Zoï Kapoula · Marine Vernet *Editors*

Aesthetics and Neuroscience

Scientific and Artistic Perspectives

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ISBN 978-3-319-46232-5 ISBN 978-3-319-46233-2 (eBook)
DOI 10.1007/978-3-319-46233-2

Library of Congress Control Number: 2016953312

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Printed on acid-free paper

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The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

The interweaving of art and science, specifically aesthetics and neuroscience, is an emerging field of research. This phenomenon has sparked interest and expanded across various countries, basing itself on the existing cultural, scientific and artistic environments. In France, we benefit from an existing pluridisciplinary research institution: *Centre National de la Research Scientifique* (CNRS, National Center for Scientific Research). Groups of research in this institution aim to bring together researchers from different fields to create networks of common interest. The Aesthetic, Art and Science group, “ESARS”, was founded in 2014 by the Institute of Biological Science of the CNRS. ESARS gathers several research teams from many laboratories and universities across France. In addition to their own field of research, whether it is mathematics, physiology, neuroscience, philosophy, psychology, these teams develop a research line related to creation, creativity and aesthetics.

This without-wall laboratory is a very rich, beehive-like structure. Several meetings have brought together artistic and scientific creations. Not only does ESARS develop pluridisciplinarity, but also transdiciplinarity to create new fields at the frontier of existing ones. Taking methods from one field and adapting it to another allows for hybridization, mutation, and transformation. New paradigms are constantly invented.

In 2013, we organized a meeting in Paris in anticipation for the creation of ESARS. This meeting incorporated formal presentations, art exhibitions, interactive installations and live performances. It covered many areas of neuroscience and aesthetics: mathematical structure of pop music, neurophysiology of creation and art perception, philosophy of art, epistemological questions related to architecture, theater performance, dance, etc. This book includes a selection from these presenters and performers as well as contributions from artists and scientists who joined ESARS afterwards.

Part I of this volume guides us through the complex process of creativity. Alain Londero, Didier Bouccara and Hervé Bozec invite us to explore how visual art impacts the vestibular system of the observer. They also have us question how an artist’s vertigo or tinnitus may have contributed to their creative process. Vincent

Mignerot offers an original hypothesis, stating that creative minds may benefit from "*heueaesthesia*", a fruitful sensory facilitation of knowledge and skills. Zoï Kapoula presents a study where dyslexic children, who have overall normal intelligence but suffer from reading troubles, might be highly creative when following an adapted educational approach.

Part II of this volume investigates the neurophysiological effect of art on observers. Yannick Bressan studies the neural substrate of "*emergentist adhesion*" in theater. This allows the spectator to perceive a character when she sees an actor, in order to believe in the functional reality in addition to the proximal reality. Amel Achour Benallegue, Jérôme Pelletier and Gwenaël Kaminski, through a cognitive, anthropological, philosophical and experimental approach, illustrate how intrinsic properties of anthropomorphic representations of faces modulate their aesthetical impact. Marine Vernet provides a brief tour on what neuroscience and art can learn from each other and how artwork can intellectually, emotionally and physically move us.

Part III of this volume exemplifies how neuroscience can help us to better understand and enhance our aesthetic experience. Coline Joufflineau and Asaf Bachrach present *Labodanse*. This ambitious project shows how first and third person experimental approaches converge in front of Myriam Gourfink's choreographic work, which is based on Energy yoga techniques. This perfectly illustrates how unique scientific questions arise from unique artworks. Solène Kalénine evaluates how perception and perhaps sensitivity towards a show by The Baltazars, can be modified after an observer has the opportunity to manipulate the visual effects of the show. Laurent Sparrow demonstrates how physiological measures and eye tracking measures can help to evaluate the well-being and interest of autistic and non-autistic children, who visit a museum with a game device to help increase their engagement.

Part IV of this volume illustrates how better training and learning could be achieved by relying on the potentiation of the art–neuroscience relationship. Daria Lippi, Corinne Jola, Victor Jacono and Gabriele Sofia present a pioneer, collective experience realized during a workshop organized by the *Fabrique Autonome des Acteurs*. They created a challenging training that merged the concepts of attention, mirror neurons and body schema, to help actors improve their ongoing and deliberate practice. Claude Bruter explains that because art and mathematics have the same fundamental aim, representation, art might constitute a great educational tool to understand mathematics. Eglantine Bigot-Doll describes how interacting with various inspirational sources and expressing the results of these interactions through language and adequate software could potentially help students to elicit original architectural creations.

Part V of this volume reveals the creative processes of artists who are inspired by or relate their work to neuroscience. Sophie Lavaud-Forest describes how her project *Matrice Active*, which transforms a painting by Wassily Kandinsky into a three-dimensional interactive dynamic system, can offer new aesthetic experiences as well as novel interdisciplinary artistic-scientific research experiments. Olga Kisseleva and Claire Leroux guide us into the different meanings of time at the physical, biological/physiological and political/economic levels. Based on these concepts, Olga Kisselva's bio-art installations plays with individual physiology, allowing visitors to accelerate or on the contrary slow down art-clocks' time. Pascale Weber and Jean Delsaux describe their own performing art experience as an experimental configuration allowing them to address multiple questions of embodied neuroscience, including space perception and body movement sensation.

Finally, Part VI of this volume uses mathematical tools, evolutionary-based theories and philosophical considerations to understand and formalize aesthetics. Moreno Andreatta and Gilles Baroin show how mathematical models applied to pop music can reveal the geometry of musical scores and contribute to new musical creations. Julien Renoult guides us through several evolutionary models of aesthetics and explains how one of them, based on the exploitation of efficient information processing, can simultaneously explain the universality of aesthetic experiences and the diversity of beautiful stimuli. Bruno Trentini closes our volume by inviting researchers in neuroaesthetics to join a philosophical tradition and to focus on the exploration of the neural substrate of the "sublime" rather than the neural substrate of the "beautiful". The former would be closely related to the experience of aesthetics.

We hope that this book will reveal the diversity of our neuroscience and art community, which build bridges between multiple disciplines such as cognitive neuroscience, psychology, physiology, evolutionary biology, mathematics, philosophy, anthropology, rely on theoretical and experimental approaches, consider third- and first-person points of view, go back and forth the unique and the ubiquitous and lastly, invent new paradigms for this novel adventure through neuroscience and art.

Paris, France Zoï Kapoula
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Editors and Contributors

About the Editors

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Part I
Neuroscience of Creativity

The Vestibular System and Artistic Painting: A Theoretical Framework for the Study of Multi-modal Interactions in Aesthetic Experience of Painting and Painting Viewing

Alain Londero, Didier Bouccara and Hervé Bozec

Abstract Neuroaesthetics is an emerging neuroscientific field aimed at explaining the cognitive processes and the neurobiological correlates actually involved in both artistic practices and aesthetic experiences. Indeed the essential role of vision has already been extensively studied, but recent data suggest that aesthetic interactions may rely upon a broader multi-sensory integration including auditory or somatic inputs. In such a context, the implication of the vestibular system, which is activated for both the control of head/body movements and the sense of balance, may be considered as a crucial issue. Taking artistic painting as an example, the main purpose of this paper is to propose a schematic comprehensive theoretical framework that might be useful to pave the way for future research in this multi-sensory, multimodal and innovative neuroaesthetic field.

Keywords Multi-sensory integration · Posture · Balance · Neuroaesthetics · Arts

> Tes derniers tableaux m'ont donné beaucoup à penser sur l'état de ton esprit quand tu les a faits. …tu t'es risqué jusqu'à l'extrême point où le vertige est inévitable.
>
> Your latest paintings have given me a great deal to think about as regards your state of mind when you made them. …you endangered yourself to the extreme point where vertigo is inevitable.
>
> Quotation from a letter (16th June 1889) by Theo Van Gogh to his brother Vincent during his stay in the hospital of Arles.
>
> Amsterdam, Van Gogh Museum, inv. no. b737 V/1962.
>
> http://vangoghletters.org/vg/letters/let781/print.html.

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Z. Kapoula and M. Vernet (eds.), *Aesthetics and Neuroscience*,
DOI 10.1007/978-3-319-46233-2_1

Introduction

Neuroaesthetics is an emerging field within the larger framework of neuroscience (Chatterjee 2011). The main goal of such a neuroscientific insight applied to the field of arts is to better understand and explain what actually happens in our sensory organs, brains and bodies when either, as an artist, one is involved in the process of art creation or when, as a spectator, one is confronted to any kind of piece of art (painting, sculpture, dance, video, literature…). Deciphering the biological and neural correlates underpinning this puzzling indirect interaction between the artist (considered as the intentional and active producer of the artwork) and the viewer (which is not only a passive bystander) via the medium (the piece of art that actively stimulates sensory organs and elicits subcortical and cortical brain activities) is indeed the very core of such a neuroscientific questioning (Nadal 2011). Even if there is still an on-going debate about the actual relevance of this kind of neuroscientific approach of arts, there is undeniably a steady increase both in the momentum of interest driven by this topic and in the amount of literature annually published in the field.

Probably due to the importance of vision in our most common aesthetic interactions, and to the huge knowledge gained in the neuroscience and psychology of vision, most of the neuro-aesthetic literature actually concentrates on the visual modality. Indeed, recent studies and reviews on neuroaesthetics focus predominantly on aesthetic experiences induced by visual forms like faces (Osaka 2012), constructions (Vartanian 2013) or different kinds of objects (Cela-Conde 2011; Chatterjee and Vartanian 2014) and by paintings (Melcher 2013). Certainly this is also why, at the end of the 20th century, even the term neuroaesthetics has been originally proposed by a vision researcher (Zeki 1999).

But aesthetic experience, even for a mere visual form of art like painting, definitely needs to be considered as a multilevel process that goes far beyond a purely visual analysis of the artwork (Nadal 2013). Undoubtedly artistic perception essentially relies upon a multi-sensory (visual, auditory, somatic…) input (Shams 2010) and a multi-modal (viscero-somatomotor, attentional, emotional…) resonance in the beholder (Cinza 2009).

The relevance of non-visual input and non-visual central pathways has been obviously studied for art production for which other sensory modalities or cognitive functions are involved (i.e. audition for the perception of music or poetry (Brattico 2013), motor system for dance performing (Calvo-Merino 2008)). But even for painting, recent research stresses the possible implication of non-visual cognitive processing and non-visual behavioral responses during the aesthetic experience induced in the beholder by paintings. For example some recent EEG data clearly demonstrate the involvement of the motor cortical areas in the viewing of static abstract artworks of Lucio Fontana in which the canvases have apparently been cut with a knife or cutter (Umiltà 2012). Other results suggest that abstract Op Art paintings providing a sense of motion in depth alike Bridget Riley's "Movements in Squares" (1961) (https://en.wikipedia.org/wiki/Bridget_Riley) and Akiyoshi Kitaoka's "Rollers" (2004) (https://en.wikipedia.org/wiki/Akiyoshi_Kitaoka) induce an increased motion illusion and a larger antero-posterior body sway both in terms of speed and displacement when compared to a control condition (Kapoula 2015).

Rather counterintuitively, it seems then even possible to suggest that painting, this very motionless and two-dimensional framed kind of visual art, is definitely an aesthetic practice that involves, even if mostly at a subconscious level, cognitive functions that are fundamentally dedicated to motion in a three-dimensional world: the control of head and body movements and the sense of balance. Both these functions depend on the activation of the vestibular system (semicircular canals, otolith organs, and cortico-subcortical vestibular pathways), which has evolved to constantly and automatically measure head motion and head position (St George 2011). Even if it does not elicit an immediate conscious perception arising from the vestibular receptors this very complex and demanding task, which may be considered as our "sixth sense" or "the sense of movement", is achieved by the means of a remarkable multimodal integration (Chen 2011). Indeed for our brains being permanently up-dated on our own head/body position is a critical prerequisite for accurate motor coordination and adequate spatial navigation. This is not only important for everyday actions, but also for artists when they create and for spectators during their aesthetic experiences. It seems then pertinent to question the possible implicit implication of the vestibular system, both from the painter's and the beholder's perspective, in this specific artistic activity (Marin 2015).

The main goal of this article is to propose a schematic comprehensive theoretical framework that might be useful for future research in this multi-sensory, multimodal and innovative neuroaesthetic field.

Vestibular Physiology: A Brief Overview

According to the Darwinian rules of species evolution, for millennia human beings have been evolving towards bipedalism. Hence, upon the two small surfaces of the soles of our feet, we need to constantly maintain our balance either in resting positions or during dynamic actions in order to immediately and automatically adapt our posture and movements in a perpetually changing environment. Maintaining a stable stance whatever the circumstances is indeed a rather challenging task. So, when discussing the notions of balance, posture, movement and gait we refer to an outstanding, and not yet fully understood, ability to stabilize our gaze, head and body whatever the environmental circumstances in which we are bound to stay or move. This system devoted to equilibrium and control of movement relies upon three different kinds of peripheral sensory inputs: the vision (eye), the proprioception (muscles, ligaments, interoception) and last, but not least, the vestibular system (inner ear or labyrinth). This multi-modal afferent information is then integrated and hierarchized, in the same multimodal way, in the vestibular nuclei that are located in the brainstem. At this level, cerebellar inputs and top-down cortical influences contribute to adapt and modulate the activation of various efferent vestibular systems originating from the vestibular nuclei among which the key vestibulo-ocular and vestibulo-spinal pathways (Brandt 2013). The physiologic maturation of this system progressively develops during childhood, one very important milestone being the progressive acquisition of walking skills (Lacour 2000). The subsequent evolution of equilibrium function with aging is also a complex phenomenon that depends eventually on multiple other sensory parameters, on different general factors such as rheumatologic, neurologic, cardiovascular associated conditions and on individual subjects' psychological profile. For example, in the elderly both the risk and the fear of falling highly contribute to the behavioral and emotional changes related to the perception of balance in these subjects (Jahn 2015). Another property of this system is its striking adaptability that relies upon rapid and efficient neuroplastic mechanisms. In many pathological conditions, such as in case of sudden or progressive vestibular deafferentation (trauma, tumors…), natural neuroplastic compensatory mechanisms will be activated leading in most of the case to a reduction of the postural consequences of vestibular disorders (Lacour 2006; Han 2011), thus permitting to remain stable if the vestibular system fails even in an extremely changing and hazardous natural environment. Concerning the subjective feelings evoked by artworks in beholders, as well as the process of creation of art pieces in artists, this peripheral vestibular sensory information integrated in wider range of sensory inputs might also constitute an essential sensory substrate underpinning higher level cognitive processing involved in aesthetic experiences.

From a phylogenetic point of view the vestibular system is the most ancient part of the inner ear, a similar system being already present in fishes and dinosaurs fossils. Along with the auditory system with which it shares strong structural analogies, the vestibular system has evolved in humans for the coding of information arising from head motion, especially angular accelerations (three angular receptors aligned along the three directions of space: anterior, posterior and lateral semicircular canals) but also linear accelerations crucially involved in speed and gravity perception (otolithic receptors: utricular and saccular maculae). Anatomically the vestibular receptors are situated at the posterior part of the cochleo-vestibular organ (membranous labyrinth) in the temporal bone at the lateral part of the head. The vestibular sensory epithelium is essentially constituted by the vestibular sensory hair cells (type I and type II) topped with stereocilia. The sensory cells are located within the endolymphatic compartment of the inner ear. The architecture of the inner ear coupled to the mechanotransduction properties of the hair cells explain the ability of the vestibular system to convert a mechanical stimulus (endolymphatic liquid displacement or otolith displacement) into an electrochemical activity transmitted to the vestibular nerve, then to the vestibular nuclei. The vestibular information follows then multiple anatomical and physiological subcortical and cortical pathways (i.e. vestibulo-ocular, vestibulo-spinal, vestibulo-cerebellar, vestibulo-vegetative, vestibule-thalamic, vestibulo-cortical pathways) explaining the wide variety of clinical consequences induced by a vestibular impairment on eye movements, posture, vegetative reflexes, cognition and emotions. Physiologically, information coming from the otolithic receptors will essentially contribute to maintaining head position during horizontal (utricule) and vertical (saccule) accelerations and, less importantly, help at the retinal image stabilization during movements. The role of the saccule is critical for the perception of gravity cues. The information arising from the semicircular canals is more directly devoted to the stabilization of retinal images during head movements and to the stabilization of the head and body during three dimensional movements (Cullen 2012).

Vestibular Pathophysiology

Balance problems are a common cause of consultation especially in otology clinics (Brandt 2013). The complexity of the multi-modal system described in the previous section explains the multiplicity of ear diseases and other medical conditions that can cause vertigo or dizziness. It also explains the very rich and complex descriptions of their symptoms made by the patients: sensation of body rotation, modification of body perception, sensation of rotation of the visual scene, illusion of linear displacement, vegetative reactions, and anxiety or depression states. However, vestibular symptomatology mainly depends on the vestibular structures lesioned (otolithic receptors, semicircular canals, and vestibular nerve or central structures), but also on the time course of the disease (sudden, progressive or fluctuating) and on the concurrent medical conditions. It is out of the scope of this article to further explain the diagnostic and therapeutic approaches of vestibular disorders. But it seems useful to stress the importance of an overall evaluation of the visual, proprioceptive and vestibular afferences by the means of static and dynamic posturography (Mbongo 2005) and of an appraisal of the subjective vertical because these evaluation techniques have already been used in the neuroaesthetic domain (Kapoula 2011).

From the Artist's Point of View: Painting, Movement and Vestibular Dysfunction

Indeed the issue of movement representation is a common trend in the history of modern painting. For example, the French painter Théodore Géricault (1791–1824) aimed at showing galloping horses' movements in his canvas entitled "Course de chevaux, traditionally called Le Derby de 1821 à Epsom" (1821) (Fig. 1). And so even if the position of the horses' legs displayed in this painting, with both front and hind legs simultaneously extended, is never actually present while galloping as this has been demonstrated by the chrono-photography techniques developed shortly after in the 19th century by the English photographer Edward James Muggeridge (1830–1904) and by the French physiologist Étienne-Jules Marey (1830–1904). Similarly Edgar Degas (1834–1917) has purposefully induced an illusion of movement in the canvas "Danseuses en bleu" (1890) (Fig. 2) by showing dancers in four different positions, figuring four "snapshots" of the ballet moving scene. The postural consequences of a similar illusion have been scientifically investigated by the means of pictures reproducing two Degas' sculptures of dancers: the first in a stable and still position, the second in a dynamic and potentially unstable dance step execution. Observing a dancing ballerina induced a significantly greater body sway when compared to the stable image, thus demonstrating that images of bodies in movement internally generate unconscious body oscillations in the viewer (Nather 2010). Indeed the multi-modal

Fig. 1 Théodore Géricault (1791–1824). "Course de chevaux, traditionally called Le Derby de 1821 à Epsom" (1821)

visuo-vestibulo-somato-motor integration of such behavioral response and the role of the vestibular system (internal model of vertical perception, real-time postural control, emotional load…) in this instability produced by an aesthetic experience remains to be understood. Although is not known if this effect has been willfully sought by the artist, the induced instability in the beholder should be taken as a relevant part of the aesthetic pleasure given by the canvas, the image or the sculpture. Later on the specific issue of figuring movement and speed in arts has also been extensively challenged by the "Movimento Futurista" (Futurists), led by Filippo Tomaso Marinetti in Italy at the dawn of the 20th century. Indeed, movement and its related concept speed constitute the very heart of the manifest published the 21th February 1909 in the French journal "le Figaro" where Marinetti stated that "the splendor of the world has been enriched by a new kind of beauty: the beauty of speed". The works of Luigi Russolo (1885–1947) such as "La rivolta" (1911) (https://en.wikipedia.org/wiki/Luigi_Russolo) or Giacomo Balla's (1871–1958) "Dinamismo di un cane al guinzaglio" (1912) (https://en.wikipedia.org/wiki/Giacomo_Balla) are some illustrative examples of such attempts aiming at giving the viewer the sensation of a moving scene via the medium of a static pictorial image. More recently a rather similar technique of overlapping images, also common in art photography, has been used by a contemporary artist Lee Horyon (http://www.horyonlee.com) to elicit a quite spectacular, elegant and erotic representation of body motion. But it is probably Op Art who has more methodically questioned the perception and induction of motion illusions by paintings. The term Op Art

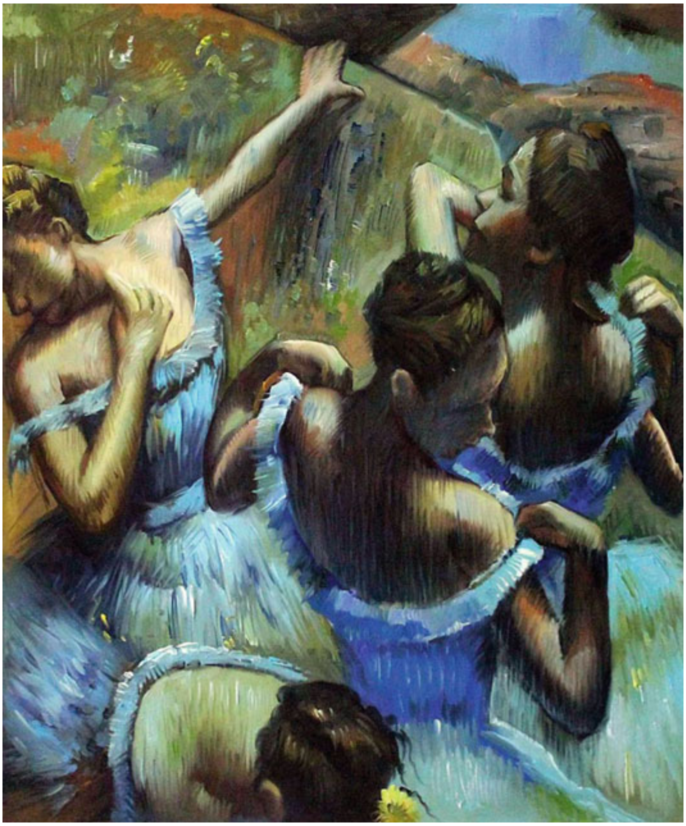

Fig. 2 Edgar Degas (1834–1917). “Danseuses en bleu” (1890)

(contraction of Optical Art) has been coined in an article of Time Magazine (1964), in reference to Julian Stanczak’s exhibition “Optical Paintings”. Op Art is a form of abstract art that uses black and white or colored geometrical patterns (lines, stripes, shapes and contours) in order to induce an optical illusion of movement produced by a tension between the foreground and the background e.g. “Cataract 3” by Bridget Riley (1967) (https://en.wikipedia.org/wiki/Bridget_Riley). The physiological causes of Op Art optical illusions are still a matter of debate (Hermens 2012; Fleming 2011). But their complex consequences on postural control (Kapoula 2015) could either be explained by the direct influence of unimodal pre-attentive visual analysis (micro or macro saccades, vergence drifts) of depth cues on body sway or by higher level conscious mechanisms (i.e.; explicit motor correlate of the perception in depth, virtual displacement in the pictorial frame). Yet this implication of a direct causal relationship between the degree of pictorial depth and body sway is challenged by other studies (Ganczarek 2015) which put forward other explanations linked to fixations to background elements in paintings or to higher embodied mental imagery (mental rotation)