Assessment of Neuroaesthetic Criteria to Select Hedonic Stimuli for Rehabilitation: A Preliminary Study

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Abstract. In recent years, research has increasingly explored the efficacy of art therapy for conditions such as stroke, uncovering benefits like the "Michelangelo effect," which enhances motor performance in individuals exposed to aesthetically pleasing artwork during specific activities. While standardized stimuli are often used, their clinical effectiveness is questionable. Providing a positive experience with subjectively appreciated visual stimuli is crucial, as it enhances patient engagement and therapeutic outcomes. For this reason, our study aims to understand which paintings, starting from an existing dataset, are most appreciated and which characteristics make them more interesting for observers. We enrolled 59 healthy subjects who evaluated 60 abstract paintings based on pleasantness and element salience. Results highlighted preferences for warm colors, prominent elements, and a sense of movement influencing aesthetic appreciation. Possible hypotheses of these results are linked to the importance of spatial attention, depth perception and visuo-motor integration when viewing paintings. These findings informed the selection of stimulus sets for future motor neurorehabilitation protocols.

Keywords: Neuroaesthetics · Hedonic Stimulus · Virtual Reality · Gestalt · Rehabilitation · Visual Attention

1 Introduction

Artwork appreciation involves spontaneous neural processes that activate brain arousal, affecting cognitive and motor areas [5]. In stroke neurorehabilitation, art observation and art therapy are used to reduce psychological disorders and

improve physical and cognitive functions [11]. Iosa et al. theorized the Michelangelo effect, developing a virtual reality task in which patients, moving their hand across a virtual canvas, have the illusion of painting masterpieces such as "The Birth of Venus" [20]. The initially blank canvas gradually fills in as the patient-controlled cursor reveals its individual parts. Further investigation into what qualities of stimuli are considered "appreciable" and deepening knowledge about the basis of the Michelangelo effect has thus become necessary to design increasingly engaging rehabilitation activities for patients.

Proposing standardized stimuli to patients during their rehabilitation can be useful and simpler from an organizational point of view, but it is highly questionable whether it is the most effective option in clinical practice. On the other hand, providing a positive experience for the patient is crucial. In this specific case, it means proposing visual stimuli that are pleasant. It is important to present something that is subjectively appreciated and liked by the individual. This can significantly enhance their overall engagement and therapeutic outcomes.

In this pilot study, 59 healthy subjects observed 60 paintings. The main aim of this study is to gather subjective data regarding the appreciation and emotional impact of selected paintings and to understand the visual patterns that are most appreciated by the participants.

Results showed that visual stimuli that reduce the attentional effort required to understand the visual hierarchy of the painting and those that give an illusion of movement are favored.

The structure of the paper begins with an overview of the current state of the art, followed by a discussion of the theoretical background. It then moves on to detail the materials and methods used in the study. The results are presented next, which lead into the discussion. Finally, the paper concludes with a summary of the findings and suggestions for future work.

2 State of the art

In the first study from which the Michelangelo effect emerged, 20 healthy subjects and 4 stroke patients performed a virtual reality painting task with artistic and control stimuli (simple coloring) [20]. In the healthy subjects, the artistic task resulted in shorter trajectories and lower perceived physical fatigue. In stroke patients, only those treated with art stimuli reduced errant movements. The group treated with virtual art therapy (VAT) showed significant improvements in independence in daily activities and pinch strength compared with conventional rehabilitation. However, it is unclear whether these effects were due to the aesthetic experience of beauty or specific to the artistic stimuli [6]. To further investigate the effect of artistic stimuli, they removed the white background used as a control and compared paintings and photos, categorizing them into beautiful and non-beautiful groups [21]. The beautiful paintings were famous artistic portraits, while the non-beautiful ones were approximate reproductions. The photos of popular people were matched to the paintings by similarity of facial features, posture, and clothing. The beautiful photos featured people renowned for

their beauty, while the non-beautiful photos depicted individuals not recognized for their aesthetic appeal. The authors found that less effort was perceived for paintings than for photos, but there was no difference between beautiful and non-beautiful stimuli. In art paintings, subjective beauty was negatively correlated with perceived fatigue and errors. These results indicate that the Michelangelo effect is significant with artistic artifacts, modulated by the perceived beauty of the artistic stimulus, rather than by the overall beauty of any stimulus.

Previous research has highlighted the benefits of art therapy and the Michelangelo effect, particularly in enhancing motor performance and reducing perceived fatigue during rehabilitation tasks. Studies have shown that using aesthetically pleasing art can lead to significant improvements in both healthy subjects and stroke patients. However, these studies often compare artistic and non-artistic stimuli without delving into the specific visual criteria that might influence the effectiveness of these stimuli. As far as we know, no comprehensive studies have attempted to systematically assess which visual characteristics, such as color, composition and movement, might modulate this phenomenon. Understanding these criteria is crucial for optimizing the use of visual art in therapeutic settings and ensuring that the stimuli employed are both engaging and effective.

Our research aims to address the following key questions:

1. Are there criteria derived from Gestalt psychology that can help maximize the liking of visual stimuli? Specifically, is the figure-ground principle more influential than other Gestalt principles? (The reasons behind these hypotheses are further explained in the 3.1 section).
2. How is visual attention, particularly as it relates to the figure-ground hypothesis, connected to the liking of visual stimuli?
3. Why does the Michelangelo effect occur with paintings but not with photographs?

3 Theoretical Background

The Michelangelo effect, that is the positive correlation between subjective beauty and improved post-stroke motor performance, appears to be associated with the satisfying feeling that comes from observing a work that is deemed pleasurable (and particularly with the reduction in perceived fatigue during movement) [21]. In the tasks related to the Michelangelo effect, the painting gradually emerges as a result of the viewer's movement. The observed phenomenon is related to perceptual grouping, the mechanism that allows the image to emerge through clustering of salient features from initially indistinguishable visual information (see Figure 1), mediated by the inferior temporal circumvolution (ITC). In Perceptual grouping addition, limbic reinforcement signaling - with the amygdala playing a leading role - is associated with satisfaction in recognizing an object or making a link between perceived visual features. The limbic system serves as a hub for vision modules (V1-5) such as space, color, depth, and motion before further processing, suggesting an important role for perceptual reinforcement [32].

Fig. 1. Perceptual grouping [32].

When a visual features cluster becomes perceptually evident as an object with boundaries, the limbic system would also make the other visual modules stick to that cluster to facilitate its processing [32].

3.1 Gestalt Psychology and figure-ground hypothesis

Exploring certain visual patterns - such as shape, color, and depth illusion - in experiments pertaining to the Michelangelo effect could clarify some mechanisms and possibly improve their effectiveness. Gestalt psychology provides interpretive and taxonomic tools for understanding the visual patterns that lead to clustering. This theory has formalized various principles that guide the observer in the perception of individual visual elements, facilitating the understanding of an overall image [36]. For a general reference to Gestalt principles, "Principles of Gestalt Psychology" by Kurt Koffka [24] is suggested.

Fig. 2. Figure-ground ambiguities, Gestalt theory

The figure-ground principle could be considered fundamental to all other Gestalt principles because it determines what is perceived as the central figure versus what is seen as the background (see Figure 2). For example, in the similarity principle, several dots are perceived as a group because they are similar. Still, to distinguish each dot, it is first necessary to distinguish the figure from the background. Thus, the figure-background principle can be considered as both the starting and ending point for the other gestalt principles. These principles serve to aggregate individual objects into a whole by distinguishing what is part of the figure from what constitutes the background.

This holds considerable interest because, as can be witnessed in the Michelangelo effect, there is a gradual (and interactive) emergence of a figure or, as mentioned earlier, a cluster of interest, which is definitely related to the figure and background perception. [36]. On the subject of perspective, it is curious that in a VR study the area V3a was considered in the results as an attention gating area [29]. It indeed plays a role as a junction between the dorsal-dorsal, ventral-dorsal and ventral streams, in a perfect position to offer preliminary input to different visual pathways and influence multiple processes within the visuomotor system. Generally speaking, visual attention defines the clustered objects vs. the non-clustered in a figure-ground fashion. As we are specifically referring to the Michelangelo effect, it must be recalled that the effect involves interaction with the visual stimulus and not mere observation. Indeed, depth perception becomes crucial in movement, such as trying to grasp an object: by keeping one eye closed and missing stereoscopic depth, the difficulty in performing the action becomes apparent.

3.2 The role of attention

Given the above, let us consider the relevance of visual attention, which based on where it is directed can define what is part of a perceptual cluster and what is not. First of all, attention seems to be strongly involved in the evaluation of a painting, with the anterior cingulate cortex being activated only when an artistic stimulus is deemed pleasurable [22]. First, it should be asked: does it act by increasing the response to an expected visual stimulus or by decreasing/filtering irrelevant information within the receptive field? The answer depends on the cortical area we are observing. The following discussions on **Attended stimuli** and **Attention filter** provide important examples for both answers.

Attended stimuli In the first case, the reaction of the posterior parietal cortex (PPC) can be investigated. The PPC shows increased neural activation when attention is focused within the receptive field of a neuron. This area directs spatial attention but does not provide details about specific stimuli. In monkey studies, the PPC is activated during attention to a bright spot, independent of eye movements [38]. In addition, cells in the PPC are activated before the stimulus becomes visible, suggesting early preparation [38]. In addition to visual attention, the PPC is also involved in other related cognitive processes, such as

the translation of visual information into appropriate actions. Some cells in this region show selectivity to the presented stimulus and the outcome of the task, indicating whether the animal is going to make a correct or incorrect choice [39].

Attention filter Spatial attention selects relevant information and filters out irrelevant information. Receptive fields of neurons increase from striatal cortex to ITC, but selective attention limits information processing. In visual area V4, the response of neurons varies according to the attention paid to specific stimuli [30]. For example, a neuron's response is greater when the monkey expects an effective stimulus than an ineffective one, even if both are present. This effect is also observed in the ITC, where the receptive fields are larger. In image interpretation, as a Dalmatian, attention facilitates the identification of relevant blobs, filtering out the irrelevant and guiding the attentional pattern (see Figure1).

4 Material and Methods

An experimental protocol was developed, given the theoretical considerations discussed in the previous sections.

4.1 The Database

As mentioned earlier, an existing database was used to select the 60 paintings used in this study. In particular, we selected paintings from the VAPS (Vienna Art Picture System) database [12]. It was important for us to measure the hedonic score of the paintings, which is why we decided to focus on abstract art: usually, it lacks the gestalt principle of past experience. Indeed, "past experience" can influence our perception of the pleasantness of a painting, as familiarity and ease of understanding can contribute to our aesthetic appreciation [37]. The original VAPS database, comprising 999 paintings, included 179 abstract paintings. For this study, we selected 60 paintings from this set of 179. This choice was made for practical reasons. The paintings were selected excluding: paintings with writing, logos, and any other elements that overtly invoke the Gestalt principle of past experience. Similarly, we omitted clearly anthropomorphic elements, which tend to draw attention and could therefore skew the analysis of compositional criteria on salience. Finally, we aimed to preserve as much internal variability as possible from the initial sample of 179 stimuli, prioritizing the removal of redundant paintings (for instance, those by an author represented multiple times in the database were more likely to be removed compared to paintings by unique authors).

4.2 Participants

In accordance with the Declaration of Helsinki, all participants received detailed written and verbal information about the study. The study was approved by

the ethics committee of the Catholic University of the Sacred Heart of Milan, protocol n. 90/24. All participants were required to have no severe visual impairments to complete the test and to be at least 18 years old. All of them were volunteers. The final sample consisted of 59 participants. The average age of the sample was 29 years, ranging from 20 to 67 years, and 74.4% of the subjects were male. Most subjects were recruited from a university, resulting in a fairly homogeneous educational background, with 58% having a high school diploma as their highest degree. Most participants had little to no formal art education to ensure optimal test conditions, aligning with the empirical standards of similar studies and supported by other research [13]. The average response to how often they visit museums was 1.8.

4.3 Experimental Protocol

Participants were welcomed by the experimenters, informed about the study procedures, and asked to read and sign the written consent. The experimenter then asked them to answer some preliminary questions (see paragraph 4.4). The experimental setup foresaw using an Alienware 15 R3 computer connected to a DELL P2719H 27" monitor. PowerPoint displayed images, with the presentation on the DELL monitor on full screen. Google Forms was utilized for questionnaires on the Alienware PC. The participants were seated with the PC and monitor in front of them, approximately 40 cm away from the PC and 60 cm from the display. The room was quiet, with only the researcher present to provide technical support if needed. The experiment was conducted in the cognitive psychology laboratory at the Catholic University of Milan (see Figure 3).

Participants were therefore subjected to observation of the 60 images, divided into 3 blocks of 20. The criterion for constructing the three blocks was simply the order in which the 60 paintings appeared in the original database. The order of exposure of the 3 blocks was randomized, and between each block, the participants were allowed to take a short break. Each image appeared on the screen for 15 seconds; after this time, the screen turned black, and participants answered questions on a nearby computer regarding the painting they had just seen (see paragraph 4.4). Once this was completed, participants pressed a key on the first computer to view the next painting for 15 seconds, and so on.

4.4 Measures

As mentioned, participants answered preliminary questions on a questionnaire created with Google Forms. Specifically, participants provided their age in completed years, gender, education level (elementary school, middle school, high school, bachelor's degree, master's degree, Ph.D, or other), frequency of visiting art galleries (using a 5-point Likert scale from "never" to "very often"), and their baseline emotional state. For this last aspect, participants completed the SAM (Self-Assessment Manikin) questionnaire [3]. This illustrated nonverbal tool was used to directly measure valence associated with a person's affective response to a stimulus.

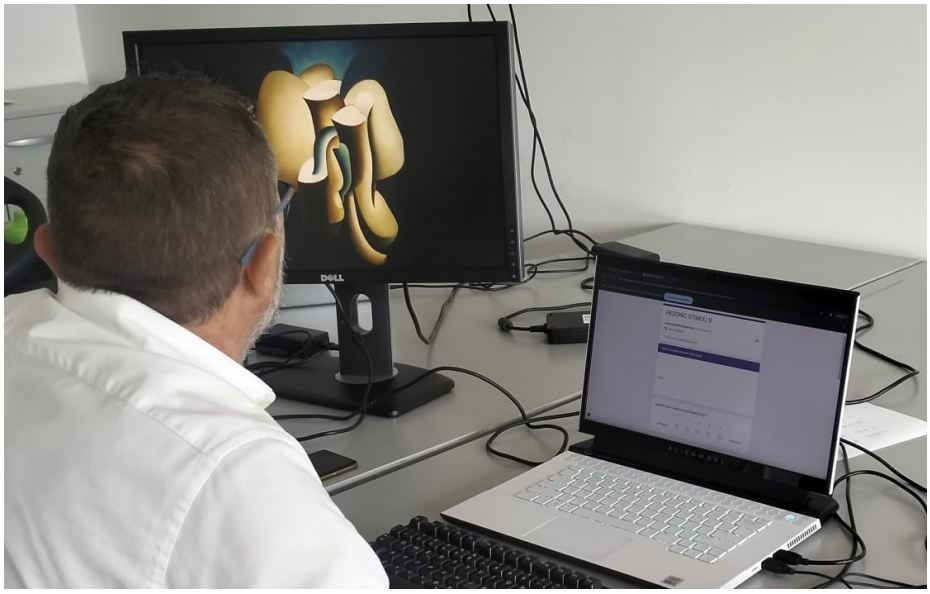

Fig. 3. The experimental setting.

Furthermore, after observing each image, the participants replied to related questions on a Google form. In particular, they scored the hedonic aspect of the painting ("How much do you like the painting you have just seen?", 5-point Likert scale) and tried to identify the element in the image that caught their attention, namely the salient stimulus ("Was there an element of the painting that first caught your attention? If so, which one?"). The hedonic aspect is - in our study - the most interesting because it is related to motor performance in the Michelangelo effect. This second question was essential to gain information on which elements might be the most involved in the clustering of visual components in the formation of the total image to find any correlations between it and the quantitative parameters. Finally, participants filled out the SAM [3].

4.5 Analysis

The collected data were analyzed through two distinct approaches.

Concerning quantitative variables, namely the responses related to hedonic aspects and the three questions addressing emotional impact, the 10 most liked and 10 least liked paintings were identified. Furthermore, the top 3 and bottom 3 paintings on the hedonic characteristic scale were compared with the top and bottom three paintings from the VAPS dataset [12], which, having a larger sample, is generally considered more reliable. The liking score within the VAPS database is shown in the Table 1. These paintings were also analyzed to determine the most frequent response to the qualitative question. This approach was chosen to test our figure-background hypothesis.

Regarding responses to the open-ended question "Was there an element of the painting that first caught your attention? If so, which one?", we categorized the answers in clusters to identify common themes or elements that catch the participants' attention, facilitating an understanding of which aspects of the paintings are most captivating.

Despite the importance of the emotional aspect in this context, in this study, we focused on the hedonic characteristic and the salience of the stimulus, which is why we did not analyze the SAM data.

Table 1 shows the paintings sorted by mean liking value, i.e., observer's liking, the value we are most interested in.

Table 1: Table 1

Title	**Liking**
Yellow and Green Brushstrokes	4,600
Giverny VII	4,400
Rêve de flamme	4,350
Coloured Composition	4,250
Sulla	4,250
Ballerina bow sea	4,100
Aufgehender Stern	4,100
Mural	4,050
Mundus est Fabula	4,000
Abra Variation I	3,950
Composition VIII	3,950
Silent World	3,950
On Brooklyn Bridge	3,950
The Passage from Virgin to Bride	3,850
Dynamik eines Fußball-Spielers	3,800
Cone (Kegel)	3,800
Convergence	3,800
Rising Sun	3,750
Proun 19D	3,750
Bather	3,750
Vonal-Stri	3,750
Fighting Forms	3,750
Untitled	3,750
The Liver is the cock‘s comb	3,700
Bi-Octans	3,692
Asheville	3,650
Abstrakte Studie	3,650
On a Sailboat	3,567
Localization of Graphic Motifs II	3,550
Eau de Vie	3,550

Beta Lambda	3,533
Gray Relief on Black	3,517
Flower Forms	3,500
Pink Compensation (Ausgleichrosa)	3,417
Two Blues I	3,400
The Tulips	3,400
Composition	3,400
Years of Fear	3,392
Ungarische Felder	3,300
Suprematische Komposition	3,300
Mahoning	3,300
Swifts, Paths of Movement and Dynamic Sequences	3,300
Composition	3,250
Small Pleasures	3,200
Composition V	3,200
Untitled	3,100
Saman n° 3313	3,100
Fire at Full Moon	3,050
Abstract Speed and Sound	3,050
Gestalt-Zoeld	3,050
The Twenty First Very New Painting	2,950
Abstract Composition	2,950
Composition Dramatique	2,800
Convexity	2,800
Black Friday	2,750
Penetrating Green	2,700
Proun (Project for Progress)	2,550
Painting	2,450
Composition	2,400
Sans Titre	2,200

5 Results

5.1 Hedonic Aspect of the Paintings

From the statistical analysis of the questionnaire results, a graph highlighting the top 10 and bottom 10 stimuli based on participants' liking was extrapolated (see table 4).

Figures 5 and 6 list the top and bottom 3 paintings on the hedonic scale resulting from our data and those of the VAPS.

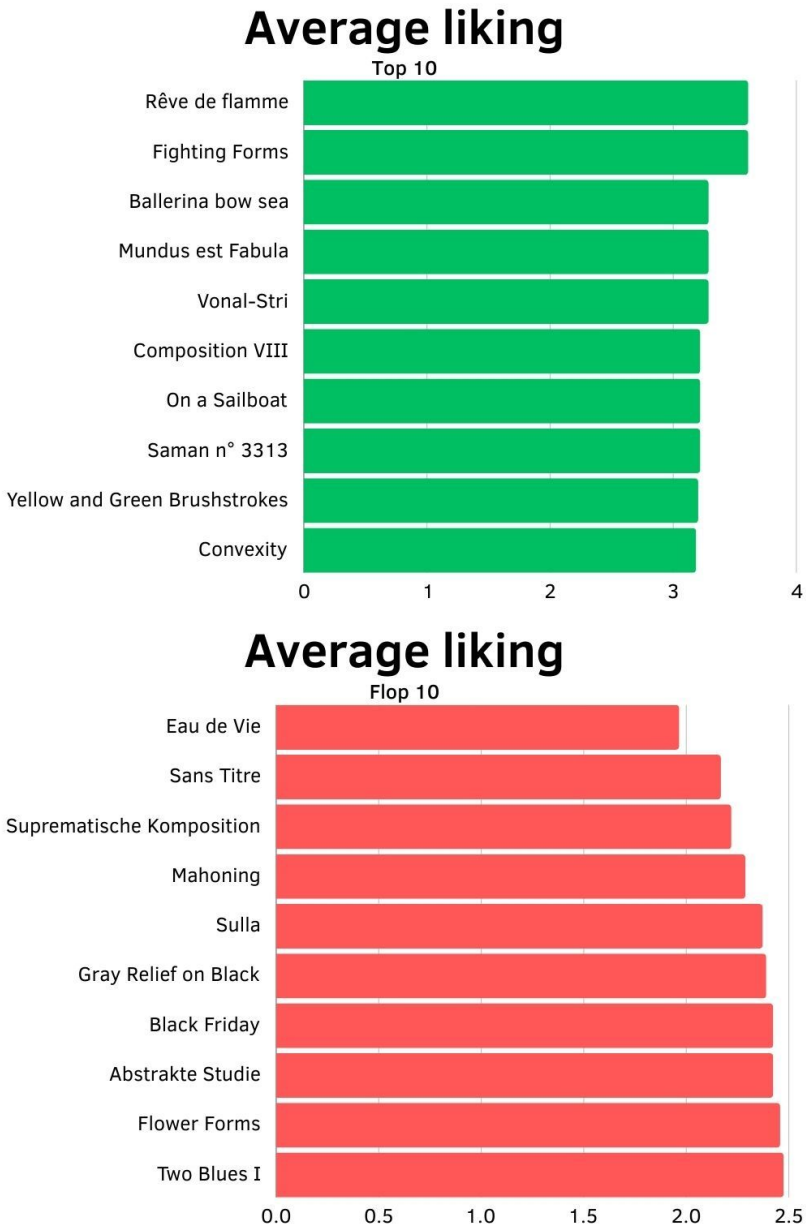

Fig. 4. The 10 most liked and 10 least liked paintings by the participants.

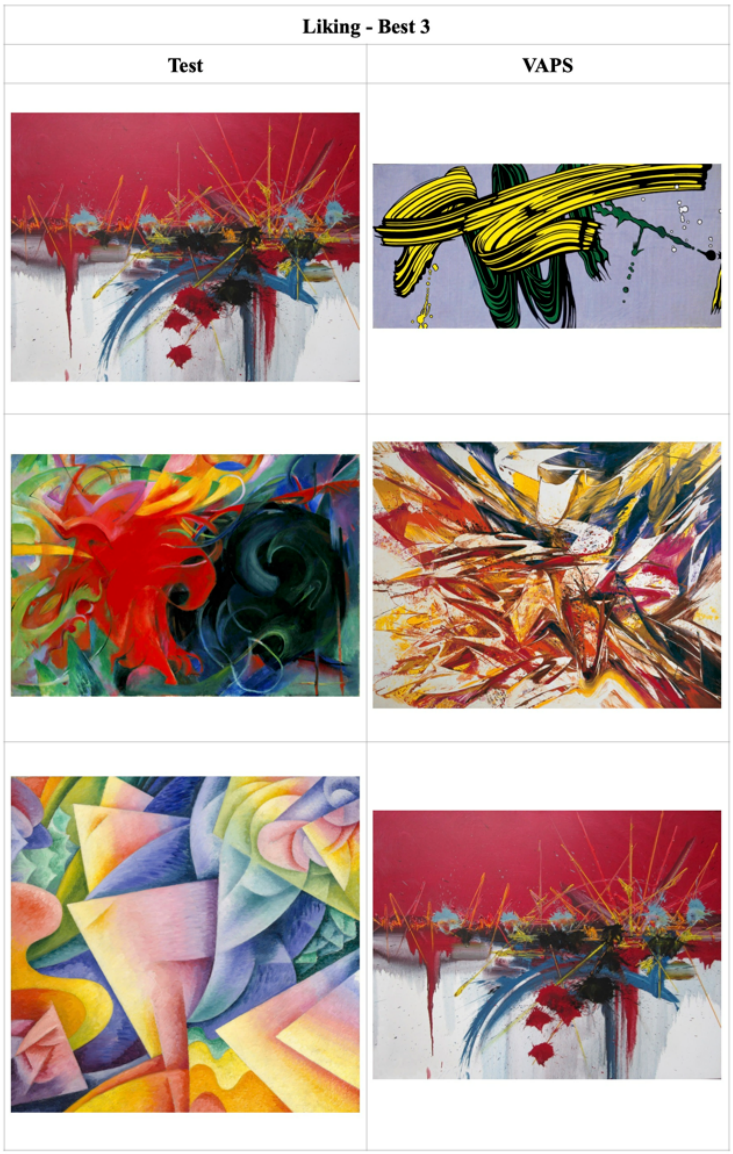

Fig. 5. Most appreciated paintings resulted from present data and VAPS.

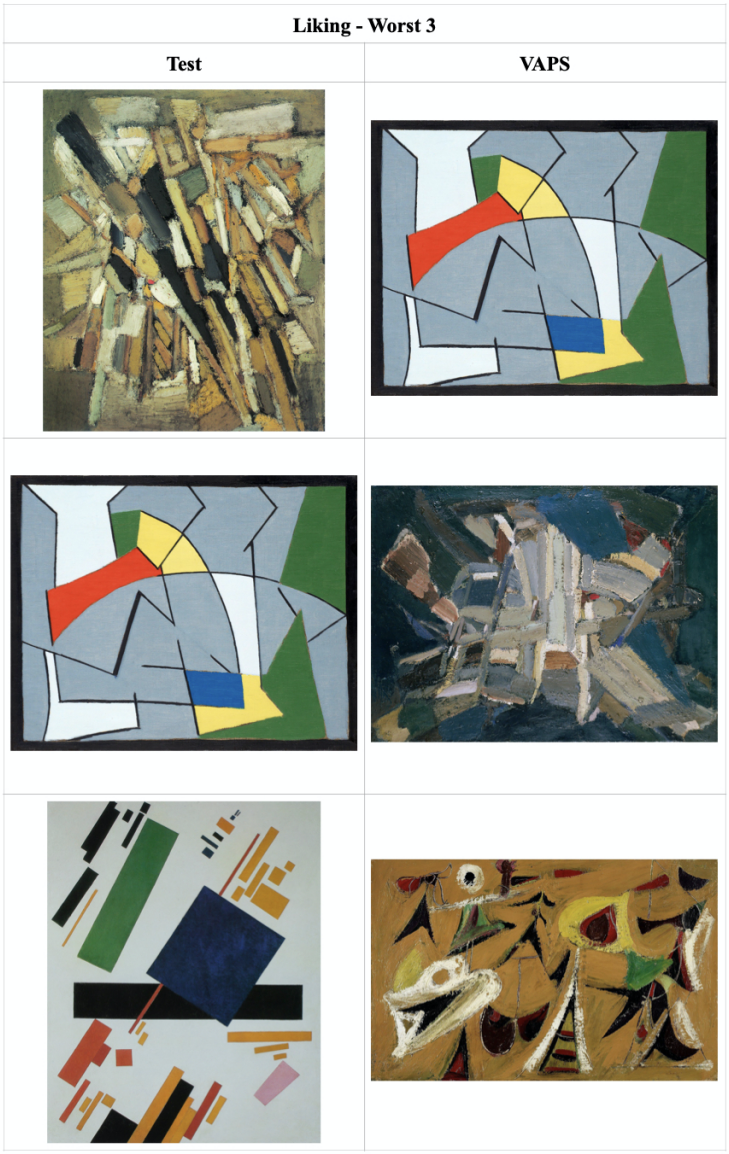

Fig. 6. Least appreciated paintings resulted from present data and VAPS.

5.2 Relation between Hedonic Characteristic and the Salient Stimulus

Table 2 reports the top 3 paintings most liked or least liked by participants, along with the most frequent reply given to the question about which aspect caught attention.

Liking +	Test	VAPS
1	Yellow lines on the center-left.	The white stripe.
2	The red vortex on the centre-left.	The red, black, and yellow U-shaped curve at the bottom on the center-right. Noteworthy is the negative response.
3	The big yellow triangle on the center-left.	The yellow lines on the center-right.
Liking -	Test	VAPS
1	Wide heterogeneity in the affirmative answers, the most noteworthy of which is the red dot on the center-left.	The red box on the center-left.
2	The red box on the centre-left.	The central vertical stripe and negative answer in a tie.
3	The central blue rectangle	The anthropomorphic figure at the top left. Noteworthy are the red and black-yellow figure on the center-right and the animal figure on the bottom left

Table 2. Top 3 most or least liked paintings, and the most common response to the qualitative question.

The analysis of the paintings with the best liking score (from both the test results and the VAPS database [12]) revealed three widespread characteristics, which were also rarer in the images with the worst liking score:

1. Warm, bright colors
2. Presence of an element unmistakably in the foreground compared to the rest. The most salient element was usually the large and conspicuous one, especially if it was brightly colored. The main exceptions were in paintings with vaguely anthropomorphic elements, particularly those resembling eyes.
3. A perceived sensation of movement, which also gives the idea of how the author has treated the surface with the brush in a decisive manner. The movement of the brushstroke projects the gesture of the extension of the hand over the medium.

6 Discussion

Our pilot study aims to identify visual stimuli's features that could positively influence liking and to take a preliminary step in this direction through an observational approach, primarily using subjective data. In this regard, some recurring features were reported by participants when asked which component of the painting had attracted their attention. These key points arise from the observation that researchers personally make of the selected paintings and the evaluation of participants' qualitative responses.

The first point, namely the presence of warm and bright colors, emphasizes the importance of color in liking. This can be interpreted in light of the high evolutionary importance of bright colors in reproductive phenomena [9], to provide signals of attraction or danger [16], or in enhancing performance in evolutionarily significant tasks for humans [17].

The second point, namely the identification of a specific object that emerges from the background, would help validate the claims made in the 'Figure-ground hypothesis' section: the presence of a salient element within the painting probably reduces the perceptual and cognitive effort needed for prioritizing, classifying, and clustering elements within the image [35]. Further quantitative studies using neuroimaging and other objective methods would be required to confirm it conclusively. It's important to note that this observation pertains to a naïve observer's perspective and may not necessarily hold for art critics. The distinction between figure and ground, or more precisely, between elements within the cluster of interest and those outside it, was far more decisive at the attentional level than initially anticipated based on other Gestalt principles. In several images, for example, groups of neighbouring and/or similar elements were rarely prioritised in terms of attention over the foreground element. On the other hand, the analysis of the least liked pictures indicates that a lack of a salient element negatively affects participants' liking and/or elicits a high degree of variability in responses. This findings suggest that the figure-ground principle might be the most influential in regard to attention and liking among all gestalt principles. Furthermore, we observed that when the figures that emerged had an anthropomorphic appearance, the fact that they were small did not matter (i.e., they captured attention regardless of size). This aligns with the anticipated outcomes described in the study protocol, which predicted that paintings with anthropomorphic features would elicit highly predictable responses. Moreover, several participants identified known objects in the abstract paintings (pareidolia). The natural tendency to perceive objects can be linked to the principle of familiarity, through which cognitive workload is mitigated, facilitating the viewer's interpretation of what they are observing. This propensity, as suggested in the model of [28], is entirely natural and spontaneous and, therefore, inevitable for humans.

The third point is indeed intriguing. It is coherent with what some authors suggested: in general, aesthetic judgment is related to movement perception [4, 7]. Regarding this aspect, a therapeutic approach that uses paintings created with a technique compatible with the specific motor deficit being addressed could be beneficial. Furthermore, future studies could investigate whether viewing paintings that depict perceived movement, thereby activating mirror neurons [10], may provide an advantage for the motor rehabilitation of post-stroke patients. We can on the one hand suppose that the Michelangelo effect and motor and premotor areas activation may be related to mirror neurons stimulation due to observing the actions performed by the painted figures [15], or from the recognition of emotions shown by the painted facial expressions [1]. Despite this, however, such activations were also found when participants observed abstract works of art (like the ones used in this study), and it has been suggested that

this is related to an empathic involvement with the viewer's implicit imagination of the movements performed by the artist to create the artworks [15]. This would at least partially validate the so-called functional parallelism theory [41], according to which the artist and the visual-cognitive system of observers are guided by the same purposes: to organize visual information to capture the essential features of the scene and produce a faithful representation of them. The originator of the theory, neuroscientist Semir Zeki, speaks more explicitly of a functional parallelism between art and visual brain, which only in a broader sense can be interpreted as between artist and observer. The involvement of mirror neurons, however, does not only gain significance from the perspective of functional parallelism theory and related possible speculations. The increased excitability of motor neurons during the observation of portraits is something that has already been attested [2], although it does not occur with all works. It is important to note, in parallel with the Michelangelo effect, how this increase occurs with the observation of the painting and not with its photographic version. The researchers of the study in question provide as a possible explanation author's skills in giving a sense of movement to the work. A further clue comes from another study [34], also providing a possible bridge between functional parallelism and liking in the Michelangelo effect. Images of a gloved hand holding a paintbrush were used as supraliminal priming before displaying a pointillist-style painting. There were three conditions: a precision grip (compatible with pointillist style), a power grip (incompatible), and a resting hand with the palm facing downward (control). The preference expressed when the paintings were preceded by priming images that activate motor programs compatible with the production of pointillist-style brush strokes was higher than that expressed for the incompatible and control conditions. all that has been said so far could be explained by hypothesising the existence of mirroring circuits whose activation would not necessarily require observing an action in itself, but would suffice the observation of its consequences. It is already known that audio-visual mirror neurons are activated both if a monkey performs an action (e.g., cracking a peanut) and if it hears the resulting noise (it hears the sound of the shell cracking) [25], and it would be worth testing whether this could also occur in artistic experience. A partial clue would come from the fact that an artist's mirror neurons are activated when he observes movements related to the style of painting familiar to him but not when he observes movements employed in styles of painting in which this is not practical. [33]. Lastly, it is important to note that when observing an event, there is a natural tendency to assume that it was produced by someone [23], and paintings are no exception to this trend. If, in addition to the movement sensation in a painting (which in itself can provide a more complete perceptual experience), it is added that the work reveals the intentions and actions of the agent who produced it, it should be quite easy to explain how the appreciation in viewing a painting can be superior to that of a photograph.

Differences between the results of our and [12] data are present, even if a specific and secure motivation cannot be pointed out. A possible hypothesis is that linguistic-geographical-cultural differences affect the subjective liking of

the paintings. Some studies suggest there is a kind of transcultural agreement regarding paintings among people interested in art [14], whereas such agreement has not been found in studies involving individuals who are not art experts [27], exactly like ours.

The identification of the most pleasing artistic stimuli provides a crucial foundation for developing adaptive eXtended Reality (XR) environments that enhance motor rehabilitation. By leveraging biocybernetic closed-loop systems, these stimuli can be dynamically adjusted in real-time based on the physiological states of patients. For instance, the system can monitor neuro/biosignals to provide real-time feedback and adapt the visual stimuli accordingly. This adaptability can increase the vibrancy of colors, enhance the prominence of elements, or adjust the perceived movement within the artwork to maintain optimal engagement and minimize fatigue. Having objective criteria for the production of effective hedonic stimuli is essential in adaptive contexts. A previous study focused on developing and evaluating an adaptive multisensory VR system for emotional self-regulation, utilizing EEG-based neurofeedback to enhance anxiety regulation capacity [8]. The approach combines adaptive visual and auditory stimuli based on neuroaesthetic principles, highlights the importance of objective criteria in producing effective hedonic stimuli. Objective criteria ensure that the stimuli can be systematically adjusted to optimize therapeutic outcomes, rather than relying on subjective judgments which may vary widely among individuals. The use of peculiar artistic elements enhances the engagement and effectiveness of the rehabilitation process. In this context, Pellegrino et al. also utilize aesthetic stimuli by incorporating puzzles of artworks into the XR environment for assessing hand apraxia [31].
A stimuli standardization is particularly important in the context of neurorehabilitation, where the precise modulation of sensory inputs can significantly impact the effectiveness of the therapy. By establishing and utilizing objective criteria, adaptive XR systems can provide consistently high levels of personalization and effectiveness, ensuring that each patient's unique needs are met in a scientifically grounded manner. In general, an ad personam selection of the stimulus to be used in the motor task may still be desirable. In this study familiarity was treated as a confounder, but in a real application it should be considered and used in favour of the treatment protocol, given its correlation with liking [26, 40]. Subjecting patients to standardised stimuli (as in this study) may be helpful for comprehension purposes, but it is highly questionable whether it can be the best option for application.

7 Conclusions and Future works

In this study, we aimed to observe which of the 60 pre-selected abstract paintings were most appreciated by participants to understand the common characteristics of more or less pleasant paintings. Our aim was to identify visually salient and engaging stimuli for potential use in future rehabilitation activities for post-stroke patients. To achieve this, participants were asked to rate their degree

of liking and identify the most salient element in each painting. The results allowed us to identify key factors that make paintings more pleasant: warm and bright colors, a prominent element that stands out from the background, and the perception of movement within the image. As a practical result of the entire study, we decided to propose paintings that are consistent with our data to post-stroke patients for their rehabilitation. Therefore, a series of portraits were collected, which, as mentioned above, are probably best suited to applying the Michelangelo effect and in which the three visual criteria are approximately met. In Figure 7 six examples recommended for the upcoming research phase are presented.

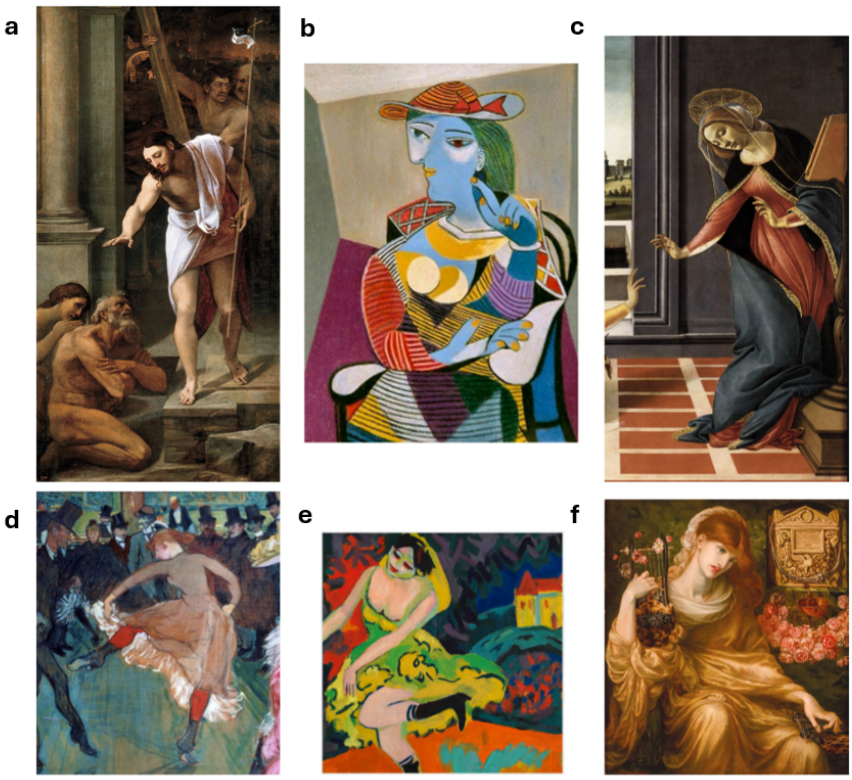

Fig. 7. Paintings recommended for the upcoming research phase: a) Christ's Descent into Limbo, b) Seated Woman, c) (Cestello) Annunciation, d) At the Moulin Rouge: The Dance, e) Varietétänzerin, f) Roman Widow.

Based on these three criteria, stimulus sets were selected and proposed for future research on virtual reality stroke motor rehabilitation protocols exploit-

ing the Michelangelo effect. Furthermore, the results of this study highlighted the possibility that occipital and parietal areas are specifically involved in the Michelangelo effect, a hypothesis to be validated with future neuroimaging studies. As for the occipital visual cortex, V3a (depth perception) and V4 (color perception) activity could be significant. As for parietal areas, in order to fully understand why the Michelangelo effect occurs with paintings and not with photos, imaging studies should be carried out to understand whether the observation of a painting is responsible for the activation of certain mirroring circuits. The peculiarity of these circuits, as hypothesized in section 6, would be that they would be activated by the mere observation of the consequences of an action (what a painting is to a brushstroke) and not necessarily by observing the action itself. Future studies should investigate whether a set of stimuli selected based on the identified criteria can enhance the Michelangelo effect, especially when compared to abstract paintings.

7.1 Future Directions in Adaptive Neurorehabilitation

This study has highlighted the potential of using art stimuli to improve motor performance in future post-stroke rehabilitation protocols. Looking forward, integrating these findings into adaptive XR environments offers a promising avenue for enhancing therapeutic outcomes. By utilizing biocybernetic closed-loop systems, it is possible to create VR environments that adapt in real-time to the physiological states of users. This allows for a higher degree of personalization and effectiveness in therapy. For example, the system can dynamically adjust visual stimuli to match the patient's attention levels and arousal states, ensuring an engaging and effective rehabilitation process. The establishment of objective criteria for the creation of effective hedonic stimuli is paramount in adaptive XR environments. These criteria provide a consistent framework for tailoring stimuli to individual needs, ensuring that adjustments are based on measurable parameters rather than subjective perceptions. This approach enhances the reliability and repeatability of therapeutic interventions, leading to more predictable and favorable outcomes. As we advance towards more physiologically adaptive systems, the importance of objective criteria becomes even more pronounced, ensuring that the adaptation process is both scientifically valid and clinically beneficial. Moreover, the Michelangelo effect could be combined with Leap Motion Training. One drawback of this, in fact, is in the absence of tactile feedback, which alters the neural response [18], but it would be bypassed in a Michelangelo effect-based task. Given what has previously been discussed regarding visual attention and the theory of functional parallelism, a study involving Leap Motion Training could further explore these aspects. This would be justified in the former aspect by the influence of LPT on the activity of frontal and occipital areas [19], and in the latter by the possible link between affordances and functional parallelism.

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