional engagement. Additionally, museums may also function as restorative spaces that support children's psychological recovery (Annechini et al., 2020), especially when considering art therapy's impact on self-expression and anxiety reduction (Wei & Zhong, 2022). However, in order for museums to fulfill their potential, careful consideration must be given to how artworks are presented, labeled, and explained, especially for non-expert and younger visitors (Castellotti et al., 2023).

Despite the numerous opportunities that museums provide, researchers have identified several barriers to learning in such contexts. For instance, Gammon (2003) states that information complexity may impair both information processing and knowledge acquisition, especially when museum exhibits are too advanced for the intended audience or not adequately explained. Additionally, poorly designed and arranged spaces or disengaging presentation methods have been found to influence visitor engagement and art appreciation (Reitstätter et al., 2022). Despite the growing understanding of these factors, many empirical studies continue to focus on adult participants in controlled laboratory settings (e.g., Ales et al., 2020) leaving a notable gap in our understanding of how children engage with art in real-world museum environments. To help address the need for better assessment tools in this area, Schindler et al. (2017) developed the Aesthetic Emotions Scale (AESTHEMOS). While the questionnaire was originally designed to measure a wide range of aesthetic and epistemic emotions in adults, its comprehensive nature and applicability to museum settings make it a valuable starting point for future research into children's aesthetic experiences, provided it is adapted and validated for younger audiences.

Visual Complexity

Visual complexity is a multidimensional concept related to the visual properties of an object as perceived by the human vision (Gartus & Leder, 2017; Snodgrass & Vanderwart, 1980). Originally, it has been associated with visual clutter (Rosenholtz et al., 2007), referring to the number of elements and details in an image (Snodgrass & Vanderwart, 1980; Van Geert & Wagemans, 2020), their organization, heterogeneity, asymmetry, and unpredictability (Berlyne, 1966; Gartus & Leder, 2017; Nadal et al., 2010). Beyond its structural characteristics, recent eye-tracking research suggests that visual complexity may influence perceptual behavior, as it has been shown to automatically trigger visual curiosity and increase exploratory eye movements (Sun & Firestone, 2021).

Complex visual stimuli of aesthetic value consist of inter-related visual elements and patterns that form a whole (Birkin, 2010). These complex patterns have been shown to affect visual attention (Sun & Firestone, 2021), with viewers tending to stare longer on complex objects, even when complexity is task irrelevant. Berlyne (1971) related visual complexity to arousal levels, supporting later arguments that complexity influences art perception and appreciation (Birkin, 2010; Nadal et al., 2010), as well as aesthetic preferences (Forsythe et al., 2011).

Gestalt psychology pioneered research on perceptual simplicity and complexity, by analyzing the organization of the whole form (Koffka, 1922). Since Gestalt means "complete form" in German, Arnheim (1974) states that unified shapes and figures are perceived by grouping discrete visual elements within hierarchical visual levels. One of the central gestaltic principles is the Law of Prägnanz (Wertheimer, 1923), which was later renamed by Hochberg (1957) as the Principle of Simplicity or Maximum Homogeneity. According to Donderi (2006), the concept of “good form” remains one of the most prominent contributions of Gestalt psychology to modern perceptual research, where "good" principally refers to forms that are simple, regular, symmetrical, and well-organized (Koffka, 1935).

Van Geert and Wagemans (2020) classified complexity into two subcategories. Subjective (or psychological) complexity is related to individual aesthetic evaluations, and it is affected by structural factors such as visual detail and clutter, organization and dissimilarity (Berlyne, 1960; Berlyne et al., 1968; Nadal et al., 2010). Furthermore, it is mainly shaped by prior exposure, meaning that unpredictable and complex artworks become easier to process through repeated encounters (Gaver & Mandler, 1987). On the other hand, objective complexity refers to quantified properties of a stimulus, assessed through computational methods such as statistical analysis, image compression, and edge detection algorithms. Common objective measures of complexity include self-similarity, anisotropy, fractal dimension, entropy, and image size after compression.

Emphasizing the role of the brain’s reward systems, Berlyne formulated his well-known inverted U-shaped hypothesis (Berlyne, 1971), stating that preference and interest increase linearly with visual complexity up to a certain threshold. Aesthetic appreciation, therefore, tends to peak at moderate levels of complexity, meaning that overly simple stimuli may be perceived as dull, while highly complex ones may be seen as overwhelming or unpleasant. However, empirical studies on this hypothesis have produced differentiating results: while some support the inverted U-shaped hypothesis (e.g., Gordon & Gridley, 2013; Imamoglu, 2000), others report a linear increase in preference with complexity (Adkins & Norman, 2016; Friedenberg & Liby, 2016).

Components of Visual Complexity

One of visual complexity’s main components is fractal dimension, which calculates the fractal properties of a stimulus. Fractals are geometric self-similar repeating patterns that are reduced-scaled copies of the whole (Hagerhall et al., 2004; Mandelbrot, 1977). When magnified, a fractal reveals the same pattern repeated at smaller scales, rather than new visual information (Birkin, 2010). Observing fractals has been shown to influence neural responses, especially in the frontal and parietal lobes, suggesting greater cognitive engagement (Hagerhall et al., 2008). It has also been proposed that artists might intentionally employ fractal structures to enhance visual interest. For example, Jackson Pollock’s paintings exhibited a progressive increase in fractal dimension over a ten-year period (Taylor et al., 1999).

Unpredictability and order are closely related components of visual complexity, often understood through the lens of information theory (Shannon, 1948). Unpredictability refers to the degree of irregularity or randomness in an image, while order represents the structured arrangement of visual elements such as repetition, alignment and symmetry (Berlyne et al., 1968; Nadal et al., 2010). According to Shannon’s information theory, regular and repeated patterns are highly predictable and therefore contain redundant information that can be compressed or simplified.

Symmetry, in particular, is believed to be inherently preferred by the human visual system over asymmetry (Van Geert & Wagemans, 2020), and it is typically associated with high regularity and balance (Wilson & Chatterjee, 2005). More specifically, mirror symmetry is quantified as the mean of symmetry scores calculated around various axes (Hübner & Fillinger, 2016).

Another important component of visual complexity is edge density. It refers to the ratio between the number of pixels and the extracted edges within a stimulus (Guo et al., 2013). Edge density has been strongly correlated with subjective ratings of complexity, with more edges generally perceived as more complex (Forsythe et al., 2003). Furthermore, entropy refers to the degree of variation, randomness, or unpredictability in pixel values or structural patterns, with higher entropy corresponding to greater complexity (De Winter et al., 2022; Marin & Leder, 2013).

Lastly, color has also been linked to perceived complexity. According to Guo et al. (2013), color entropy refers to the variation in hue, saturation, color and brightness across different image regions (Nagy & Sanchez, 1992). Similarly, Root Mean Square (RMS) contrast is a measure of local luminance variations, defined as the standard deviation of the L channel within the L*a*b color space (Peli, 1990). However, findings on color as a complexity factor seem to contradict. While some studies suggest that it increases perceived complexity by adding more elements (Massaro et al., 2012; Zellner et al., 2010), others have found no significant correlation between the two (Ciocca et al., 2015; Gartus & Leder, 2017).

Measuring Visual Complexity

Measuring visual complexity is an intricate task, as perception is influenced not only by stimulus properties, but also by prior knowledge, context, and top-down cognitive processes (Berlyne, 1974; Machado et al., 2015). The need for valid objective measures of visual complexity that are not affected by familiarity (Nadal et al., 2010) has led to the emergence of computational approaches that align more with subjective judgements.

One of the most influential mathematical approaches on visual complexity is Algorithmic Information Theory (AIT), also known as Kolmogorov Complexity (Solomonoff, 1964; Kolmogorov, 1968). Taking into account irregularity and heterogeneity (Birkhoff, 1932; Eysenck, 1941), AIT defines complexity as the length of the shortest algorithm required to reproduce a data pattern, suggesting that homogeneous stimuli with repetitive elements and limited variability are highly compressible and can be described using shorter algorithms (Donderi, 2006; Forsythe, 2009). Applying AIT in aesthetics research, Forsythe et al. (2011) found that image compression techniques (e.g., JPEG and GIF) significantly correlate with subjective judgements of complexity, with GIF compression showing the strongest correlation with human ratings.

Other approaches to visual complexity include fuzzy inference systems, that are based on widely cited image properties such as contrast, homogeneity, symmetry edge density, compression ratio, and colorfulness (Cardaci et al., 2009; Madrid-Herrera et al., 2019). Additionally, Guo et al. (2013) formulated a machine learning framework to algorithmically predict visual complexity in paintings, reaching an accuracy of 88.13%, a result closely correlated to human ratings.

To address the challenge of conflicting results on visual complexity that are due to dissimilar metrics and analytical methods among researchers, Redies et al. (2025) developed the Aesthetics Toolbox, a computational framework designed to standardize and quantify image properties widely used in aesthetics research. It calculates a wide variety of image properties including entropy, edge density, fractal dimension, color variation metrics, and symmetry. By integrating methods from multiple research groups and implementing original code for each metric, the toolbox ensures consistency, comparability and replicability across studies.

Measuring Visual Engagement

Eye-tracking is a widely used psychophysiological technique, which quantifies visual engagement by recording eye movements, gaze location and pupil dilation (Carter & Luke, 2020). Two of the most prominent eye movements usually studied are fixations and saccades, which seem to mainly affect visual information intake. More specifically, fixations are brief ocular pauses, typically lasting 200-400ms, during which the eye remains relatively stable, in order to process visual information (Rayner, 2009). The duration and frequency of these pauses are indicative of the cognitive effort required to process the visual content. On the other hand, saccades are rapid eye movements (20-60ms) that shift the gaze from one fixation point to the next (Rayner, 2009). Visual perception is suppressed during saccades to maintain perceptual stability. By measuring these parameters, eye-tracking provides valuable insights into an individual's visual engagement and the allocation of their cognitive resources.

Visual Complexity and Museum Engagement

While museum research often prioritizes contextual variables and interactive or digital tools (e.g. De Winter et al., 2022; Reitstätter et al., 2022), the role of artworks' visual properties in shaping engagement remains underexplored, despite their cognitive and developmental significance.

Engaging young audiences with visual art, particularly when artworks are visually complex, remains a challenge (Mallos, 2017). From a neuropsychological standpoint, children's visual perception differs fundamentally from that of adults, due to continuous development of perception and attention-related brain regions (Morozova et al., 2008). Visual systems seem to develop at different rates (Farber & Beteleva, 2005), with important changes occurring between the ages of five and seven (Bezrukikh et al., 2009). Supplementarily, research on visual perceptual learning (VPL) has shown that, compared to adults, children present improved performance when task-irrelevant visual properties are present, possibly due to their underdeveloped selective attention and their sensitivity to visually complex elements (Frank et al., 2021). In a museum context, this suggests that children may not be entirely distracted by detail, but rather intrigued by it. This makes children a valuable age group for studying how visual complexity affects gaze engagement in museum settings.

In an attempt to create engaging experiences, museums often deploy various forms of mediation such as explanatory labels, audio guides, or interactive audio tools. These interpretive tools usually affect points of interest, interpretations and personal reflections on artworks, by challenging traditional transmitter-receiver models of learning and attempting a more constructive learning process (Reitstätter et al., 2022). For example, labels and painting descriptions in museums have been found to influence and direct gaze patterns toward areas that might otherwise be overlooked (Bailey-Ross et al., 2019; Walker et al., 2017, 2024). Additionally, audio guides provide brief segments of information related to key exhibits and points of interest, and have been shown to positively influence visitor engagement and aesthetic experiences (Aoki et al., 2002; Vallez et al., 2020). However, labels are often found to be adult-centered (Walker et al., 2017), while audio guides usually require manual activation, which might interfere with attention and disrupt the museum experience (Wacker et al., 2016).

Along with traditional audio guides, interactive tools have also become part of museum learning, since interactivity has been found to support deeper engagement, memorability and more active conversations (Hsu et al., 2006; Tenenbaum et al., 2010). For instance, the *Toniebox* is an interactive audio storytelling system, originally developed to provide children with a screen-free, engaging alternative to digital entertainment and learning (Tonies, n.d.; den Otter, 2024). More specifically, the device includes a speaker and small, character-shaped figures (*Tonies*), which activate specific audio tracks. In museum contexts, *Tonies* have been adapted to deliver explanatory and educational content, with the Kunstpalast in Düsseldorf being one of the first museums to incorporate them in an exhibition setting, using them to accompany their Rhino Tour for kids (Kunstpalast, 2024).

The Present Study

This research addresses a significant gap in the literature by examining how varying levels of visual complexity in artworks may influence children’s engagement and whether different types of audio guidance (standard vs. tailored for children) may sustain engagement when complexity is high. Existing findings are inconclusive: while some studies suggest that high complexity reduces preference (Birkin, 2010; Van Geert & Wagemans, 2020), others indicate that moderate complexity may increase interest and engagement (Berlyne, 1971; Birkin, 2010).

Building on these mixed findings, the present study tests two hypotheses in a real museum setting, using three artworks that vary in artistic style and visual complexity. Hypothesis 1 predicts that higher visual complexity will reduce engagement, indicated by fewer fixations and saccades. Moreover, Hypothesis 2 predicts that audio guidance will moderate this effect, with children receiving guidance remaining more engaged with complex artworks compared to those in the control group.

This research is expected to provide insights that are both practically relevant and scientifically significant, contributing to how we understand and support children’s engagement with art.

Methods

Participants

Forty-five children (age range = 5–13, M = 9, SD = 1.90; 17 female, 26 male, 2 no gender data) participated in the study. This specific age range is chosen, due to children’s ongoing development of visual perception and attention systems (Morozova et al., 2008), which makes them more sensitive to complex visual details and less selective in filtering information, compared to adults (Frank et al., 2021).

Participants were recruited on site at the Kunstpalast Museum in Düsseldorf, Germany, and were randomly assigned to one of the three following conditions: [1] no audio guide (16 participants), [2] traditional audio guide (15 participants), or [3] *Tonies* audio guide (14 participants). All children were accompanied by at least one parent or guardian, who provided written informed consent prior to participation. The study was approved by the Psychology Research Ethics Committee (PREC) of Leiden University on March 13, 2025 (Ref. No: 2025-03-03-Z.P.Pilz-V2-5912).

Six participants were excluded from the analysis due to poor or missing eye-tracking data (gaze sample below acceptable thresholds or calibration issues), resulting in a final sample of 39 valid recordings.

Materials and Stimuli

Artworks

Three paintings from the Kunstpalast collection were selected for this study: *Murnau* (Wassily Kandinsky, 1909), *Carnival* (Max Beckmann, 1925), and *Blue and Pink Pigeons* (Max Ernst, 1926) (see Figures 1–3). The selection was based on three main criteria: (1) variation in visual complexity and artistic style, to enable systematic comparison and broader interpretation, (2) the availability of both traditional and *Tonies* audio guides for all paintings, (3) the physical proximity of the artworks within the gallery, ensuring children could view them sequentially without excessive walking. All paintings were presented in their natural museum context, supporting an ecologically valid data collection process.

Figure 1

Artworks

Note: Artworks in the following order: *Murnau* (Wassily Kandinsky, 1909), *Carnival* (Max Beckmann, 1925), *Blue and Pink Pigeons* (Max Ernst, 1926).

Audio Guidance

Participants in the two guided conditions heard brief audio descriptions of each artwork. The traditional audio guide provided standard museum narration and lasted about ninety seconds per artwork. The *Tonies* guides, designed specifically for children, used child-friendly language, storytelling, and interactive prompts, and lasted approximately three minutes per artwork. This condition involved two interactive elements: children used a small map to locate each painting, and the audio was activated by placing a small figure on the playback box. The control group received no audio guidance.

Eye-Tracking Equipment

The Tobii Pro Controller App was pre-installed on the researchers' devices to enable data recording. Gaze data were collected with Tobii Pro Glasses 3, sampled at 100 Hz with an accuracy of 0.6° (Tobii AB, 2025). Each child underwent a one-point calibration to ensure precise gaze mapping. Data collection took place directly inside the museum, without modifications to lighting, layout, or visitor flow.

AESTHEMOS Questionnaire

Following the eye-tracking session, participants completed a shortened, age-adapted German version of the AESTHEMOS Questionnaire (Schindler et al., 2017). The children's version, created by Ines Schindler, is a new adaptation with illustrations to make the questions easier to understand, and was kindly provided to us for this study, as it has not yet been officially published. This questionnaire measured children's overall aesthetic experience of interacting with the three paintings, focusing on curiosity, interest levels, attention, comprehension, and enjoyment. Items were rated on a four-point Likert scale (1 = not at all, 2 = a little, 3 = moderately, 4 = strongly).

Responses were documented on paper forms, which included participant ID, age, gender, and assigned audio condition (none, traditional audio guide, *Tonies*), as well as whether the child had previously visited the museum. At the end of the short interview, when asked what struck them about the paintings, children were also prompted to indicate their favorite artwork and share any additional comments. These responses were noted on the same forms.

For the data analysis, questions were coded as Q01-Q21. Detailed mapping of these codes to their full wording is provided in Appendix B.

The *AESTHETICS* Toolbox

The visual complexity of each artwork was quantified using the Aesthetics Toolbox (Redies et al., 2025), an open-source Python tool that integrates scripts from four research groups to calculate commonly studied Quantitative Image Properties (QIPs).

The QIP Machine of the Aesthetics Toolbox does not extract a single complexity score, but rather calculates numerous image properties that have been proven to influence visual engagement. To avoid redundancy or low relevance to our research questions, the initial set of properties used in our analysis included: RMS Contrast, Lightness Entropy, Edge Density, Color Entropy, Mirror Symmetry, CNN Symmetry, Balance, 2D Fractal Dimension, Self Similarity (CNN), Homogeneity and Anisotropy. These computerized measures of complexity are widely preferred in similar research, since they reduce subjective bias and allow direct comparison with prior empirical aesthetics research (Redies et al., 2025).

Study Design

The study used a mixed-methods quasi-experimental design. Audio guidance (none, traditional, *Tonies*) was manipulated between subjects, while all participants viewed the same three artworks (within subjects). Engagement was measured through the following eye-tracking metrics: number of fixations, time to first fixation, number of saccades, and average pupil dilation.

The visual complexity metrics from the Aesthetics Toolbox were correlated with these metrics to test whether visual complexity of artworks influences engagement in young children, and if audio guidance moderates this relationship.

Procedure

The experiment took place on May 1–5, 2025, at the Kunstpalast Museum in Düsseldorf. Children were recruited onsite, always accompanied by an adult, and participated only after formal written consent had been obtained. In addition, one school class was pre-recruited, with parental consent forms collected in advance by the teacher and provided to the researchers.

Participants were randomly assigned to one of three conditions: (1) no audio guidance, (2) traditional audio guide, and (3) *Tonies* audio guide. For those in the audio conditions, recordings were played immediately upon arriving at each painting. Data collection lasted approximately twenty five minutes per participant.

The viewing order of the paintings was counterbalanced. After viewing all three artworks, the AESTHEMOS questionnaire was administered, with assistance from the researcher.

Eye-Tracking Data Processing

Recordings were imported to Tobii Pro Lab V. 25.7 (Tobii AB, April 2025). Participant IDs and recording titles were renamed to match the questionnaire forms.

Data quality was assessed using Tobii Pro Lab’s gaze sample index. A gaze sample is a single data point that represents the measured gaze position of the participant’s eyes at a specific point in time. They are a key indicator of whether a recording should be included in the analysis: Perfect = 95+%, Good = 70-95%, Questionable = <70%. Low gaze data may indicate severe data loss, calibration issues, and unreliable metrics. For the above reason, six recordings below 70% gaze sample index were excluded from the analysis: P06 (0%), P08 (11%), P12 (0%), P16 (calibration issues, heard audio guide twice, 40% and 10% in both recordings), P29 (44%), and P34 (no eye-tracking data).

Gaze data were then mapped to high-resolution images of the artworks. Areas of Interest (AOIs) were defined for each painting to separate gaze directed at the artwork itself from gaze directed at frames or surrounding distractions. Automatic AOI mapping was conducted using a similarity threshold of 50, followed by manual review and correction to ensure accuracy. The Tobii Attention Filter was applied to the eye-tracking data.

Due to the three conditions differing in average duration, data normalization was conducted to account for individual trial length, by dividing the total number of fixations and saccades by the exact exposure time (in seconds). Fixations and saccades are therefore measured per second, providing a duration-independent index of visual engagement, while time-based measures (time to first fixation and pupil dilation) were not normalized.

Statistical Analysis

The statistical analysis was conducted in JASP V. 0.95.0 (JASP Stats, 2025). A Linear Mixed Model (LMM) was selected to analyze the eye-tracking data, as it provides an appropriate framework for the study’s combined between and within subjects design.

The fixed effects included experimental condition (audio guidance), artwork, visual complexity scores, and the interaction between the condition and each visual complexity metric. Random effects for participants and artworks were also included to account for repeated measures within individuals and across stimuli. Significance of fixed effects was assessed with the Satterthwaite formula of degrees of freedom, as this method provides more accurate inference in models with complex structures. Effects were considered significant at $p < .05$, and parameter estimates are reported with 95% confidence intervals.

Results

Correlation of Visual Complexity Metrics

A Pearson's correlation matrix was initially created to assess potential multicollinearity among the nine visual complexity metrics. The analysis revealed several strong correlations, indicating significant overlap among variables. RMS contrast was nearly perfectly correlated with edge density ($r = .999$, $p < .001$), balance ($r = .988$, $p < .001$), self-similarity ($r = .987$, $p < .001$), and lightness entropy ($r = .996$, $p < .001$). Similarly, 2D fractal dimension was perfectly correlated with homogeneity ($r = 1$, $p < .001$) and highly correlated with anisotropy ($r = .982$, $p < .001$) and color entropy ($r = .965$, $p < .001$).

To address multicollinearity, three metrics were selected for the final analysis, based on both the correlation matrix and their theoretical relevance: RMS contrast, 2D fractal dimension, and mirror symmetry. According to Redies et al. (2025), each of these metrics is measured on a different scale and represents a distinct aspect of visual complexity. RMS contrast, defined as the standard deviation of pixel intensity, captures lightness and color variance. Moreover, 2D fractal dimension, ranging from 1 to 2, is calculated from a binary image and reflects scale invariance and self-similarity. Finally, mirror symmetry represents the percentage of balance and symmetry in an image. The detailed correlation matrix is provided in Appendix A (Table A1).

Visual Complexity Scores

The visual complexity scores for each artwork are summarized in Table 1. *Carnival* exhibited the highest RMS contrast (24.38), indicating strong luminance variation and visual saliency. On the other hand, *Murnau* (18.02) and *Pigeons* (19.47) showed lower levels of contrast. In terms of mirror symmetry, both *Carnival* (49.14%) and *Murnau* (47.34%) were highly symmetric, while *Pigeons* demonstrated substantially lower symmetry (21.80%). Finally, *Pigeons* had the highest 2D fractal dimension score (1.644), indicating stronger structural complexity and irregularity, followed by *Carnival* (1.551) and *Murnau* (1.417).

Table 1

Complexity Metrics for Murnau, Carnival, and Pigeons

Artwork	RMS Contrast	2D Fractal Dimension	Mirror Symmetry (%)
Murnau	18.02	1.417	47.34
Carnival	24.38	1.551	49.14
Pigeons	19.47	1.644	21.80

General Engagement Trends

Table 2 provides an overview of gaze engagement across the three artworks and audio guidance conditions. Overall, fixation and saccade rates (per second) were relatively similar between the Audio and Tonies conditions, while they both exceeded the Free condition. This suggests that audio guidance increased visual engagement compared to free viewing, although differences between the two guided conditions were less pronounced.

Table 2

Mean Visual Engagement Scores, Across Artworks and Conditions

	Cond.	**Artwork**	**Mean**		**Cond.**	**Artwork**	**Mean**
Fixations	Free	*Murnau*	1.77	**First Fix.**	Free	*Murnau*	0.06
		Carnival	1.75			*Carnival*	0.08
		Pigeons	1.43			*Pigeons*	0.02
	Audio	*Murnau*	1.55		Audio	*Murnau*	0.63
		Carnival	2.01			*Carnival*	0.07
		Pigeons	1.54			*Pigeons*	0.06
	Tonies	*Murnau*	1.78		Tonies	*Murnau*	0.01
		Carnival	1.93			*Carnival*	0.14
		Pigeons	1.39			*Pigeons*	0.06
Saccades	Free	*Murnau*	0.71	**Pup. Dil.**	Free	*Murnau*	5.30
		Carnival	0.97			*Carnival*	4.25
		Pigeons	0.66			*Pigeons*	4.60
	Audio	*Murnau*	0.64		Audio	*Murnau*	5.52
		Carnival	1.29			*Carnival*	4.49
		Pigeons	0.73			*Pigeons*	4.61
	Tonies	*Murnau*	0.63		Tonies	*Murnau*	5.37
		Carnival	0.93			*Carnival*	4.90
		Pigeons	0.53			*Pigeons*	4.95

Notes: Fixation and saccade values are normalized and shown per second. Time to first fixation is calculated in seconds.

Fixation rates varied moderately across conditions. For *Carnival*, participants in the Audio condition showed the highest rate (M = 2.01 fixations/sec), followed closely by *Tonies* (M = 1.93) and Free (M = 1.75). A similar pattern was observed for *Murnau* (Tonies: M = 1.78; Free: M = 1.77; Audio: M = 1.55). Regarding *Blue and Pink Pigeons*, fixation rates were lower overall, with Free (M = 1.43) and Audio (M = 1.54) slightly higher than *Tonies* (M = 1.39). These results indicate that both Audio and *Tonies* conditions led to similar levels of visual engagement, with neither type of audio guidance showing a significant advantage.

Time to first fixation also showed small differences across conditions. For *Carnival*, the *Tonies* condition yielded a slightly higher mean of 0.14 seconds, compared to 0.07 seconds in the Audio condition and 0.08 seconds in the Free condition. For *Murnau* and *Pigeons*, means were close to zero, indicating that many participants fixated on the artworks almost immediately. This suggests that time to first fixation was relatively insensitive to the experimental manipulation.

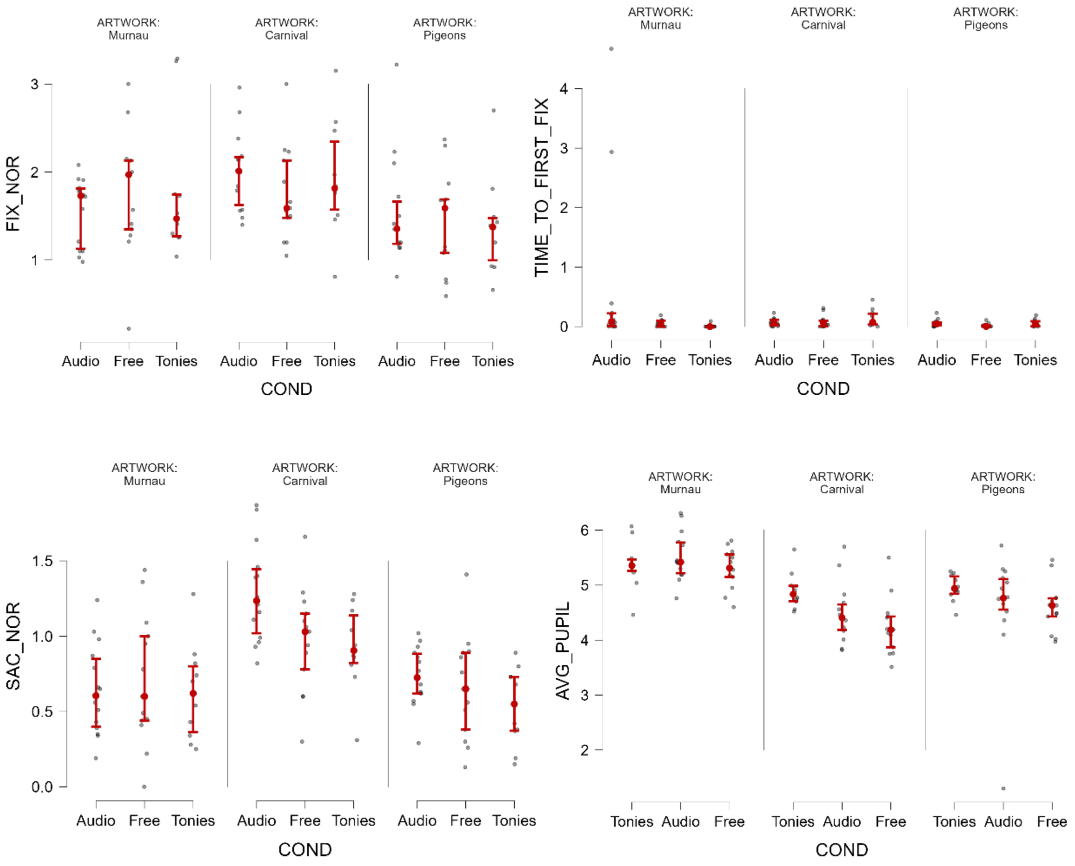
Saccade rates revealed a similar pattern to fixations. For *Carnival*, participants in the Audio condition had the highest rate (M = 1.29), compared to Free (M = 0.97) and *Tonies* (M = 0.93). For *Murnau*, the Free condition produced slightly more saccades (M = 0.71) than Audio (M = 0.64) and *Tonies* (M = 0.63). For *Pigeons*, rates were generally the lowest, with Audio (M = 0.73) exceeding both Free (M = 0.71) and *Tonies* (M = 0.53). Together, these findings suggest that the Audio condition led to more visual exploration than *Tonies* and, in some cases, Free viewing (*Carnival*), though this effect was not consistent for *Murnau*.

Lastly, pupil dilation also varied moderately across conditions. *Tonies* consistently had the highest mean values (*Murnau*: 5.37, *Carnival*: 4.90, *Pigeons*: 4.95), however Audio yielded similar or even higher averages (*Murnau*: 5.52, *Carnival*: 4.49, *Pigeons*, 4.61). Free viewing, in turn, produced slightly lower values, especially for *Carnival* (M = 4.25). These results indicate that pupil dilation may reflect a general arousal effect under guided listening, but with minor differences between viewing conditions.

The following plots visually support these findings. Fixation and saccade plots show that guided conditions generally increased engagement relative to Free viewing, with Audio yielding higher values. Pupil dilation plots indicate higher arousal for both guided conditions compared to Free, while time to first fixation showed minimal variability across conditions.

Figure 2

Visual Engagement Across Artworks and Conditions



The Effects of Visual Complexity and Audio Guidance on Engagement

Fixations counts were significantly influenced by the visual properties of the artworks. Across models, RMS contrast (F(1, 70.04) = 17.27, p < .001), 2D fractal dimension (F(1, 66.28) = 26.49, p < .001), and mirror symmetry (F(1, 69.62) = 18.02, p < .001) were all associated with differences in fixation counts. In addition, a main effect of artwork was observed (F(1, 70.04) = 8.65, p = .004), indicating that baseline fixation rates depend on the painting’s properties. Analyses of fixation rates revealed neither a significant main effect for condition (F(2,63.93) = 1.33, p = .272) nor for any interaction between condition and the complexity metrics, indicating that the influence of visual features on fixations was consistent across experimental groups.

Overall, these results indicate that RMS contrast, fractal dimension, and mirror symmetry were associated with changes in fixation rates. Trial-level effects were small, indicating that these differences mainly reflected systematic variation between artworks rather than changes within experimental conditions.

Time to first fixation was less sensitive to visual properties and guidance. The only significant effect was for artwork identity in general (F(1, 68.73) = 4.59, p = .036), with some artworks eliciting slightly longer latencies before the first fixation. Audio guidance, RMS contrast, 2D fractal dimension, and mirror symmetry, as well as their interactions with condition, were all not significant (p > .1). These findings suggest that initial visual engagement might be determined by artwork identity rather than guidance or the specific visual properties under examination.

Saccadic behavior was influenced by both visual features and the guidance condition, with visual properties having the strongest effects on visual exploration. RMS contrast significantly increased saccade frequency (F(1,69.98) = 57.17, p < .001; B = 0.050, p < .001), as did 2D fractal dimension, which was the most powerful predictor (F(1,58.76) = 67.84, p < .001; B = 1.086, p < .001). In contrast, mirror symmetry reduced saccadic rates, though the effect was minimal (F (1,60.99) = 51.56, p < .001; B = −0.017, p < .001). The experimental condition (COND) had a moderate effect (F(2,68.27) = 3.96, p = .024), with COND (2) decreasing saccade counts (B = −0.636, p= .009), while simultaneously strengthening the influence of RMS contrast on saccades (B = 0.036, p = .002). Finally, artwork type had a small positive effect (F(1,70.00) = 4.43, p = .039; B = 0.085, p = .039). Overall, these findings suggest that visual complexity and task-related guidance jointly shape active exploratory scanning, with complexity features having the most influence.

Pupil dilation was primarily driven by artwork characteristics rather than by audio guidance condition, as it varied significantly across the three paintings F(1, 69.99) = 30.80, p < .001). Visual predictors also contributed: higher 2D fractal dimension was associated with reduced pupil dilation (B = –4.27, p < .001; F(1, 77.65) = 4.25, p = .043), while higher mirror symmetry predicted increased dilation (B = 0.067, p < .001). However, the ANOVA for mirror symmetry only managed to approach significance (F(1, 50.62) = 3.05, p = .087), suggesting that this effect should be interpreted with caution. RMS contrast and guidance condition did not yield significant effects, nor did any interactions between condition and visual predictors. These patterns indicate that pupil dilation was more sensitive to the visual complexity features of the artworks than to differences in guidance condition, with greater fractal complexity reducing dilation and higher symmetry modestly enhancing it. A detailed overview of all effects is provided in Tables 3 and 4 below.

Table 3

ANOVA Results for the Effects of Visual Complexity Properties and Audio Guidance on Eye-Tracking Metrics

Dep. Variable	Effect	df	F	p
Fixations	Cond	2, 63.93	1.329	.272
	RMS_Contrast	1, 70.04	17.274	< .001
	Artwork	1, 70.04	8.655	.004
	2D_Fractal_Dimension	1, 66.28	26.495	< .001
	Mirror_Symmetry	1, 69.62	18.021	< .001
Saccades	Cond	2, 68.27	3.961	.024
	Rms_Contrast	1, 69.98	57.177	< .001
	Artwork	1, 70.00	4.437	.039
	Cond ✻ RMS_Contrast	2, 68.12	5.155	.008
	2D_Fractal_Dimension	1, 58.76	67.844	< .001
	Mirror_Symmetry	1, 60.99	51.566	< .001
First fix.	Artwork	1, 68.73	4.592	.036
Pup. Dil.	Artwork	1, 69.99	30.806	< .001
	2D_Fractal_Dimension	1, 77.65	4.245	.043
	Mirror_Symmetry	1, 50.62	3.050	.087

Note. This table presents the significant and trend-level F-tests for the effects of visual complexity properties, artwork, and audio guidance condition on eye-tracking metrics. Complete model results are available in Appendix A (Table A2).

Table 4

Fixed Effects Estimates for the Influence of Visual Complexity Properties and Audio Guidance on Eye-Tracking Metrics

Dep. Var	Effect	Est. (B)	SE	df	t	p
Fixations	Artwork	0.225	0.076	70.04	2.942	.004
Saccades	Artwork	0.085	0.040	70.00	2.106	.039
	Cond (2)	-0.636	0.236	68.27	-2.695	.009
	RMS_Contrast	0.050	0.012	70.15	4.110	< .001
	Cond (2) * RMS_Contrast	0.036	0.011	68.12	3.143	.002
	2D_Fractal_Dimension	1.086	0.305	41.69	3.557	< .001
	Mirror_Symmetry	-0.017	0.004	72.36	-4.090	< .001
First fix.	Artwork	0.145	0.068	68.73	2.143	.036
Pup. Dil.	Artwork	0.408	0.074	69.99	5.550	< .001
	2D_Fractal_Dimension	-4.275	0.509	54.05	-8.394	< .001
	Mirror_Symmetry	0.067	0.007	79.89	9.478	< .001

Note: This table presents the significant fixed-effect estimates for the influence of visual complexity properties, artwork, and audio guidance condition on eye-tracking metrics. Complete model results are available in Appendix A (Table A3).

Artwork Features and Their Influence on Visual Engagement

The observed engagement patterns are strongly associated with the visual properties of each artwork, with the audio guidance conditions playing only a moderate role.

Carnival, with the highest RMS contrast (24.38), yielded the highest engagement, with the Audio condition producing the most fixations (M=2.01/sec) and saccades (M=1.29/sec) across artworks, indicating that luminance variation may increase overall engagement. However, the most powerful positive predictor for both fixations and saccades was 2D fractal dimension. *Pigeons*, having the highest 2D fractal dimension (1.644), drove this effect, meaning that its greater structural complexity and irregularity led to more active exploratory scanning (Audio: M=0.73 saccades/sec). In contrast, mirror symmetry reduced saccade frequency but was positively associated with fixation counts. This suggests that *Pigeons*, with its lower mirror symmetry (21.80%), required more active visual scanning, while the highly symmetric artworks, *Carnival* (49.14%) and *Murnau* (47.34%), promoted more frequent fixation.

The guidance condition only had a moderate effect on saccadic behavior and no significant main effect on fixations, reflecting the mixed patterns: while Audio led to the highest saccades for *Carnival* and *Pigeons*, the Free condition produced slightly more saccades for *Murnau* (M=0.71/sec). These nuances suggest that while visual complexity features were the dominant influence, audio guidance led to varying degrees of increased visual engagement, depending on the artwork's properties.

Discussion

This study aimed to examine how visual complexity influences children's visual engagement with artworks and whether audio guidance modifies this relationship. Using eye-tracking data collected in a real museum setting, we found that complex artworks, characterized by high contrast and structural detail, led to increased exploratory viewing, whereas symmetric ones encouraged more focused attention. Although audio guides subtly influenced overall engagement, the visual properties of the paintings themselves appeared to be the primary drivers of curiosity and engagement during art viewing.

The first hypothesis predicted that higher visual complexity would reduce visual engagement. However, this assumption was not supported, as complexity was found to increase both fixation and saccade counts. Contradicting Berlyne's Inverted U-Shaped Hypothesis (1971), findings support previous evidence that visual intricacy may enhance visual interest and exploration (Birkin, 2010), especially in younger audiences. Yet, each complexity component offers discrete insights and requires further elaboration.

RMS contrast emerged as the strongest bottom-up attention driver, since artworks with high contrast, such as *Carnival*, elicited more fixations and saccades (mean fixations ~1.90/sec, mean saccades ~1.06/sec). This suggests that strong luminance variation may stimulate visual exploration in such free-viewing context, opposite to former task-based evidence that contrast reduces fixations (Näsänen, 2001). Moreover, 2D fractal dimension, which reflects structural intricacy, positively predicted saccades ($B = 1.086$, $p < .001$), aligning with earlier indications that children's visual system is in fact intrigued and not overwhelmed by complex stimuli (Frank et al., 2021).

In contrast, mirror symmetry negatively predicted saccades ($B = -0.017$, $p < .001$), with symmetric artworks such as *Carnival* and *Murnau* eliciting less exploratory scanning. This suggests that symmetry may facilitate easier perceptual processing, even though fMRI studies show that symmetrical patterns produce stronger activation in the visual cortex (Sasaki et al., 2005). However, both developmental (Huang et al., 2018) and expertise-based (Leder et al., 2019) studies indicate that evaluations of symmetry are shaped by learning, plasticity, and experience, challenging the idea that symmetry is a universal predictor of aesthetic preference.

Supplementary eye-tracking metrics were not significantly affected by visual complexity. In particular, time to first fixation consistently indicated immediate gaze orientation across all paintings, likely due to children being guided to the artworks, suggesting this metric may have been unsuitable for detecting attentional differences in this specific experimental context. Similarly, pupil dilation, an index of cognitive arousal, showed only minor correlations with fractal dimension and mirror symmetry, with the only significant increase driven by overall artwork identity ($B = 0.508$, $p < .001$). Given that pupil dilation is highly sensitive to micro-variations in luminance (Knapen et al., 2016), results should be interpreted cautiously, despite the artworks remaining in fixed locations within the museum during the experiment.

The second hypothesis, which predicted that audio guidance would moderate the impact of visual complexity, was only partially supported. Although both traditional and *Tonies* audio guides generally sustained engagement compared to free viewing, the differences across some eye-tracking metrics were modest. However, positive effects suggest that top-down input may enhance the viewing experience, in line with prior evidence that interpretive labels and guides influence gaze behavior (Vallez et al., 2020) and extend viewing time (Eghbal-Azar et al., 2016; Hutchinson & Eardley, 2021), therefore emphasizing the scaffolding role of audio guidance in information processing (Neuman et al., 2020).

Among the audio guidance conditions, the traditional guide emerged as the strongest moderator between RMS contrast and saccades ($B = .036$, $p = .002$). This effect was most evident for *Carnival*, where the traditional guide produced the highest saccade rate (1.29/sec). Rather than indicating greater engagement per se, this increased saccadic activity may also reflect more extensive visual exploration resulting from less guided viewing, suggesting that the classic narration-based audio guide may have promoted broader, but potentially less targeted, scanning. Accordingly, Othman et al. (2021) also reported the inability of game-based mobile guides to significantly enhance children’s overall museum experience. Instead, positive effects were only observed for kids' emotional connection to exhibits, although these were assessed via self-report measures, which may limit reliability.

Strikingly, and contrary to initial expectations, the *Tonies* guide generally showed no significant interactions and did not increase engagement or visual exploration, compared to the traditional guide. These findings seem to contradict research on child-centered interventions. For instance, Walker et al. (2024) found that child-tailored text descriptions in Amsterdam's Rijksmuseum increased gaze duration on specific Areas of Interest (AOIs), yet this might imply that delivery mode (audio vs. reading) and content may be more effective at sustaining attention than gamified child-oriented designs.

The present study demonstrated several methodological strengths. Unlike prior lab-based research (e.g., Ales et al., 2020; Machado et al., 2015), conducting the experiment within a museum setting enhanced ecological validity in assessing children's engagement with art. The use of real artworks also addressed methodological limitations of earlier studies that have relied on artificial or computer-generated stimuli (e.g., Gartus & Leder, 2017; Mühlenbeck et al., 2016; Sun & Firestone, 2021), while eye-tracking offered objective indices of visual engagement beyond the constraints of self-report methods (e.g., Othman et al., 2021). The Aesthetics Toolbox minimized subjective bias by providing algorithmic measures of visual complexity, however the observed intercorrelations among them illustrate the field's ongoing conceptual and analytical challenges. Finally, by focusing on children aged five to thirteen, the study addressed a key gap in the literature, extending aesthetic perception research beyond adult populations (Bailey-Ross et al., 2019; Hu et al., 2021; Lucia et al., 2024).

Despite these strengths, several methodological aspects are susceptible to refinement. Given the practical challenges of data collection in museum settings, our sample size (N = 39) provided valuable insights and was close to or larger than those in previous studies (e.g., Eghbal-Azar & Widlok, 2013, n = 16; Krogh-Jespersen et al., 2020, n = 31; Teo et al., 2024, n=16). However, larger samples could enhance statistical power and detect underlying interactions between complexity and audio guidance. Additionally, the strong influence of artworks themselves suggests that a larger and more diverse set of paintings could possibly reveal other factors that drive visual engagement. Finally, future studies could control for the content and delivery style of the *Tonies* guides, assessing the optimal balance between playful design and informational content for sustaining engagement.

In this study, we examined how visual complexity and audio guidance influence children’s visual engagement with artworks in museums. Visual complexity, particularly in terms of contrast and structural irregularity, was shown to drive visual exploration and engagement in children, whereas symmetric artworks elicited more focused but less active gaze patterns. Such evidence is able to inform museum curators, who could sequence exhibitions accordingly, by moving simpler artworks in rest-zones that aim to minimize cognitive load. The ability of audio guidance to generally modulate engagement further highlights the value of strategic scaffolding, however the lack of *Tonies*’ advantage over the traditional guides suggests that effectiveness might depend more on content and attentional direction rather than on playful features, although this needs further investigation. Altogether, these results support the design of child-appropriate museum experiences that embrace complexity, integrate thoughtful guidance, and prioritize substantive engagement.

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Appendix A

Table A1

Pearson's Correlation Matrix of All Complexity Metrics

			r		p
RMS_CONTRAST	-	EDGE_DENSITY	0.999	***	< .001
RMS_CONTRAST	-	ANISOTROPY	-0.489	***	< .001
RMS_CONTRAST	-	2D_FRACTAL_DIMENSION	0.317	***	< .001
RMS_CONTRAST	-	HOMOGENEITY	-0.288	**	.002
RMS_CONTRAST	-	BALANCE	0.988	***	< .001
RMS_CONTRAST	-	SELF_SIMILARITY(CNN)	-0.987	***	< .001
RMS_CONTRAST	-	LIGHTNESS_ENTROPY	0.996	***	< .001
RMS_CONTRAST	-	MIRROR_SYMMETRY	0.356	***	< .001
RMS_CONTRAST	-	CNN_SYMMETRY	-0.672	***	< .001
RMS_CONTRAST	-	COLOR_ENTROPY	-0.058		.549
EDGE_DENSITY	-	ANISOTROPY	-0.461	***	< .001
EDGE_DENSITY	-	2D_FRACTAL_DIMENSION	0.286	**	.002
EDGE_DENSITY	-	HOMOGENEITY	-0.257	**	.007
EDGE_DENSITY	-	BALANCE	0.982	***	< .001
EDGE_DENSITY	-	SELF_SIMILARITY(CNN)	-0.991	***	< .001
EDGE_DENSITY	-	LIGHTNESS_ENTROPY	0.999	***	< .001
EDGE_DENSITY	-	MIRROR_SYMMETRY	0.386	***	< .001
EDGE_DENSITY	-	CNN_SYMMETRY	-0.695	***	< .001
EDGE_DENSITY	-	COLOR_ENTROPY	-0.025		.794
ANISOTROPY	-	2D_FRACTAL_DIMENSION	-0.982	***	< .001
ANISOTROPY	-	HOMOGENEITY	0.976	***	< .001
ANISOTROPY	-	BALANCE	-0.620	***	< .001
ANISOTROPY	-	SELF_SIMILARITY(CNN)	0.341	***	< .001
ANISOTROPY	-	LIGHTNESS_ENTROPY	-0.412	***	< .001
ANISOTROPY	-	MIRROR_SYMMETRY	0.641	***	< .001
ANISOTROPY	-	CNN_SYMMETRY	-0.317	***	< .001

ANISOTROPY	-	COLOR_ENTROPY	0.899	***	< .001
2D_FRACTAL_DIMENSION	-	HOMOGENEITY	-1.000	***	< .001
2D_FRACTAL_DIMENSION	-	BALANCE	0.461	***	< .001
2D_FRACTAL_DIMENSION	-	SELF_SIMILARITY(CNN)	-0.158		.097
2D_FRACTAL_DIMENSION	-	LIGHTNESS_ENTROPY	0.234	*	.013
2D_FRACTAL_DIMENSION	-	MIRROR_SYMMETRY	-0.773	***	< .001
2D_FRACTAL_DIMENSION	-	CNN_SYMMETRY	0.490	***	< .001
2D_FRACTAL_DIMENSION	-	COLOR_ENTROPY	-0.965	***	< .001
HOMOGENEITY	-	BALANCE	-0.434	***	< .001
HOMOGENEITY	-	SELF_SIMILARITY(CNN)	0.128		.180
HOMOGENEITY	-	LIGHTNESS_ENTROPY	-0.204	*	.031
HOMOGENEITY	-	MIRROR_SYMMETRY	0.792	***	< .001
HOMOGENEITY	-	CNN_SYMMETRY	-0.516	***	< .001
HOMOGENEITY	-	COLOR_ENTROPY	0.973	***	< .001
BALANCE	-	SELF_SIMILARITY(CNN)	-0.949	***	< .001
BALANCE	-	LIGHTNESS_ENTROPY	0.971	***	< .001
BALANCE	-	MIRROR_SYMMETRY	0.206	*	.030
BALANCE	-	CNN_SYMMETRY	-0.548	***	< .001
BALANCE	-	COLOR_ENTROPY	-0.213	*	.025
SELF_SIMILARITY(CNN)	-	LIGHTNESS_ENTROPY	-0.997	***	< .001
SELF_SIMILARITY(CNN)	-	MIRROR_SYMMETRY	-0.503	***	< .001
SELF_SIMILARITY(CNN)	-	CNN_SYMMETRY	0.783	***	< .001
SELF_SIMILARITY(CNN)	-	COLOR_ENTROPY	-0.106		.269
LIGHTNESS_ENTROPY	-	MIRROR_SYMMETRY	0.435	***	< .001
LIGHTNESS_ENTROPY	-	CNN_SYMMETRY	-0.733	***	< .001
LIGHTNESS_ENTROPY	-	COLOR_ENTROPY	0.029		.764
MIRROR_SYMMETRY	-	CNN_SYMMETRY	-0.931	***	< .001
MIRROR_SYMMETRY	-	COLOR_ENTROPY	0.913	***	< .001
CNN_SYMMETRY	-	COLOR_ENTROPY	-0.701	***	< .001

Note: * p < .05, ** p < .01, *** p < .001

Table A2

ANOVA Results for the Effects of Visual Complexity Properties and Audio Guidance on Eye-Tracking Metrics

Dep. Variable	Effect	df	F	p
Fixations	COND	2, 63.93	1.329	.272
	RMS_CONTRAST	1, 70.04	17.274	< .001
	ARTWORK	1, 70.04	8.655	.004
	COND * RMS_CONTRAST	2, 70.04	1.520	.226
	COND	2, 34.58	0.995	.380
	2D_FRACTAL_DIMENSION	1, 66.28	26.495	< .001
	ARTWORK	1, 36.58	27.364	< .001
	COND * 2D_FRACTAL_DIMENSION	2, 34.58	1.014	.373
	COND	2, 47.16	0.304	.739
	MIRROR_SYMMETRY	1, 69.62	18.021	< .001
	ARTWORK	1, 70.20	3.106	.082
	COND * MIRROR_SYMMETRY	2, 69.11	0.437	.647
Saccades	COND	2, 68.27	3.961	.024
	RMS_CONTRAST	1, 69.98	57.177	< .001
	ARTWORK	1, 70.00	4.437	.039
	COND * RMS_CONTRAST	2, 68.12	5.155	.008
	COND	2, 34.29	0.766	.473
	2D_FRACTAL_DIMENSION	1, 58.76	67.844	< .001
	ARTWORK	1, 36.29	97.838	< .001
	COND * 2D_FRACTAL_DIMENSION	2, 34.29	1.028	.369
	COND	2, 62.02	0.501	.609
	MIRROR_SYMMETRY	1, 60.99	51.566	< .001
	ARTWORK	1, 68.07	50.007	< .001
	COND * MIRROR_SYMMETRY	2, 53.68	0.198	.821
First Fix.	COND	2, 39.72	2.124	.133
	RMS_CONTRAST	1, 68.95	0.374	.543
	ARTWORK	1, 68.73	4.592	.036
	COND * RMS_CONTRAST	2, 42.23	1.958	.154
	COND	2, 102.19	1.890	.156
	2D_FRACTAL_DIMENSION	1, 100.90	0.206	.651
	ARTWORK	1, 101.72	0.699	.405
	COND * 2D_FRACTAL_DIMENSION	2, 100.34	1.874	.159

	COND	2, 73.54	0.113	.893
	MIRROR_SYMMETRY	1, 79.81	0.102	.750
	ARTWORK	1, 69.25	2.522	.117
	COND * MIRROR_SYMMETRY	2, 71.74	0.566	.570
Pupil Dilation	COND	2, 57.33	1.613	.208
	RMS_CONTRAST	1, 69.89	2.556	.114
	ARTWORK	1, 69.99	30.806	< .001
	COND * RMS_CONTRAST	2, 67.51	2.645	.078
	COND	2, 50.34	1.786	.178
	2D_FRACTAL_DIMENSION	1, 77.65	4.245	.043
	ARTWORK	1, 70.65	34.751	< .001
	COND * 2D_FRACTAL_DIMENSION	2, 47.25	1.860	.167
	COND	2, 36.10	0.471	.628
	MIRROR_SYMMETRY	1, 50.62	3.050	.087
	ARTWORK	1, 69.80	96.819	< .001
	COND * MIRROR_SYMMETRY	2, 42.06	0.503	.608

Table A3

Fixed Effects Estimates for the Influence of Visual Complexity Properties and Audio Guidance on Eye-Tracking Metrics

Dep. Var		**Est. (B)**	**SE**	**df**	**t**	**p**
Fixations	Intercept	1.759	0.481	70.26	3.660	< .001
	ARTWORK (1)	0.225	0.076	70.04	2.942	.004
	COND (1)	0.615	0.460	63.93	1.335	.187
	COND (2)	-0.637	0.452	63.93	-1.408	.164
	RMS_CONTRAST	-0.004	0.023	70.04	-0.157	.876
	COND (1) * RMS_CONTRAST	-0.031	0.022	70.04	-1.450	.152
	COND (2) * RMS_CONTRAST	0.032	0.021	70.04	1.485	.142
	2D_FRACTAL_DIMENSION	-0.139	0.579	39.24	-0.241	.811
	COND (1) * 2D_FRACTAL_DIMENSION	-0.462	0.778	34.58	-0.593	.557
	COND (2) * 2D_FRACTAL_DIMENSION	1.089	0.764	34.58	1.424	.163
	MIRROR_SYMMETRY	0.001	0.008	70.29	0.178	.859
	COND (1) * MIRROR_SYMMETRY	-0.001	0.005	69.11	-0.249	.804
	COND (2) * MIRROR_SYMMETRY	-0.003	0.005	69.11	-0.715	.477

Saccades	Intercept	-0.247	0.253	70.13	-0.977	.332
	ARTWORK (1)	0.085	0.040	70.00	2.106	.039
	COND (1)	0.448	0.240	68.27	1.863	.067
	COND (2)	-0.636	0.236	68.27	-2.695	.009
	RMS_CONTRAST	0.050	0.012	70.15	4.110	< .001
	COND (1) * RMS_CONTRAST	-0.022	0.012	68.12	-1.909	.060
	COND (2) * RMS_CONTRAST	0.036	0.011	68.12	3.143	.002
	2D_FRACTAL_DIMENSION	1.086	0.305	41.69	3.557	< .001
	COND (1) * 2D_FRACTAL_DIMENSION	-0.210	0.402	34.29	-0.522	.605
	COND (2) * 2D_FRACTAL_DIMENSION	0.566	0.395	34.29	1.431	.161
	MIRROR_SYMMETRY	-0.017	0.004	72.36	-4.090	< .001
	COND (1) * MIRROR_SYMMETRY	-0.002	0.003	53.68	-0.612	.543
	COND (2) * MIRROR_SYMMETRY	0.001	0.003	53.68	0.388	.700
First Fix.	Intercept	1.053	0.525	73.18	2.006	.049
	ARTWORK (1)	0.145	0.068	68.73	2.143	.036
	COND (1)	-0.468	0.590	39.72	-0.793	.432
	COND (2)	1.194	0.580	39.72	2.060	.046
	RMS_CONTRAST	-0.045	0.024	76.66	-1.848	.068
	COND (1) * RMS_CONTRAST	0.019	0.027	42.23	0.723	.474
	COND (2) * RMS_CONTRAST	-0.052	0.026	42.23	-1.975	.055
	2D_FRACTAL_DIMENSION	-0.922	0.688	100.4	-1.340	.183
	COND (1) * 2D_FRACTAL_DIMENSION	0.687	0.944	100.3	0.727	.469
	COND (2) * 2D_FRACTAL_DIMENSION	-1.794	0.928	100.3	-1.934	.056
	MIRROR_SYMMETRY	0.016	0.008	79.74	1.916	.059
	COND (1) * MIRROR_SYMMETRY	-0.002	0.005	71.74	-0.415	.680
	COND (2) * MIRROR_SYMMETRY	0.006	0.005	71.74	1.064	.291
Pup. Dil.	Intercept	8.990	0.469	70.62	19.188	< .001
	ARTWORK (1)	0.408	0.074	69.99	5.550	< .001
	COND (1)	0.498	0.455	57.33	1.095	.278
	COND (2)	0.373	0.447	57.33	0.836	.407
	RMS_CONTRAST	-0.199	0.022	70.12	-8.943	< .001
	COND (1) * RMS_CONTRAST	-0.033	0.021	67.51	-1.542	.128
	COND (2) * RMS_CONTRAST	-0.019	0.021	67.51	-0.906	.368
	2D_FRACTAL_DIMENSION	-4.275	0.509	54.05	-8.394	< .001

COND (1) * 2D_FRACTAL_DIMENSION	-0.205	0.662	47.25	-0.310	.758
COND (2) * 2D_FRACTAL_DIMENSION	-1.041	0.651	47.25	-1.600	.116
MIRROR_SYMMETRY	0.067	0.007	79.89	9.478	< .001
COND (1) * MIRROR_SYMMETRY	-0.003	0.005	42.06	-0.628	.533
COND (2) * MIRROR_SYMMETRY	0.005	0.005	42.06	0.973	.336

Appendix B

Aesthetic Emotions Scale (AESTHEMOS; Shindler et al., 2017)

Q01 – I felt happy.

Q02 – I felt joy.

Q03 – It was beautiful.

Q04 – It gave me energy.

Q05 – I felt relaxed.

Q06 – It was moving.

Q07 – I felt enchanted.

Q08 – I felt affection.

Q09 – I felt fascinated.

Q10 – I felt amazed.

Q11 – I felt overwhelmed.

Q12 – It was interesting.

Q13 – It was exciting.

Q14 – It made me understand.

Q15 – It was challenging.

Q16 – I felt surprised.

Q17 – I felt bored.

Q18 – I felt confused.

Q19 – It was hideous.

Q20 – I felt angry.

Q21 – I felt sad.

Faculty of Social Sciences
Faculty of Psychology

Consent Form for Study Participants

I have been asked to give my consent for my child to take part in the study *Investigating the Impact of "Tonies" vs. Traditional Audioguides on Children's Art Engagement at Kunstpalast Düsseldorf*. By signing below, I declare the following:

- I have read the information sheet <approved version 2025-01-08-Z.P. Pilz-V1-5811>.
- I have had the opportunity to ask questions. If I had any questions, they were answered to my satisfaction.
- I had sufficient time to decide whether my child should take part.
- I know whom to contact in case of complaints.
- I understand that participation is voluntary. I also understand that I can decide at any time that my child will no longer take part in the study. I do not have to give a reason for this decision, and there will be no disadvantages as a result.
- I understand that the research data will be securely stored (coded or anonymized) and kept for at least 10 years.
- I understand that audio and eye-tracking recordings will be made as part of the study. These are necessary for the research and will be used exclusively for scientific purposes.
- I understand that the researchers may share anonymized data that cannot be traced back to my child with other researchers.
- This the first time my child is taking part in this study.

I give my consent for my child to participate in this study.

Signed by:
Date:
Signature:

Child's Consent

Hello!

The people conducting this study would like to learn more about how children like you look at art in a museum. If you take part, you'll look at some paintings while we use special glasses to see where you're looking. You might also hear an exciting story about the pictures!

You don't have to take part if you don't want to. If you start and then decide you don't want to continue, that's completely fine — just tell us, and we'll stop right away. No one will be upset with you!

If you have any questions, you can ask me, your parents, or the people running the study.

Would you like to take part in the study?

Please check one box:
☐ Yes, I want to help!
☐ No, I don't want to.

CEP version March 2024–2025-01-08-Z.P. Pilz-V1-5811