Drawing and the Language of Creativity

Gaia Leandri

Abstract

This paper examines the communication of cognitive and emotional elements between a drafter and an observer through drawings. Although this topic has been explored from philosophical and psychological perspectives, it still lacks sufficient scientific evidence to determine its biological foundations. Electroencephalography (EEG) is now a recognized instrumental tool that can be used to assess the cognitive and emotional engagement of both the drawing's creator and its viewer. This study reports the results of experiments in which EEG recordings were made from four subjects who acted as both drafters and observers of drawings with presumed differences in cognitive-emotive content. As drafters, the participants were asked to create both a freehand drawing and a CAD version of an architectural landscape. It was hypothesized that the freehand version would carry a stronger cognitive-emotive charge than the CAD one. Qualitative and quantitative analyses of the EEG data showed that both drafters and observers exhibited parallel responses to the same image. These findings provide experimental support for the theory that specific feelings and perceptions of the drafter are transmitted to the observer, who responds as if him/herself were the author of the drawing.

Keywords: cognition, communication, electroencephalography, freehand, CAD

Introduction

In Western culture, drawing has been regarded since the Renaissance as an aesthetic medium for transmitting the perceptions, intuitions, and ideas of its creator. A widely held view is that drawing functions as a form of visual language, as the marks made by a tool on a surface can convey meaning to the observer. The etymology of the word *disegno* supports this interpretation, although it offers a somewhat reductive view of its many dimensions. While the signs of the alphabet are now conventional symbols, a traditionally defined language cannot evoke meaning in the same immediate and expressive way as a drawing. Drawing establishes a direct form of communication between the drafter and the viewer.
This idea was first articulated by Leonardo da Vinci, who, in his reflections on painting, and, by extension, drawing, asserted that "the purpose of painting is understood by all generations across the universe, for it engages the sense of sight [...] it needs no translation into different tongues" [da Vinci 1817, p. 47, translation by the author] [1]. And again, "the painter will create countless things that words cannot name, for want of appropriate terms" [da Vinci 1817, p. 4, translation by the author] [2]. Leonardo's words transcend the theoretical and mechanistic boundaries within which drawing was once confined, seen merely as a means of developing techniques to represent visual reality. It was only in the last century that drawing began to receive serious attention from philosophers and psychologists as a distinct mode of perception, experience, creativity and communication. Initially regarded as a representation of something perceived in the visible world,

Fig. 1. Drawing as an inner language (drawing by the author).

drawing came to be understood also as a reflection of the drafter's imagination or as an attempt to formulate new ideas. The forms in a drawing are categories of thought that conventional language cannot fully express. Speaking about drawing, Merleau-Ponty said "It is more accurate to say that I see according to it, or with it, than that I see it" [Merleau-Ponty 1996, p. 126].
This insight underscores the idea that the human body, with all its senses, plays a central role in perceiving, thinking and drawing. Merleau-Ponty's theories linking the eye, mind and hand highlight the interplay between manual and mental activity. Historically, this connection has been acknowledged by both artists and thinkers. The Italian painter Cennino Cennini, in the fourteenth century, recognized the hand as both a creative and cognitive instrument, stating: "do you know what will happen when you practice freehand drawing? It will make you skilled and experienced, and will foster many drawings within your head" [Cennini 1821, p. 11, translation by the author] [3]. Similarly, Leonardo claimed: "whatever exists in the universe by essence, presence, or imagination, the drafter first holds it in the mind, and then in the hands" [da Vinci 1817, p. 7, translation by the author] [4]. These artists understood drawing as a process that reveals, through images, what cannot be expressed in any other way. Drawing is the act of invention, it is itself an invention. This mental process becomes a generative act through the drafter's body (fig. 1). Making a drawing and looking at it are two intertwined activities of bodily subjectivity. As Merleau-Ponty explains, "between the see-er and the visible, between touching and touched, between one eye and the other, between hand and hand a kind of crossover occurs" [Merleau-Ponty 1996, p. 125]. The hand's capacities: perception, action, cognition, social interaction and communication, demonstrate its centrality to drawing as a creative and intellectual endeavor.
Even with the widespread adoption of computer graphics, the importance of bodily engagement and manual skills in the drawing process remains paramount. Pallasmaa asserts: "All students of design and architecture should first be taught to work with their internalized mental imagery and their hands before they are allowed to use the computer. […] Without this mental internalization, however, the computerized design process tends to turn into a purely retinal journey in which the student him/herself remains an outsider and observer without having built a vivid mental model of the conceived reality" [Pallasmaa 2009, p. 99]. Calatrava echoes this sentiment: "With drawing, you are always working with the same two instruments, your hand and your intuition; even if it seems you have no conscious aim, you're continually trying to solve a real construction problem" [Carrillo de Albornoz, Calatrava 2018, p. 180].
The complex network of feelings and thoughts embedded in a drawing can be perceived by the observer, who apprehends what is communicated through interaction with the drafter's creation. A drawing that begins as a monologue becomes, in the end, a fruitful dialogue. Leonardo describes this process of visual communication succinctly: "those paintings, if the crafted acts are well proportioned with the ideas, will be understood as if they spoke" [da Vinci 1817, p. 12, translation by the author] [5].
It is interesting that theoretical reflections on the bodily and mental features of drawing, in its broadest sense, are now recognised as being firmly grounded in biological

principles, sometimes with surprising implications. For instance, line drawing, is a preferred method for sketching easily recognizable objects. This preference parallels the behavior of specialized neurons in the visual pathway that process the edges of an image, which correspond to sharp changes in luminance [Marrocco, Li 1977]. Evidence has been found that "visual processing is, both on neural and perceptual level, highly edge dominated" [Kilpeläinen, Georgeson 2018, p. 1593.1].
Similarly, the highly complex process of facial recognition seems to be mainly performed by well identified neurons [Freiwald, Tsao 2014; Gross 2002].
Research on the neural basis of movements and their preparation has long detected neurons involved in the fine motor control of the hand, whose movements represent the final stage of creative mental processes [Sobinov, Bensmaia 2021]. The numerous sensory organs pertaining to the hand are not only essential for precise movement execution, but also play a critical role in generating further ideas of movement [Leandri et al. 2022; Orth et al. 2017]. Since the early 20th century, advancements in electrophysiology have allowed for the non-invasive recording of neural activity of the brain cortex from the surface of the skull, which goes under the general name of electroencephalography (EEG), a completely safe technique. Two specific variants of electroencephalography have been instrumental in assessing cognitively salient perceptions and gestures. These are the Visual Event Related Potentials (VERPs) and Movement Related Potentials (MRPs), which are obtained by synchronizing movements or image presentation with the EEG recording. However, these techniques have yet to be applied to the creative process of freehand drawing, particularly as a communicative tool, or to the cognitive responses evoked in the observer by the drawing itself.

Aims of the research

This paper is the report of a series of experiments performed to fill such a gap, with a completely new approach using Movement Related Potentials (MRPs) [Shibasaki, Hallett 2006] and Visual Event Related Potentials (VERPs) [Luck 2014] recorded during both the creation and observation of drawings. The primary aim of this study was to detect and investigate the cognitive link that is supposedly established between drafter and observer through the drafted image. A further aim was to ascertain the effect that different saliency attributed to the image could have on the recorded potentials.

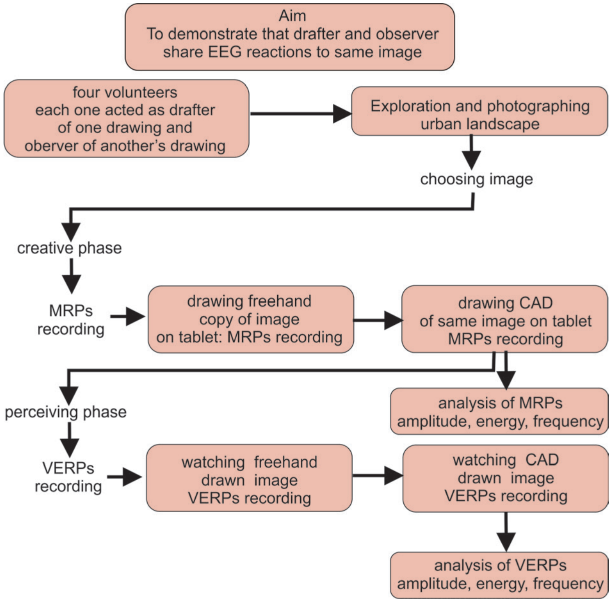

Fig. 2. General plan flowchart (elaboration by the author).

Methods

This investigation is a proof of concept and feasibility study involving the fields of design, neurophysiology and neuropsychology. The experiments described in this paper are just a part of a larger set that is already under way and that are meant to confirm and integrate the results so far achieved.

General plan
Four subjects, experienced in the use of a drawing tablet for freehand drawing and Computer Aided Design (CAD), have been studied. They were of female gender, between 20 and 25 years of age, all right handed. They had no known neurologic or medical condition, and no history of alcohol or drug abuse. All of them provided informed consent to the procedure. The experimental procedure

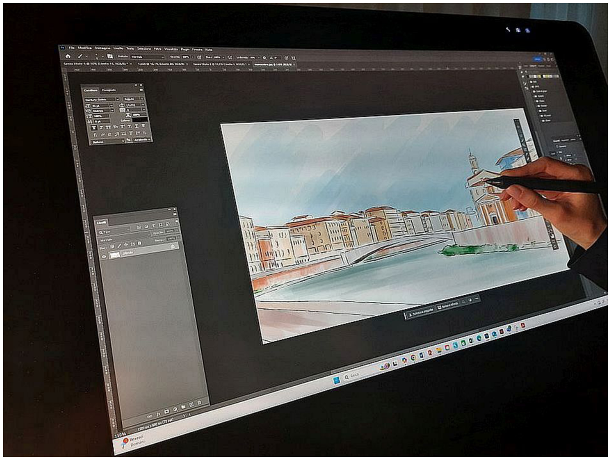

Fig. 3. Photography of freehand drawing on tablet to provide synchronization for recording MRPs (photograph by the author).

was structured in four stages, as follows. First stage: photographs of urban landscape were taken. Second stage: each subject chose one photograph, which inspired a freehand drawing, in color, drafted on a digital drawing tablet. The same photograph was used to draw a very simple CAD; during both activities, the electroencephalogram (EEG) was recorded to obtain the MRPs. Third stage: the freehand drawn image and CAD were shown to an observer (one of the four subjects, but not the author of the drawing) and VERPs were recorded. Fourth stage, offline analysis of MRPs and VERPs was performed to seek possible connecting elements between the drafter and observer recordings. The general plan is summarized in the flowchart of figure 2.

Recording Movement Related Potentials (MRPs)
Two electrodes were placed on the scalp, the active one over the cortical projection of the right hand movements, and the reference at the left mastoid. Signals were amplified 50,000 times digitalized at 10,000 samples/s and stored onto computer disc. Only epochs of 1,000 ms before and 1,000 ms after movements were analyzed. Synchronism with the start of each drawing movement was provided by reading the 'pen down' event from the tablet driver. Approximately 150-300 movements were acquired per each subject. The drawer was asked to draw with slow strokes, with a time gap of at least 3 seconds in between. The system automatically avoided recording faster strokes. Signal storage and further analysis were performed by dedicated applications. Figure 3 shows the tablet used to draw freehand and CAD providing the necessary synchronism.

Recording Visual Event Related Potentials (VERPs)
The aim was to record the slow components linked to cognitive/emotional activity of the observer after the visual stimulus. The best derivation to such an end implies an active electrode at the vertex and the reference at one mastoid. Signal amplification, digitalization and storage were as for MRPs. Analysis times also were identical as for MRPs, 1,000 ms before and 1,000 ms after the stimulus. The visual stimuli were presented on a 24", 16:9 computer screen, with image dimension 1,500 x 800 pixels sited 80 cm in front of the subject. The protocol of image presentation was the traditional oddball type, where the meaningful stimulus image, also called 'target', was randomly presented in low probability fashion (20% in our case) amid a more frequent (80%) stimulus image of irrelevant content, called 'distractor'. In one session the freehand drawing was presented as the target image. The CAD image was the target in a second session. In each case approximately 150 presentations were performed. Figure 4 shows the sequence of images presented on the screen. The setup for recording VERPs is shown in figure 5. The electrodes are just two and kept in contact with the head skin by two Velcro strips in lieu of the usual annoying rubber head net. This way the subject is almost unaware of wearing the electrodes and concentrates better on the shown images.

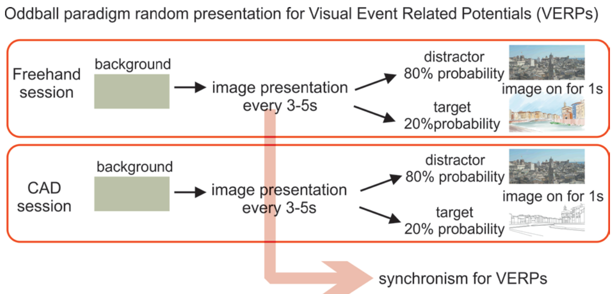

Fig. 4. Sequence of visual stimuli (flow chart by the author).

Offline processing
The EEG activity evoked by movements (MRPs) and image presentations (VERPs) has a very small amplitude and is obscured by larger, spontaneous random EEG activity, resulting in an unfavorable signal-to-noise ratio. To enhance this ratio, repeated movements and image presentations are employed, enabling the use of the statistical 'averaging' process to obtain reliable data. Statistical significance of the means derived from averaging single responses was assessed using one-way ANOVA for independent measures, with a significance threshold of $p < 0.05$. The amplitude and energy of the signal epochs of interest were calculated. Additionally, the single-sided, scaled amplitude spectrum (in µV) of the signal in the frequency domain was computed using the discrete Fast Fourier Transform.

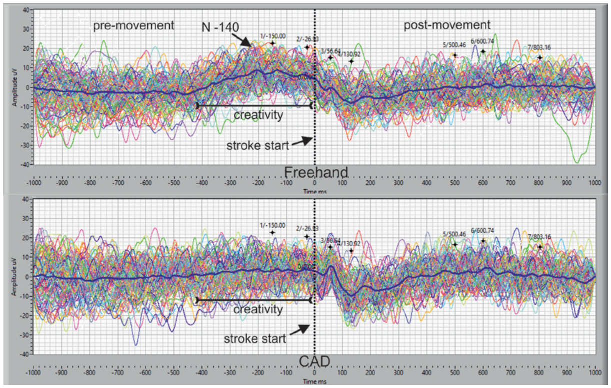

Fig. 6. The upper vignette shows the MRPs recorded during freehand drawing, the lower shows the recording during CAD drawing (elaboration by the author).

Results

The EEG recording in drawing: the creative phase
Voluntary movements of the hand are preceded and followed by a well known EEG activity, called Movement Related Potentials (MRPs); its main feature is a negative slow rising deflection starting at approximately 400 ms before muscle contraction and is generated in those areas of the brain cortex devoted to initiate and plan movements. We recorded such activity in all of our subjects either during freehand or CAD drawing on the drawing tablet. But there were very significant differences between the two. In figure 6 the recordings from subject number 2 are shown. The upper graph depicts the 140 EEG epochs relative to as many movements recorded during freehand drawing and the thick blue trace is their mean. The dotted vertical line marks the time 0, that is the moment when the pen goes down and the drawing stroke is initiated. The graph time domain (X axis) goes from -1,000 to +1,000 ms (relative to the moment of stimulus presentation), with the negative values relating to pre-movement events and positive values to post-movement events. From the mark -400 ms a negative going deflection (in neurophysiology the negative polarity is conventionally represented by upward going deflections) can be seen, peaking approximately at -150 ms and therefore called N-150 (reported in the graphs of figure 6 and in table 1). Its amplitude and energy are the reflection of the overall neural activity taking place in the time span of the wave duration (mean values are reported in table 1). The post-movement waves reflect the activity of the sensory area, receiving impulses from the hand receptors, informing that it has moved. The lower graph reports the recordings performed during the CAD drawing. It is quite evident that the deflection before time 0 is almost absent, whilst the trace after time 0 shows better defined peaks, because is devoid of the interfering influence of the pre-movement MRP. However, post-movement activity will not be further discussed

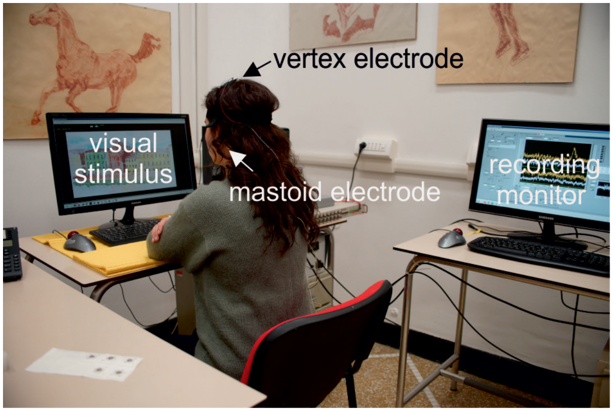

Fig. 5. Photo of recording VERPs, with freehand drawn image on the screen (photograph by the author).

MRP	N-150 amplitude		N-150 energy	
	mean	sd	mean	sd
Subject n.1 Freehand	**10.29**	5.73	**9.95**	7.31
Subject n.1 CAD	**7.5**	5.89	**5.31**	4.15
Subject n.2 Freehand	**8.33**	5.43	**7.91**	4.54
Subject n.2 CAD	**5.29**	4.38	**6.72**	4.91
Subject n.3 Freehand	**24.34**	6.12	**46.34**	14.01
Subject n.3 CAD	**7.16**	6.87	**11.41**	12.62
Subject n.4 Freehand	**28.14**	7.41	**66.7**	19.84
Subject n.4 CAD	**6.67**	5.33	**9.43**	5.35

Tab. 1. Mean amplitude of the N-150 peaks and mean energy of the signal region of interest for each subject (elaboration by the author).

MRP	Delta wave amplitude	
	mean	sd
Subject n.1 Freehand	**2.48**	1.34
Subject n.1 CAD	**0.89**	0.48
Subject n.2 Freehand	**2.24**	1.43
Subject n.2 CAD	**1.05**	0.67
Subject n.3 Freehand	**1.94**	0.92
Subject n.3 CAD	**0.53**	0.23
Subject n.4 Freehand	**2.92**	1.51
Subject n.4 CAD	**1.45**	0.89

Tab. 2. Mean amplitude of the 1 Hz (Delta) frequency of the MRP (elaboration by the author).

here, as it is not directly relevant to the creative phase, though potentially involved in the feedback loop of a broad creative process [Leandri et al. 2022].
Table 1 reports the mean values of the main assessed parameters of the signal related to the freehand and CAD drawing. The first column lists the subject number and drawing modality (Freehand/CAD); the second and third columns report the amplitude mean value and standard deviation (sd) of the N-150 wave; the fourth and fifth columns report the mean energy and standard deviation of the pre-movement signal in the time domain between -400 and 0 ms marked by an underscore in figure 5. For the sake of simplicity, and in reference to its possible function, this region of interest of the signal has been labelled 'creativity' both in the table and in figure 5. Amplitude is reported in μV units referred to the 0 line, whilst energy is in conventional units. In all subjects larger values were always obtained during freehand than CAD drawing (ANOVA analysis, significancy $p < 0.05$). These results suggest that a larger population of cortical neurons, are involved in freehand drawing than CAD, possibly reflecting creativity [Leandri, Schenone, Leandri 2021]. A further analysis has been performed as to the involved EEG frequencies embedded in the recorded MRPs and VERPs. The detailed results are reported in figure 7. The graphs depict the mean amplitude (μV) of the 0-20 Hz frequency spectrum assessed in the pre-movement epoch (Y axis reports amplitude in μV and X axis frequency in Hertz). The data clearly show that in the case of freehand drawing (graph on the left) there is a prevalence of low frequencies (0.5-4 Hz: the EEG Delta rhythm), with a high peak of 2.24 mV at 1 Hz. In CAD drawing (graph on the right) the 1 Hz peak has amplitude of only 1.43 μV. In previous work where a different EEG modality had been recorded (continuous, spontaneous EEG) [Harmony 2013] it had been found that cognitive tasks implying insight were associated with power increase of Delta rhythm. On the contrary, if the task implied attention directed towards the external world, higher frequencies (Theta, Alpha and Beta) would prevail. These changes in EEG frequencies induced by insight had been interpreted as reflecting modulation of EEG frequencies by the cognitive activity. It was also observed that the power increase of one set of frequencies would inhibit the other, as if the cortical neurons would hamper

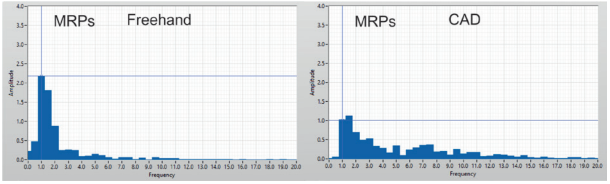

Fig. 7. Frequency spectrum of subject No. 2 during freehand (left) and CAD (right) drawing (elaboration by the author).

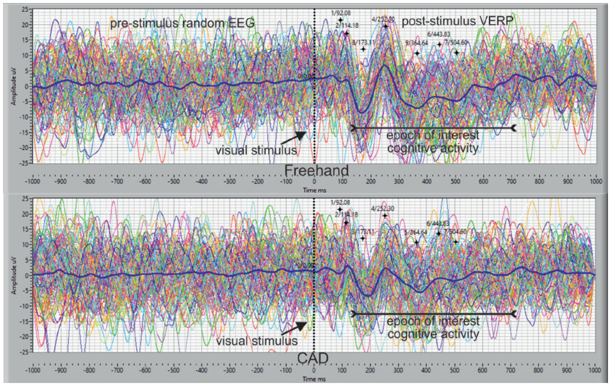

Fig. 8. Visual Event Related Potentials VERPs recorded during presentation of Freehand or CAD drawing in subject No. 1 (elaboration by the author).

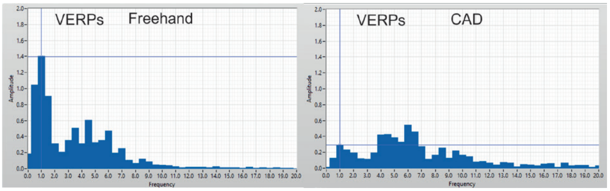

Fig. 9. Mean amplitude versus frequency in subject No. 1 while watching freehand (on the left) and CAD generated image (right) (elaboration by the author).

the less relevant, interfering thread of activity. It is straightforward, then, that freehand drawing, which requires much more insight than CAD, at least in the task performed by our subjects, is associated with more intense Delta activity. Looking at the graphs it may be inferred that the insight necessary to freehand drawing, reflected by the increased amplitude in the 0.5-4 Hz frequencies, also determines a decrease of amplitudes of the following frequences (Theta, Alpha and Beta), starting from 4.0 to 20 Hz. On the contrary, the simple CAD task, not requiring insight, does not evoke Delta activity and the higher frequencies are allowed to thrive, especially the Theta and Alpha rhythms. Table 2 reports the mean frequency amplitudes (in μV) of all subjects, with their standard deviations, showing that the observation described in the example of subject number 2 is also true for the others. ANOVA analysis confirmed the freehand-CAD differences in all subjects at significant level ($p < 0.05$).

The EEG recording in the watching phase

The produced drawings, either freehand and CAD, where made to watch by the observer, who was one of the four volunteers, but not the author of the specific drawing. The position of the active electrode was at the vertex, the best site to detect the electrical activity elicited by cognitive or emotional processing of the visual perception, which is recorded as a series of positive negative slow waves occurring at approximately 300-600 ms after the stimulus [Luck 2014]. This type of evoked response is called an Event Related Visual Evoked Potential, as it is elicited by a visual stimulus. It is not a specific reflection of the stimulus physical feature, rather it is related to other more abstract properties, like surprise, emotional drive, aesthetic appreciation or other cognitively associated characteristics [Luck 2014].
In this research the attention has been focused on the set of waves occurring between 150 and 600 ms after T0, as the most representative components of the cognitive reaction to the visual stimulus.
In figure 8 the recordings of 142 responses to visual stimuli in subject number 1 are shown, with superimposed their mean value (blue thick trace). In the upper graph a freehand drawing has been presented, whilst in the lower one a CAD drawing has been shown. It is evident how watching the freehand drawing evokes a larger amplitude set of responses. In table 3 the mean amplitudes and standard deviations of the prominent peak are reported for

VERP	Late peak amplitude		Late peak energy	
	mean	sd	mean	sd
Subject n.1 Freehand	**9.91**	6.80	**14.80**	4.49
Subject n.1 CAD	**8.15**	6.28	**11.80**	3.94
Subject n.2 Freehand	**10.44**	8.06	**20.40**	1.08
Subject n.2 CAD	**9.23**	7.26	**16.00**	5.47
Subject n.3 Freehand	**23.99**	9.23	**45.90**	10.30
Subject n.3 CAD	**13.66**	8.45	**23.50**	8.45
Subject n.4 Freehand	**22.81**	11.91	**69.50**	17.00
Subject n.4 CAD	**9.30**	7.56	**36.60**	12.20

Tab. 3. Mean amplitude and energy of VERPs in subject No.1 while watching freehand and CAD drawings (elaboration by the author).

VERP	Delta wave amplitude	
	mean	sd
Subject n.1 Freehand	**2.75**	1.23
Subject n.1 CAD	**1.92**	0.34
Subject n.2 Freehand	**1.39**	0.87
Subject n.2 CAD	**0.54**	0.28
Subject n.3 Freehand	**2.12**	1.58
Subject n.3 CAD	**0.81**	0.47
Subject n.4 Freehand	**1.69**	0.98
Subject n.4 CAD	**1.12**	0.41

Tab. 3. Mean amplitude of the VERPs 1Hz (Delta) frequency (elaboration by the author).

each subject, which show a significant difference between the two conditions (ANOVA $p < 0.05$). More important than the peak amplitude is the energy calculation of the signal in the whole time span 150-600 ms, as its result is determined by the cumulative activity of discharging neurons, with a much more comprehensive relation to the stimulus than the instantaneous amplitude measured on one of the peaks. This is reported in the fourth column of table 3 as a mean value, with standard deviation in the fifth column. Differences between freehand and CAD are highly significant, in agreement with the behavior of amplitudes. Even in the case of the VERPs potentials the EEG frequencies have been investigated. In figure 9 two frequency-amplitude graphs of the means obtained in subject 1 are shown, calculated as in figure 7. On the left is the result watching the freehand drawing, and on the right is the outcome of CAD. Even on the observer's side it is evident that the watched freehand drawing is related to a significantly larger amount of Delta EEG frequencies than the CAD. On the other hand, though we did not statistically analyze the higher frequencies, the latter show an inverse trend, that is to say they seem to be of lower amplitude in the freehand case. Such behavior parallels the one detected in MRPs while drafting the two images. Amplitudes of the delta frequency peaking at 1 Hz, in all subjects, are reported in table 4. All differences between freehand and CAD have been ascertained as significant ($p < 0.05$) with ANOVA analysis.

Conclusions

The reported findings are suggestive of common electroencephalographic features present in the creator and in the observer of a drawing. Changing the features of the drawing from freehand to CAD changes the electroencephalographic recordings in both characters to a very similar extent. In making the freehand image the drawer is afforded a wide range of possibilities to express his/her perception, emotion and mind. Thus, the drawing is not merely a representation of the external world, but it is imbued, either consciously or unconsciously, with those cognitive and emotive entities that prompted its creator. This is especially true as freehand drawing implies a strong motor activity by the hand, which has long since been considered a source of inspiration in itself, feeding the proprioceptive brain circuits as recently demonstrated [Leandri, Schenone, Leandri 2021]. The making of CAD is much less meaningful, usually requiring less insight and definitely fewer hand movements. Its generative simplicity is reflected in the sparsity of its constitutive elements, just points and lines, which only communicate the contours of objects and little more. It is no surprise, then, that the observer's perception of the visual primitives of the CAD does not excite the association areas devoted to cognitively processing the image. In the reported experiments the involvement of motor and visual association areas of the cerebral cortex is quantified mainly by the energy of the electroencephalographic signal either before movement in the case of the drawer, or after image presentation in the case of the observer. In both cases, freehand consistently induced a deeper and broader cortical involvement. Another parameter that can be measured in the electroencephalogram is its frequency, with low frequencies (Delta waves) indicative of insight, a hallmark of association area activity (association areas of the cerebral cortex are regions of the brain that handle complex cognitive functions both on the motor and sensory side). It is worth mentioning that the insight activity competes with attention directed towards external objects. Whilst insight increases the very low frequency Delta waves, attention to the outside world diminishes it while increasing higher frequencies, like Alpha or Beta rhythms. Therefore, the finding of high amplitude low frequency (Delta rhythm) and small high frequency waves suggests insight both in the creation and in the visual perception of freehand drawings. In contrast, CAD making and watching were associated with small amplitude low frequency waves, and larger high amplitude frequencies, clear indicator of attention directed towards external objects. It may be deduced that freehand drawing is internalized, but CAD seems rather to be exteriorized. These conclusions, drawn from experimental data, fit well with the long-established theories on the role of the communicative power of the drawing, which reaches its maximum in the freehand drawing, where the creative pulse can be transmitted to the observer. The limitations of this study are inherent in its exploratory nature, as a pathfinding investigation intended to guide future experiments. The current findings are based on a small number of participants, and increasing the sample size, both for creators and observers, will be essential to provide a more robust foundation for the observed effects. Assessing both intra- and inter-subject variability will be critical, and this should involve multiple trials within the same individuals. With a larger dataset, statistical evaluation of variability and reliability will become feasible. These aspects are planned for inclusion in the full-scale research program, which we aim to undertake as soon as possible.

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Notes

[1] The original text in Italian reads: "*la pittura ha il suo fine comunicabile a tutte le generazioni dell'universo, perché il suo fine è subietto delle virtù visive* [...] *non ha bisogno d'interpreti di diverse lingue*".

[2] The original text in Italian reads: "*infinite cose farà il pittore, che le parole non potranno nominare per non avere vocaboli appropriati a quello*".

[3] The original text in Italian reads: "*sai che t'averrà praticando il disegnare di penna? Che ti farà 'sperto, pratico e capace di molto disegno entro la testa tua*".

[4] The original text in Italian reads: "*ciò che è nell'universo per essenza, presenza o immaginazione, esso [the drafter] lo ha prima nella mente, e poi nelle mani*".

[5] The original text in Italian reads: "*Le quali pitture, se saranno ben proporzionati gli atti con i loro accidenti mentali, saranno intese, come se parlassino*".

Author

Gaia Leandri, Department of Architecture and Design, University of Genova, gaia.leandri@unige.it

Reference List

Carrillo de Albornoz, C., Calatrava, S. (2018). *Santiago Calatrava: Drawing, building, reflecting*. New York: Thames & Hudson Inc.

Cennini, C. (1821). *Di Cennino Cennini Trattato della Pittura, messo in luce la prima volta con annotazioni dal cavaliere Giuseppe Tambroni*. Roma: Co' torchj di Paolo Salviucci.

da Vinci, L. (1817). *Trattato della pittura di Lionardo da Vinci tratto da un codice della Biblioteca Vaticana e dedicato alla maestà di Luigi XVIII, Re di Francia e di Navarra, a cura di Guglielmo Manzi*. Roma: Stamperia De Romanis.

Freiwald, W.A., Tsao, D.Y. (2014). Neurons that keep a straight face. In *Proceedings of the National Academy of Sciences*, No. 111(22), pp. 7894-7895. <https://doi.org/10.1073/pnas.1406865111> (accessed 13 January 2025).

Gross, C.G. (2002). Genealogy of the "Grandmother Cell". In *The Neuroscientist*, No. 8(5), pp. 512-518. <https://doi.org/10.1177/107385802237175> (accessed 13 January 2025).

Harmony, T. (2013). The functional significance of delta oscillations in cognitive processing. In *Frontiers in Integrative Neuroscience*, No. 7, pp. 1-10. <https://doi.org/10.3389/fnint.2013.00083> (accessed 26 January 2025).

Kilpeläinen, M., Georgeson, M.A. (2018). Luminance gradient at object borders communicates object location to the human oculomotor system. In *Scientific Reports*, No. 8(1), pp.1593.1-1593.11. <https://doi.org/10.1038/s41598-018-19464-1> (accessed 13 January 2025).

Leandri, G., Schenone, A., Leandri, M. (2021). Detection of movement related cortical potentials in freehand drawing on digital tablet. In *Journal of Neuroscience Methods*, No. 360, pp. 109231.1-109231.12. <https://doi.org/10.1016/j.jneumeth.2021.109231> (accessed 4 November 2025).

Leandri, G., Iñarra Abad, S., Juan Vidal, F., Leandri, M. (2022). El cerebro del arquitecto y la mano pensante. In *EGA Revista de Expresión Gráfica Arquitectónica*, No. 27(46), pp.184-193. <https://doi.org/10.4995/ega.2022.18434> (accessed 10 December 2025).

Luck, S.J. (2014). *An introduction to the event-related potential technique*. New York: The MIT Press. [Fist ed. New York: MIT Press 2005].

Marrocco, R.T., Li, R.H. (1977). Monkey superior colliculus: Properties of single cells and their afferent inputs. In *Journal of Neurophysiology*, No. 40(4), pp. 844-860. <https://doi.org/10.1152/jn.1977.40.4.844> (accessed 13 January 2025).

Merleau-Ponty, M. (1996). Eye and mind. In G.A. Johnson (Ed.). *The Merleau-Ponty Aesthetics Reader*, pp. 121-149. Evenston: Northwestern University Press. <https://pg2009.wordpress.com/wp-content/uploads/2009/05/eye-and-mind-merleu-pontymmp-text1.pdf> (accessed 22 January 2025).

Orth, D., Van Der Kamp, J., Memmert, D., Savelsbergh, G.J.P. (2017). Creative motor actions as emerging from movement variability. In *Frontiers in Psychology*, No. 8, pp. 1903.1-1903.8. <https://doi.org/10.3389/fpsyg.2017.01903> (accessed 13 January 2025).

Pallasmaa, J. (2009). *The thinking hand: Existential and embodied wisdom in architecture*. Chichester: Wiley.

Shibasaki, H., Hallett, M. (2006). What is the Bereitschaftspotential? In *Clinical Neurophysiology*, No. 117(11), pp. 2341-2356. <https://doi.org/10.1016/j.clinph.2006.04.025> (accessed 13 March 2025).

Sobinov, A.R., Bensmaia, S.J. (2021). The neural mechanisms of manual dexterity. In *Nature Reviews Neuroscience*, No. 22(12), pp. 741-757. <https://doi.org/10.1038/s41583-021-00528-7> (accessed 13 January 2025).