The art of pain: A quantitative color analysis of the self-portraits of Frida Kahlo

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Frida Kahlo (1907−1954) was a Mexican artist who is remembered for her self-portraits, pain and passion, and bold, vibrant colors. This work aims to use her life story and her artistic production in a longitudinal study to examine with quantitative tools the effects of physical and emotional pain (rage) on artistic expression. Kahlo suffered from polio as a child, was involved in a bus accident as a teenager where she suffered multiple fractures of her spine and had 30 operations throughout her lifetime. She also had a tempestuous relationship with her painter husband, Diego Rivera. Her physical and personal troubles however became the texture of her vivid visual vocabulary—usually expressed through the depiction of Mexican and indigenous culture or the female experience and form. We applied color analysis to a series of Frida's self-portraits and revealed a very strong association of physical pain and emotional rage with low wavelength colors (red and yellow), indicating that the expression of her ailments was, consciously or not, achieved by increasing the perceived luminance of the canvas. Further quantitative analysis that used the fractal dimension identified "The broken column" as the portrait with higher compositional complexity, which matches previous critical acclaim of this portrait as the climax of her art. These results confirm the ability of color analysis to extract emotional and cognitive features from artistic work. We suggest that these tools could be used as markers to support artistic and creative interventions in mental health.

KEYWORDS

Frida Kahlo, art, painting, portrait, pain, anger, color analysis, perceptual lightness

Introduction

Preamble

Creating visual art is one of the defining characteristics of the human species (Morriss-Kay, 2010) and is layered by both conscious and unconscious activities (Sapolsky, 2017), so that canvases may contain elements stemming from the physical and mental ailments of the artist. We now have the tools to extract and resolve these by use of quantitative tools (Turkheimer et al., 2020).

From the early decoration of human bodies with skin coloring and beads and the early 2-dimensional forms created at least 30,000 years ago to the increasing sophistication of images represented on various surfaces and materials, visual art has been the vehicle of expression for the historical and social narratives of civilizations, their aesthetics, and their values (Morriss-Kay, 2010; Kim et al., 2014; Sigaki et al., 2018). At the same time, artistic production may be the vehicle for the author's personal and intimate narratives and mirror her/his craft and unique creative ambitions, as well as inner impulses and subconscious mental states - as represented by the Art Brut collection in Lausanne (Dubuffet, 1976) that contains multiple art pieces created by individuals with psychiatric disorders.

We suggest that it is of interest to develop quantitative approaches that can extract from visual art features strongly associated with underlying pathology that, besides the inherent cultural interest, may ultimately inform the use of art as a therapeutic intervention in mental health (Uttley et al., 2015).

Art, neuropathology and the longitudinal design

Features extracted from works of art can be simply associated to certain diagnostic categories (Hacking et al., 1996), but they become true biomarkers when they can be meaningfully connected to underlying pathology. For example, in the case of the dementias, Gretton and Ffytche (2014) were able to distinguish changes in the use of the canvas, the color palette and artistic themes amongst artists with Alzheimer's disease, frontotemporal dementias and Lewy Bodies disease and link these features to neurological deficits and imaging findings. This insight is harder to achieve in psychiatric conditions as pictorial characteristics are not necessarily closely associated with diagnosis (Wadeson and Carpenter, 1976); this likely stems from the heterogeneous and dynamic nature of these disorders and the far less defined neuropathology (Borsboom and Cramer, 2013; Turkheimer et al., 2021). However, it turns out that pictorial features are of great value in longitudinal studies that provide a dynamic understanding of the patient, regardless of diagnosis (Wadeson and Carpenter, 1976). In a seminal longitudinal study of ~200 patients with unipolar depression,

bipolar depression and acute schizophrenia, conducted at N.I.H. in the 70's, Wadeson and Carpenter used the qualitative categories of color, fullness of space utilized, extent of development and organization to score >1,000 pieces produced by the participants (Wadeson and Carpenter, 1976). They were not able to use these pictorial characteristics to reliably classify participants in the three diagnostic groups but the longitudinal information extracted for each participant was found to be helpful in the planning of their treatment; in their own words:

> "*the art evaluations have proved most useful in comparing pictures made by the same patient at different times thereby eliminating variables of artistic ability, art experience, hand-eye coordination, intelligence and other factors that may affect comparisons across individuals*" (Wadeson and Carpenter, 1976).

Quantitative approaches for the analysis of life-time artistic trajectories

It is clear that art can be effectively integrated into psychiatric lines of inquiry if (a) experimental designs focus on the individual trajectory of the author's compositions and her/his symptoms, (b) the methods used are quantitative as variation of features is likely to be subtle and (c) features can be linked to the underlying neurobiology.

The value of life trajectories in artistic analysis is now well recognized (Lopes and Tenreiro Machado, 2019). Computational methods that extract quantitative features from canvases are commonly used by art collectors, art dealers and museums for the detection of forgeries but also in art history to identify styles and artists, determine cross-influences, and, more experimentally, have been applied to predict aesthetic ratings [please see review of these methods in Brachmann and Redies (2017)]. Recently, we have been able to integrate all three steps above in a longitudinal, quantitative study of the self-portraits of Vincent van Gogh to demonstrate his mental illness as likely due to interneuron deficits due to the significant association of color contrast and expressionist style with his consumption of absinthe, a strong liquor with potent activity on gamma-aminobutyric acid (GABA) receptors (Turkheimer et al., 2020).

Self-portraits

In the context of quantitative analysis of visual art, the value of self-portraits is two-fold. Firstly they provide a reasonably controlled subject matter as the focus is on the figure of the author within a reasonable variation in terms of pose and context (Turkheimer et al., 2020). More importantly though, they are not

a mere depiction of oneself but a "*complex and multidimensional project, a cultural and social act, a call for connection, and part of people's ever-incomplete identity projects*" (Kozinets et al., 2017). In the West, self-portraits have a long history emerging as a visual genre since the sixteenth century and were mastered by painters such as Albrecht Dürer, Rembrandt, Edvard Munch and Vincent Van Gogh. These painters used self-portraiture not as a mere documentation of their current appearance but to delve into the inner depths of their character and invite the beholders to trigger their associations and imaginations to be personally touched and so to empathize with the artist (Carbon, 2017). In this regard the physical features of the painter, the face, the pose, are as important as the surrounding context and are all part of a complex identity project (Carbon, 2017).

Frida Kahlo and the art of pain and anger

Here we present a life-time analysis of the art of the Mexican painter Frida Kahlo (1907–1954) that utilizes quantitative tools to investigate the relationship between the color palette and the artist's mental health at various times of her life.

As before, we have chosen to restrict the analysis to the very rich collection of self-portraits that the artist produced to exert some control over the subject matter of the art. We then projected digital copies of these portraits in the three cardinal color spaces and quantified features. These features were used in a fashion different from the previous work on van Gogh as here the question was not about neuropathology. We have instead used Frida Kahlo's medical history to establish how physical pain and anger may have percolated into her painting style and used detailed biographical notes to establish those color features best associated with her medical and life history.

Hypothesis

The hypothesis tested here was that the colors with high perceptual intensity, and red in particular, would be present in the self-portraits of artist Frida Kahlo as the result of the painter's physical pain or deep emotional anger.

Colors are an ubiquitous part of our percepts and it has been known for some time that they have differing effects on human cognition and behavior [please see Elliot and Maier (2014) for a review].

Color also has a modulating effect on pain and, depending on wavelengths, visual stimuli may induce analgesia or hyperalgesia (Cheng et al., 2021). In particular, visual application of red light (long wavelength at 660 nm) has been shown to exacerbate pain in both human and animal models, and even induce functional pain in an injury-free model (Khanna et al., 2019; Wiercioch-Kuzianik and Babel, 2019) through a number of pathways that modulate pain processing in the cerebrum

and brainstem and reflect on parasympathetic and sympathetic functions with the release of a number of neurotransmitters and hormones (e.g., dopamine, GABA, histamine, orexin, melanin-concentrating hormone, oxytocin, and vasopressin) (Noseda et al., 2010, 2017; Okamoto et al., 2010; Martenson et al., 2016).

Interestingly, the color red also seems to exert effects at higher levels of cortical processing and modulate the response to affective images (Fetterman et al., 2012; Elliot and Maier, 2014). There is no agreed mode of explanation for this association as this color could appear in emotional situations with evolutionary significance (e.g., red blood) or may become arbitrarily associated in individual cultures (e.g., red faces in angry people of Caucasian tribes), or both (Jonauskaite et al., 2020), ultimately becoming part of a human process of grounding abstract concepts (e.g., moods) in perceptual experience (Meier and Robinson, 2009). The exact mechanisms of regulation of mood by light perception and vice versa have not been precisely worked out, but there is ample evidence that they impinge on the same sympathetic and parasympathetic pathways involved in pain processing (Elliot, 2015).

Methods

To test the hypothesis, two parallel data sets were employed, a series of color self-portraits together with biographical material and detailed catalog notes. The former dataset was treated with standard computational tools to extract color features while the information contained in the latter was used to score (0—no pain, anger, 1—yes pain and anger) to determine whether the physical and/or emotional pain was expressed intentionally or sub-consciously in the individual art piece.

Lifetime trajectory and medical history

Few artists of the twentieth century have had their personal and private lives as closely examined as the Mexican painter Frida Kahlo (1907–1954). Her career was relatively short with an output of little more than 150 paintings; of these 55 were self-portraits. Yet her aesthetic and conceptual ideas have inspired an ever-growing fascination across the world as her career was marked by a series of upheavals that were intimately connected to her private life, hence the intense scrutiny and interest concerning even the most minute biographical detail.

Here we will focus on three main factors that dominated her physical and mental health during her life: pain, heartache and anger as described in the detailed clinical analysis written by Budrys (2006).

Frida Kahlo was born in 1907 with a congenital anomaly, spina bifida that manifests with several neurological and skeletal abnormalities, in her case in the lower part of the body and feet. Aged six, she then caught poliomyelitis that aggravated the

deformity on her right leg and occasionally caused discomfort and pain. Later in her life, she underwent several surgical procedures on her right foot and leg that eventually led to gangrene and amputation of her leg shortly before her death in 1954.

In 1923 at the age of 18, she was involved in a bus accident where she suffered severe injuries to the spine and further damage to her right leg. The forced confinements in bed during the following months made her change her career path, abandoning medical school and turning to painting as a way to deal with boredom and pain. Later she joined the local Communist Party where she met Diego Rivera, an established Mexican artist 30 years her senior, who become her husband in 1929, and the love of her life. The state of her spine and pelvis deteriorated throughout the years, was the source of excruciating pain at times and caused three miscarriages ultimately preventing her from having any children. Between 1946 and 1951 she underwent eight surgical procedures that were meant to ameliorate her deteriorating condition but, ultimately, made her situation worse as she became confined to a wheelchair.

The meeting with Diego Rivera had a major professional impact as his international reputation and his contacts with American and European circles facilitated the propulsion of Frida into fame. However, the relationship was tumultuous with Diego's multiple extra-marital affairs; one in particular with Frida's sister Cristina, once her closest confidant, which enraged Frida and caused their divorce in 1939 only for them remarry again 1 year later. However, the events leading to the separation had changed Frida. She was now far more independent, both personally and professionally, carrying on several romantic liaisons of her own, one famously with Leon Trotsky.

Frida Kahlo was a key figure of Mexican revolutionary modern art and international surrealism, her canvases expressing her personal turmoil but also mirroring her philosophy and vision as she was a pioneer of the politics of gender, sexuality, and feminism. To isolate/identify objectively the expression in her art of the physical and emotional factors of interest, we relied on the most complete catalog of her production recently published by Taschen (Lozano et al., 2021). In the catalog, we searched the extensive notes that reference each self-portrait and scored the art piece with a pain factor of 1 if the notes clearly referred to an intent to express pain, heartache, or anger.

Color extraction and features

The hypothesis to be tested was about a potential association of colors of high intensity and the painter's physical pain or deep emotional anger.

This required the extraction of features related to the color red. The color itself can be characterized by hue (wavelength)

and redness (contribution of the primary color red); moreover, the effect of the color could be exerted by its overall perceptual lightness or by the light contrasts created by the painter in the canvas.

Forty-three self-portraits that are in color, on canvas and catalogued (Lozano et al., 2021) were downloaded from the on-line digital exhibition of her work available at www.FridaKahlo.org. Frames, when present in the digital images, were removed manually. The digital self-portraits were then analyzed to extract the relevant features following established protocols (Romero et al., 2017). The analysis considered the whole canvas without any particular focus on specific areas (e.g., face, body) as both figure and background were considered part of the identity project of the artist. Local color analysis however has its value and the interested reader is referred to Kim et al. (2019) and Yoo et al. (2021) for its applications.

The paintings were first analyzed in the original Red, Green and Blue (RGB) space, in which the contents of the RGB channels were separated from one another and mean values for each channel calculated.

The data were then projected into the Hue, Saturation, Value space, in which we calculated the percentage of voxels contained in the first bin of the hue channel to estimate the number of red pixels in the painting (Romero et al., 2017).

The data were then projected into the CIELAB space that also has three dimensions called L^*, a^* and b^*. The perceptual lightness value, L^*, defines black at 0 and white at 100, the a^* axis defines the green–red spectrum, and the b^* axis represents the blue–yellow spectrum. Here we calculated the mean perceptual lightness of L^*.

To quantify the contrast of the luminance in the portraits, we calculated the average contrast across the image. For each digital image, the luminance of a pixel was obtained from its red, green, blue components as $0.299R + 0.587G + 0.114B$ (International Telecommunication Union, Recommendation BT 0.601). We then calculated the power spectrum of the image intensity using the 2-D Fourier Fast Transform (FFT) and the value at the origin of the FFT produced the required average image contrast (Chatfield, 1989; Turkheimer et al., 2020).

Furthermore, we examined the canvases for indications of neurological deterioration following the worsening of her condition, particularly after 1945 and the numerous and ineffective surgical procedures during the last years before her death (Budrys, 2006). To this end, we calculated the fractal dimension (FD) of each self-portrait using a previously described procedure specific to RGB images (Nayak and Mishra, 2016). Fractals are self-repeating patterns across scales that are the hallmark of certain natural objects or organisms such as snowflakes, river beds, and coastal lines, as well as the human brain and its functional signatures, from neuronal activity to motor behavior, such as writing and painting (Squarcina et al., 2015; Turkheimer et al., 2015, 2021; Forsythe et al., 2017). The
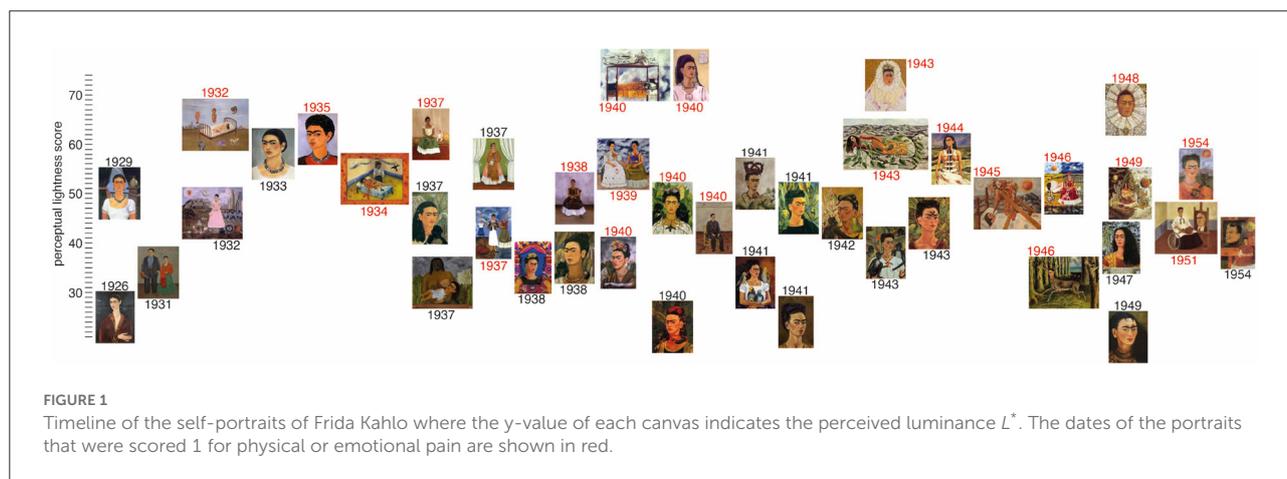
TABLE 1   The list of the self-portraits with corresponding year of production, pain/anger scores that were assigned based on the intent of the author to express pain or anger, the reference the scores were based upon [pages and catalog numbers as in Lozano et al. (2021)] and brief notes on what the pain score is based upon.

Title	Year	Score	Reference	Notes
Self portrait in a velvet dress	1926	0	pp.471, cat.4	–
Self portrait time flies	1929	0	pp.491, cat.28	–
Frieda and Diego Rivera	1931	0	pp.494, cat.32	–
Self portrait along the border line between Mexico and the United States	1932	0	pp.500, cat.37	–
Henry Ford Hospital	1932	1	pp.502, cat.39	Miscarriage
Self-portrait with necklace	1933	0	pp.508, cat.43	
Self portrait with curly hair	1935	1	pp.511, cat.46	Anger for treason
A few small nips—passionately in love	1934	1	pp.511, cat.47	Anger for treason
Fulang Chang and I	1937	0	pp.517, cat.52	–
My nurse and I	1937	0	pp.520, cat.54	–
Me and my doll	1937	1	pp.521, cat.55	Miscarriage
Memory the heart	1937	1	pp.523, cat.56	Anger for treason
Self-portrait dedicated to Leon Trotsky	1937	0	pp.524, cat.57	–
Self-portrait the frame	1938	0	pp.535, cat.68	–
Self-portrait with a monkey	1938	0	pp.537, cat.70	–
Itzcuintli dog with me	1938	1	pp.536, cat.69	Miscarriage
The two Fridas	1939	1	pp.546, cat.78	Divorce
The dream the bed	1940	1	pp.549, cat.80	Divorce
Self-portrait dedicated to dr Eloesser	1940	1	pp.550, cat.81	Divorce
Self-portrait with necklace of thorns	1940	1	pp.551, cat.82	Divorce
Self portrait with monkey	1940	0	pp.553, cat.83	–
Self-portrait dedicated to Sigmund Firestone	1940	1	pp.554, cat.84	Divorce
Self-portrait with cropped hair	1940	1	pp.555, cat.85	Divorce
Self-portrait with braid	1941	0	pp.556, cat.86	–
Me and my parrots	1941	0	pp.557, cat.87	–
Self-portrait with Bonito	1941	0	pp.558, cat.88	–
Self-portrait in red and gold dress	1941	0	pp.558, cat.89	–
Self-portrait with monkey and parrot	1942	0	pp.563, cat.96	–
Self-portrait with monkeys	1943	0	pp.564, cat.97	–
Roots	1943	1	pp.566, cat.99	–
Self-portrait as a Tehuana	1943	1	pp.567, cat.101	–
Thinking about death	1943	0	pp.569, cat.102	–
The broken column	1944	1	pp.574, cat.110	Physical pain
Without hope	1945	1	pp.584, cat.120	Physical pain
Tree of hope remain strong	1946	1	pp.586, cat.121	Physical pain
The wounded deer	1946	1	pp.587, cat.122	Physical pain
Self-portrait with loose hair	1947	0	pp.589, cat.123	–
Self-portrait in medallion	1948	1	pp.591, cat.125	Physical pain
Diego and I	1949	0	pp.594, cat.127	–
The love embrace of the universe the earth Mexico myself Diego and- señor Xolotl	1949	1	pp.592, cat.126	Physical pain
Self-portrait with the portrait of doctor Farill	1951	1	pp.598, cat.131	Physical pain
Self-portrait with a portrait of Diego on the breast and Maria between the eyebrows	1954	1	pp.609, cat.145	Anger
Self-portrait with Stalin	1954	0	pp.610, cat.148	–

TABLE 2 Results of the group comparison of features between self-portraits scored 0 for pain and anger and those scored 1.

Features	Score 0	Score 1	T (df = 41)	P-value
R-Channel	115.8 (±20.6)	147.4 (±26.3)	4.37	0.00008**
G-Channel	94.2 (±24.1)	123.6 (±24.1)	4.20	0.00015**
B-Channel	70.7 (±26.6)	100.5 (±26.8)	3.66	0.00071**
Contrast	0.195 (±0.080)	0.303 (±0.092)	4.09	0.00017**
Lightness	40.2 (±10.7)	55.3 (±11.7)	4.39	0.00007**
Red Pixels (%)	0.47 (±0.18)	0.46 (±0.21)	0.09	0.92
FD	2.39 (±0.22)	2.43 (±0.18)	0.61	0.55

Results are reported as mean values ± standard deviation, Student-t statistic and p-value. P-values smaller than 0.05/7 (0.007) are indicated with the double asterisk and are significant as they survive Bonferroni correction.

FIGURE 1
Timeline of the self-portraits of Frida Kahlo where the y-value of each canvas indicates the perceived luminance L^*. The dates of the portraits that were scored 1 for physical or emotional pain are shown in red.

FD quantifies the space filling property of the object measured; from a neurological perspective, larger FD indicates the ability of the artist to control the object on canvas in a cohesive fashion and meaningfully connect all the scales of its realization from small details, to the large scenery or background (Forsythe et al., 2017). Longitudinal analysis of the FD has revealed either a stable or rising trajectory in the work of painters with no obvious medical history, the latter likely indicating increasing artistic maturity, while decreasing values were found in those with neurological or neurodegenerative conditions (Forsythe et al., 2017).
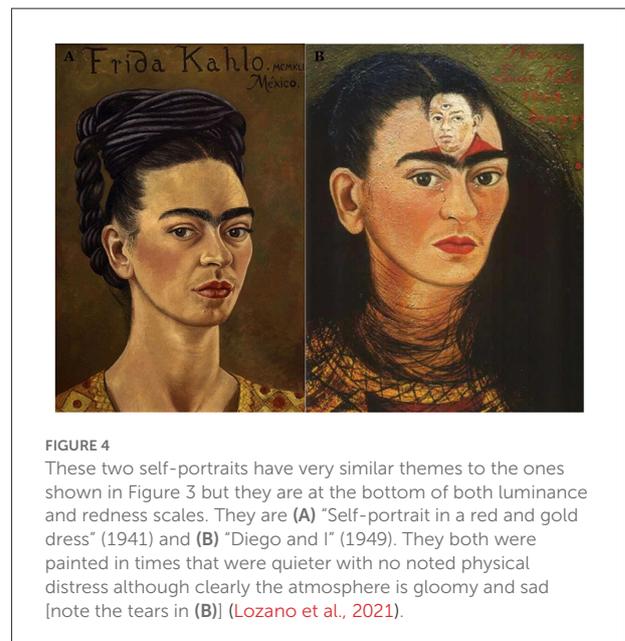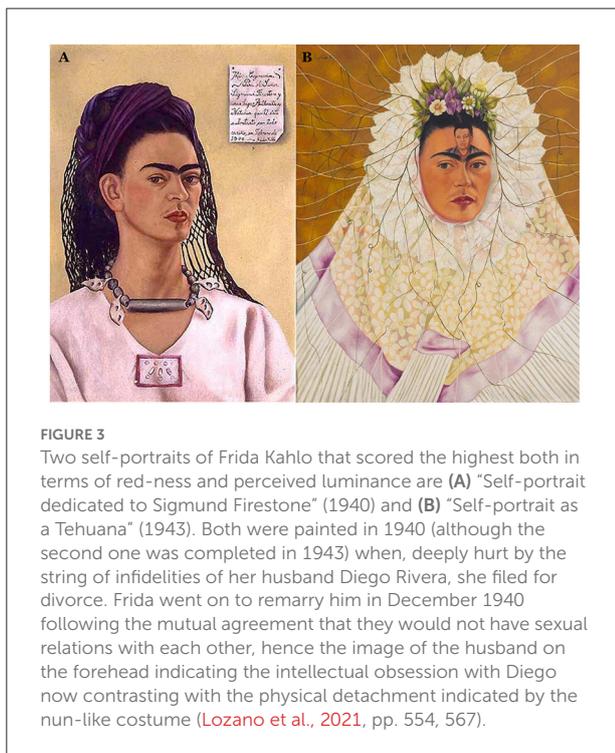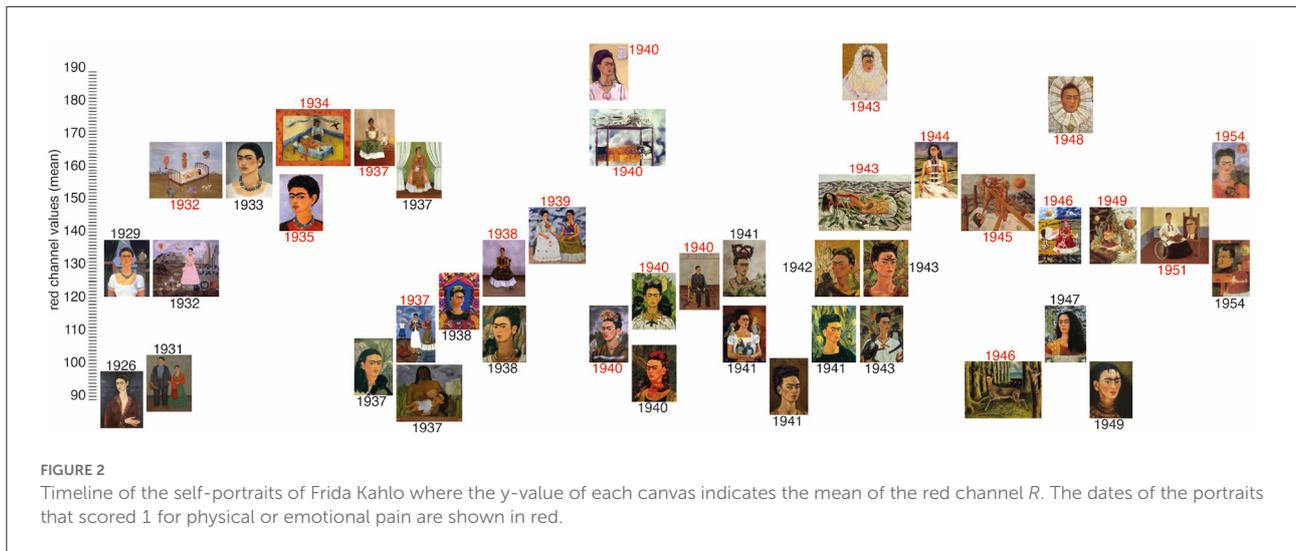
Analysis

The process described above produced the following 7 features: red-channel, green-channel, blue channel mean intensities, luminance contrast, mean perceptual lightness, percentage of red pixels and fractal dimension.

These features were then tested for differences between the two groups of portraits, one expressing pain/anger (pain score = 1) vs. the control group (pain score = 0). Given the normal-like distribution of the scores, independent group Student t-tests were conducted, preceded by a Levene test for equality

of variances. In the case of FD, the effect of time (in units of years) was controlled for prior to testing using a standard Pearson correlation test. Features were considered significant if the resulting p-value was <0.05/n where n = 7 accounts for the increased expected number of false positives given the multiple tests and implements the Bonferroni correction (Turkheimer et al., 2001). All calculations were performed using Matlab (v. R2018b, The Mathworks Inc., Natick, MA, USA) while statistical analyses were conducted in SPSS v.25 (IBM Corp).

Results

A total of 43 self-portraits were identified, downloaded, and processed. Table 1 contains the list of the portraits together with the corresponding year of production, pain/rage score, the catalog references where text clearly referred to pain or anger and a brief note of explanation. Out of these, about half (n = 22) had a positive score as the catalog entries clearly referred to the intent of Frida to express pain or anger (Lozano et al., 2021). This could have been for a number of reasons including the anger about a miscarriage or the physical pain accompanying the many

FIGURE 2
Timeline of the self-portraits of Frida Kahlo where the y-value of each canvas indicates the mean of the red channel *R*. The dates of the portraits that scored 1 for physical or emotional pain are shown in red.

FIGURE 3
Two self-portraits of Frida Kahlo that scored the highest both in terms of red-ness and perceived luminance are **(A)** "Self-portrait dedicated to Sigmund Firestone" (1940) and **(B)** "Self-portrait as a Tehuana" (1943). Both were painted in 1940 (although the second one was completed in 1943) when, deeply hurt by the string of infidelities of her husband Diego Rivera, she filed for divorce. Frida went on to remarry him in December 1940 following the mutual agreement that they would not have sexual relations with each other, hence the image of the husband on the forehead indicating the intellectual obsession with Diego now contrasting with the physical detachment indicated by the nun-like costume (Lozano et al., 2021, pp. 554, 567).

FIGURE 4
These two self-portraits have very similar themes to the ones shown in Figure 3 but they are at the bottom of both luminance and redness scales. They are **(A)** "Self-portrait in a red and gold dress" (1941) and **(B)** "Diego and I" (1949). They both were painted in times that were quieter with no noted physical distress although clearly the atmosphere is gloomy and sad [note the tears in **(B)**] (Lozano et al., 2021).

surgical procedures she endured, or the anger toward her unfaithful husband.

The results of the feature comparison between the two groups of paintings are reported in Table 2 in terms of mean values ± standard deviations, student-t statistic and *p*-values. As expected, redness (mean of the R channel) was very much increased in the pain/anger group of portraits (Cohen's d 1.33); however so was the green channel (Cohen's d 1.27) and the blue channel (Cohen d 1.11). This confirmed the qualitative

impression that in this group, Frida Kahlo made abundant use of yellow (R+G) and white (R+G+B). In fact, the difference between the two groups is better captured by the increase in perceived lightness (L*), that corresponds to whiteness. The red hue, e.g., the percentage of red pixels, was unchanged across groups. The fact that lightness and not hue varied between groups is further supported by a substantial increase of luminance contrast in the pain/anger portraits. In other words, at least for Frida Kahlo, the expression of physical and emotional pain was obtained by increasing the total perceived luminance and the localized luminance contrast on the canvas.
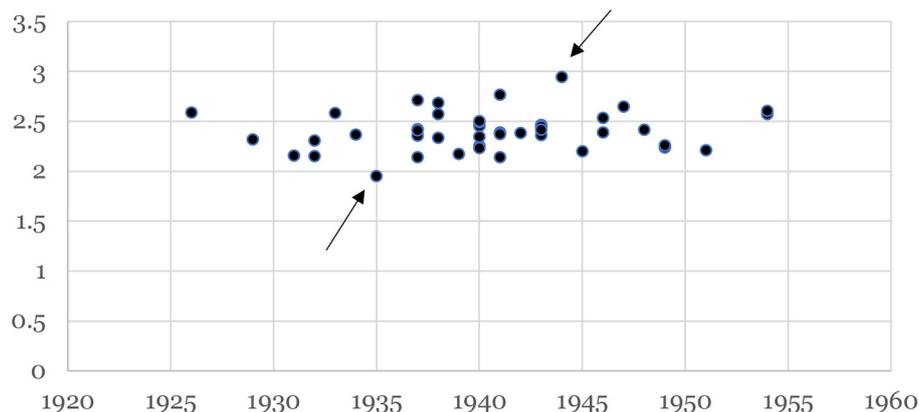
FIGURE 5
Plot of the fractal dimension FD across time. The data shows no trend and describes quantitatively the varying complexity of Frida's work that remained constant, on average, along her professional life. There are extreme values indicated by arrows, one with value 1.9 produced in 1935 and one with FD = 2.9 painted in 1944. These two portraits are shown in Figure 6.

Figures 1, 2 demonstrate the timeline for the self-portraits in relation to perceived luminance L* and R channel intensity. Figures 3, 4 display two portraits each, at the top and bottom of the luminance and the redness scales. The portraits were chosen as they display very similar themes, but a completely different mood is clearly reflected in the lightness that is high in the first set and much lower in the second.

The FD was clearly un-differentiated between the two groups. The timeline of the FD is shown in Figure 5 and, although it does not show a significant trend with time (i.e., correlation with years was not significant) it does however give insight into her style. Figure 6 illustrates the two outlying portraits, "Self-portrait with curly-hair" (1935), the one with the lowest FD, and "The broken column" (1944) that has the highest FD. The latter is of particular interest because it is commonly recognized as her masterpiece or, at least, the apex of her artistic journey that would afterwards take a painful turn because of the many surgical procedures she underwent (Lozano et al., 2021, p. 511). Indeed, the FD of the subsequent portraits show a substantial drop and recovers only before her sudden death in 1954.

Finally, when the physical pain condition was contrasted with anger, no features were significantly different in the portraits.

Discussion

This work has used the personal and artistic timelines of Frida Kahlo to investigate the effects of physical and psychological distress on visual art.

The results, the first of their kind to our knowledge, confirm what has been suggested by experimental work, that there is an association between colors and physical and emotional pain
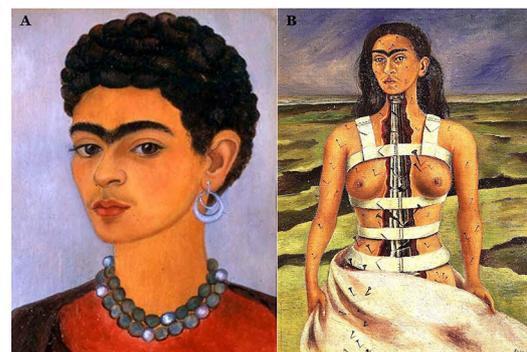

FIGURE 6
These two portraits **(A)**" Self-portrait with curly-hair" (1935) and **(B)** "The broken column" (1944) represent the two extremes in terms of canvas structuring in Frida Kahlo's art. The first, inspired by Roman-Egyptian portraits, uses simple superposition of tones to convey the stern but dignified outrage of Frida toward the betrayal of her husband with her closest confidante, her sister Cristina. Note the cropped hair that was drawn in protest of Diego who liked her long hair (Lozano et al., 2021, p. 511). The second one, inspired by Greek architecture as by the ionic column standing for her damaged spine, is instead a highly structured piece. High FD quantifies the complexity of the color structure on canvas. This piece has been critically acclaimed for the realistic representation of her pain that runs across the whole representation from the rigidity of the spine that dominates the central part through the nails running down her leg; these depict the lumbar radiculopathy (or sciatica), a pain radiating down the leg along the dermatom. This piece is recognized as the climax of her art (Lozano et al., 2021, pp. 575).

(Schilling et al., 2019; Wiercioch-Kuzianik and Babel, 2019) The R channel was significantly increased in the pain/anger group of self-portraits but so were the G and B channels, the latter to a lower extent. In fact the data suggest that the association is

driven not by hue but by the perceived lightness of the colors (whiteness) that, for the human eye, is higher for colors with low wavelength, red and yellow. This is further supported by it corresponding with an increase in luminance contrasts in the canvas.

The use of fractal analysis attempts a quantification of the impact of cognitive ailments on the artist's artwork. The effect of pain on this marker was roughly constant across her lifetime, albeit with significant variability, which is likely to contain relevant information as the portrait that scored the highest FD value was her recognized masterpiece, "The broken column". In our view, this indicates that, although pain was clearly reflected in Frida's art, it did not compromise her technical or expressive ability.

Conclusion

In conclusion, this paper supports the value of quantitative image analysis in extracting psychological themes from visual art and in revealing the mental state of the artist. Hopefully these tools will become part of the clinical armory of art intervention in in individuals with mental health problems cohorts in the future.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

Funding

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Borsboom, D., and Cramer, A. O. (2013). Network analysis: an integrative approach to the structure of psychopathology. *Annu Rev Clin Psychol.* 9, 91–121. doi: 10.1146/annurev-clinpsy-050212-185608

Brachmann, A., and Redies, C. (2017). Computational and experimental approaches to visual aesthetics. *Front. Comput. Neurosci.* 11, 102. doi: 10.3389/fncom.2017.00102

Budrys, V. (2006). Neurological deficits in the life and works of Frida Kahlo. *Eur Neurol.* 55, 4–10. doi: 10.1159/000091136

Carbon, C. C. (2017). Universal principles of depicting oneself across the centuries: from renaissance self-portraits to selfie-photographs. *Front. Psychol.* 8, 245. doi: 10.3389/fpsyg.2017.00245

Chatfield, C. (1989). *The Analysis of Time Series—An Introduction.* London: Chapman and Hall.

Cheng, K., Martin, L. F., Slepian, M. J., Patwardhan, A. M., and Ibrahim, M. M. (2021). Mechanisms and pathways of pain photobiomodulation: a narrative review. *J. Pain.* 22:763–77. doi: 10.1016/j.jpain.2021.02.005

Dubuffet, J. *Collection de l'Art Brut Lausanne* (1976). Available online at: https://www.artbrut.ch/en_GB/authors/the-collection-de-l-art-brut

Elliot, A. J. (2015). Color and psychological functioning: a review of theoretical and empirical work. *Front. Psychol.* 6, 368. doi: 10.3389/fpsyg.2015.00368

Elliot, A. J., and Maier, M. A. (2014). Color psychology: effects of perceiving color on psychological functioning in humans. *Annu. Rev. Psychol.* 65, 95–120. doi: 10.1146/annurev-psych-010213-115035

Fetterman, A. K., Robinson, M. D., and Meier, B. P. (2012). Anger as "seeing red": evidence for a perceptual association. *Cogn. Emot.* 26, 1445–58. doi: 10.1080/02699931.2012.673477

Forsythe, A., Williams, T., and Reilly, R. G. (2017). What paint can tell us: a fractal analysis of neurological changes in seven artists *Neuropsychology.* 31, 1–10. doi: 10.1037/neu0000303

Gretton, C., and Ffytche, D. H. (2014). Art and the brain: a view from dementia. *Int J. Geriatr Psychiatry.* 29, 111–26. doi: 10.1002/gps.3975

Hacking, S., Foreman, D., and Belcher, J. (1996). The descriptive assessment for psychiatric art. A new way of quantifying paintings by psychiatric patients. *J. Nerv. Ment. Dis.* 184, 425–30. doi: 10.1097/00005053-199607000-00005

Jonauskaite, D., Abu-Akel, A., Dael, N., Oberfeld, D., Abdel-Khalek, A. M., Al-Rasheed, A. S., et al. (2020). Universal patterns in color-emotion associations are further shaped by linguistic and geographic proximity. *Psychol. Sci.* 31, 1245–60. doi: 10.1177/0956797620948810

Khanna, R., Patwardhan, A., Yang, X., Li, W., Cai, S., Ji, Y., et al. (2019). Development and characterization of an injury-free model of functional pain in rats by exposure to red light. *J. Pain.* 20:1293–306. doi: 10.1016/j.jpain.04008

Kim, D., Son, S. W., and Jeong, H. (2014). Large-scale quantitative analysis of painting arts. *Sci. Rep.* 4, 7370. doi: 10.1038/srep07370

Kim, G., Kim, J. G., Kang, K., and Yoo, W. S. (2019). Image-based quantitative analysis of foxing stains on old printed paper documents. *Heritage.* 2, 2665–77. doi: 10.3390/heritage2030164

Kozinets, R., Gretzel, U., and Dinhopl, A. (2017). Self in art/self as art: museum selfies as identity work. *Front. Psychol.* 8, 731. doi: 10.3389/fpsyg.2017.00731

Lopes, A. M., and Tenreiro Machado, J. A. (2019). Complexity analysis of Escher's art. *Entropy.* 21, 553. doi: 10.3390/e21060553

Lozano, L-. M., Kettenmann, A., Vazquez Ramos, M., and Frida Kahlo. Cologne: Taschen GmbH (2021).

Martenson, M. E., Halawa, O. I., Tonsfeldt, K. J., Maxwell, C. A., Hammack, N., Mist, S. D., et al. (2016). A possible neural mechanism for photosensitivity in chronic pain. *Pain.* 157, 868–78. doi: 10.1097/j.pain.0000000000000450

Meier, B. P., and Robinson, M. D. (2009). The mataphorical representation of affect. *Methaphor Symbol.* 20, 239–57. doi: 10.1207/s15327868ms2004_1

Morriss-Kay, G. M. (2010). The evolution of human artistic creativity. *J. Anat.* 216, 158–76. doi: 10.1111/j.1469-7580.2009.01160.x

Nayak, S. R., and Mishra, J. (2016). An improved method to estimated the fractal dimension of colour images. *Pers. Sci.* 8, 412–6. doi: 10.1016/j.pisc.2016.04.092

Noseda, R., Kainz, V., Jakubowski, M., Gooley, J. J., Saper, C. B., Digre, K., et al. (2010). A neural mechanism for exacerbation of headache by light. *Nat. Neurosci.* 13, 239–45. doi: 10.1038/nn.2475

Noseda, R., Lee, A. J., Nir, R. R., Bernstein, C. A., Kainz, V. M., Bertisch, S. M., et al. (2017). Neural mechanism for hypothalamic-mediated autonomic responses to light during migraine. *Proc. Natl. Acad. Sci. U. S. A.* 114, E5683–92. doi: 10.1073/pnas.1708361114

Okamoto, K., Tashiro, A., Chang, Z., and Bereiter, D. A. (2010). Bright light activates a trigeminal nociceptive pathway. *Pain.* 149:235–42. doi: 10.1016/j.pain.2010.02.004

Romero, J., Gomez-Robledo, L., and Nieves, J. (2017). Computational color analysis of paintings for different artists of the XVI and XVII centuries. *Color Res. Applied.* 43, 296–303. doi: 10.1002/col.22211

Sapolsky, R. M. *Behave: The Biology of Humans at Our Best and Worst.* New York, NY: Penguin Press (2017).

Schilling, T., Sipatchin, A., Chuang, L., and Wahl, S. (2019). Looking through "rose-tinted" glasses: the influence of tint on visual affective processing. *Front. Hum. Neurosci.* 13, 187. doi: 10.3389/fnhum.2019.00187

Sigaki, H. Y. D., Perc, M., and Ribeiro, H. V. (2018). History of art paintings through the lens of entropy and complexity. *Proc. Natl. Acad. Sci. U. S. A.* 115, E8585–94. doi: 10.1073/pnas.1800083115

Squarcina, L., Luca, A. D. E., Bellani, M., Brambilla, P., Turkheimer, F. E., Bertoldo, A., et al. (2015). Fractal analysis of MRI data for the characterization of patients with schizophrenia and bipolar disorder. *Phys. Med. Biol.* 60, 1697–716. doi: 10.1088/0031-9155/60/4/1697

Turkheimer, F. E., Fagerholm, E. D., Vignando, M., Dafflon, J., Da Costa, P. F., Dazzan, P., et al. (2020). A GABA interneuron deficit model of the art of vincent van gogh. *Front. Psychiatry.* 11, 685. doi: 10.3389/fpsyt.2020.00685

Turkheimer, F. E., Leech, R., Expert, P., Lord, L. D., and Vernon, A. C. (2015). The brain's code and its canonical computational motifs. From sensory cortex to the default mode network: A multi-scale model of brain function in health and disease. *Neurosci. Biobehav. Rev. (2015)* 55:211–22. doi: 10.1016/j.neubiorev.2015.04.014

Turkheimer, F. E., Rosas, F. E., Dipasquale, O., Martins, D., Fagerholm, E. D., Expert, P., et al. A complex systems perspective on neuroimaging studies of behavior and its disorders. *Neuroscientist.* (2022) 28:382–99. doi: 10.1177/1073858421994784

Turkheimer, F. E., Smith, C. B., and Schmidt, K. (2001). Estimation of the number of "true" null hypotheses in multivariate analysis of neuroimaging data. *Neuroimage.* 13, 920–30. doi: 10.1006/nimg.2001.0764

Uttley, L., Stevenson, M., Scope, A., Rawdin, A., and Sutton, A. (2015). The clinical and cost effectiveness of group art therapy for people with non-psychotic mental health disorders: a systematic review and cost-effectiveness analysis. *BMC Psychiatry.* 15, 151. doi: 10.1186/s12888-015-0528-4

Wadeson, H., and Carpenter, W. T. A. (1976). comparative study of art expression of schizophrenic, unipolar depressive, and bipolar manic-depressive patients. *J. Nerv Ment Dis.* 162, 334–44. doi: 10.1097/00005053-197605000-00004

Wiercioch-Kuzianik, K., and Babel, P. (2019). Color hurts. The effect of color on pain perception. *Pain Med.* 20, 1955–62. doi: 10.1093/pm/pny285

Yoo, W. S., Kim, J. G., Kang, K., and Yoo, Y. (2021). Extraction of colour information from digital images towards cultural heritage characterisation applications. *SPAFA J.* 5, 1–14. doi: 10.26721/spafajournal.2021.v5.690