Review

Historical Perspective

Galileo Galilei's vision of the senses

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Neuroscientists have become increasingly aware of the complexities and subtleties of sensory processing. This applies particularly to the complex elaborations of nerve signals that occur in the sensory circuits, sometimes at the very initial stages of sensory pathways. Sensory processing is now known to be very different from a simple neural copy of the physical signal present in the external world, and this accounts for the intricacy of neural organization that puzzled great investigators of neuroanatomy such as Santiago Ramón Y Cajal a century ago. It will surprise present-day sensory neuroscientists, applying their many modern methods, that the conceptual basis of the contemporary approach to sensory function had been recognized four centuries ago by Galileo Galilei.

Introduction

In 1609, Galileo initiated telescopic observations that were of crucial importance in heralding the modern scientific revolution. The new conception of the universe, as advocated by Copernicus, placed the sun in the central place rather than the earth. To derive support for this new conception, Galileo introduced a similar revolutionary shift in the conception of sensory processing and of vision in particular.

Visual contrast and cosmology

Visual optics was transformed in Galileo's lifetime, largely as a consequence of the endeavours of two fellow astronomers, Johannes Kepler and Christoph Scheiner. Kepler described the dioptrics of the eye and Scheiner married this to its gross anatomy [1]. Galileo sought to cast light on vision by looking, with perspicacity, at the stars. He used spatial contrast and other visual phenomena to undermine received wisdom concerning the stars and the senses. Traditional cosmology conceived of heavenly bodies as perfect spheres but Galileo observed mountains and craters on the moon and variable spots on the sun (Figures 1 and 2). He used evidence based on visual contrast and 'thought experiments' (considering observations that were then impossible to make) to support his view. This led to a controversy with Scheiner (Figure 2), who was not willing to admit the existence of spots on the surface of the sun 'blacker than those seen on the Moon' [2]. Galileo stressed that the sun spots were actually brighter that the brilliant zone of the moon. He argued that vision can be fallacious and that, in order to provide useful information about reality, visual images must be compared and matched under similar viewing conditions [3,4]; this is a fundamental tenet of modern visual science. His telescopic observations of the sun indicated that the black spots are not darker than the area surrounding the sun. Having proved, through a comparison with Venus (the brightest planet), that the full moon would become invisible if placed near the sun, he wrote:

> 'If therefore the darkness of the sun spots is not more than that of the field that surrounds the Sun itself; and if, moreover, the splendour of the Moon would remain imperceptible in the brightness of the same ambiance, then, by a necessary consequence, one concludes the sun spots to be not less clear than the most splendid parts of the Moon'. [4] p. 13

Galileo's conclusion was that sun spots are physically more luminous than the shining moon but they appear darker because they are seen against the bright surface of the sun.

In the same discussion, Galileo developed another important argument regarding the nature of the surface of the moon by comparing the moon to terrestrial objects. When a room, illuminated by the sun, is connected to another by means of an aperture (subtending an angle equivalent to that of the moon) the second room appears more intensely illuminated than if it was exposed directly to moon light. Indeed one 'might be able to read a book more easily with the secondary reflection of the wall than with the first of the Moon' [4] p. 135. Subsequently, Galileo established another thought comparison between the brightness of celestial bodies and that of the earth struck by the sun. At night it might be difficult to decide whether a light appearing near the edge of a distant mountain is a (terrestrial) fire or a star low on the horizon. The earth, being on fire and full of flames, could then be confused with a star by an observer situated in a remote part of the universe. However, the earthly fire would be less intense than that induced by sunlight because a candle flame is almost invisible when viewed against a stone directly illuminated by the sun. Therefore, the earth illuminated by the sun and seen from the tenebrous part of the moon will appear bright like any other star.

Galileo used the mutual reflection of sunlight between the earth and moon to refute a fundamental tenet of classical cosmology – that they were distinguished by differences in surface perfection. The discussion of the dim light visible in the dark zone of the moon is elaborated

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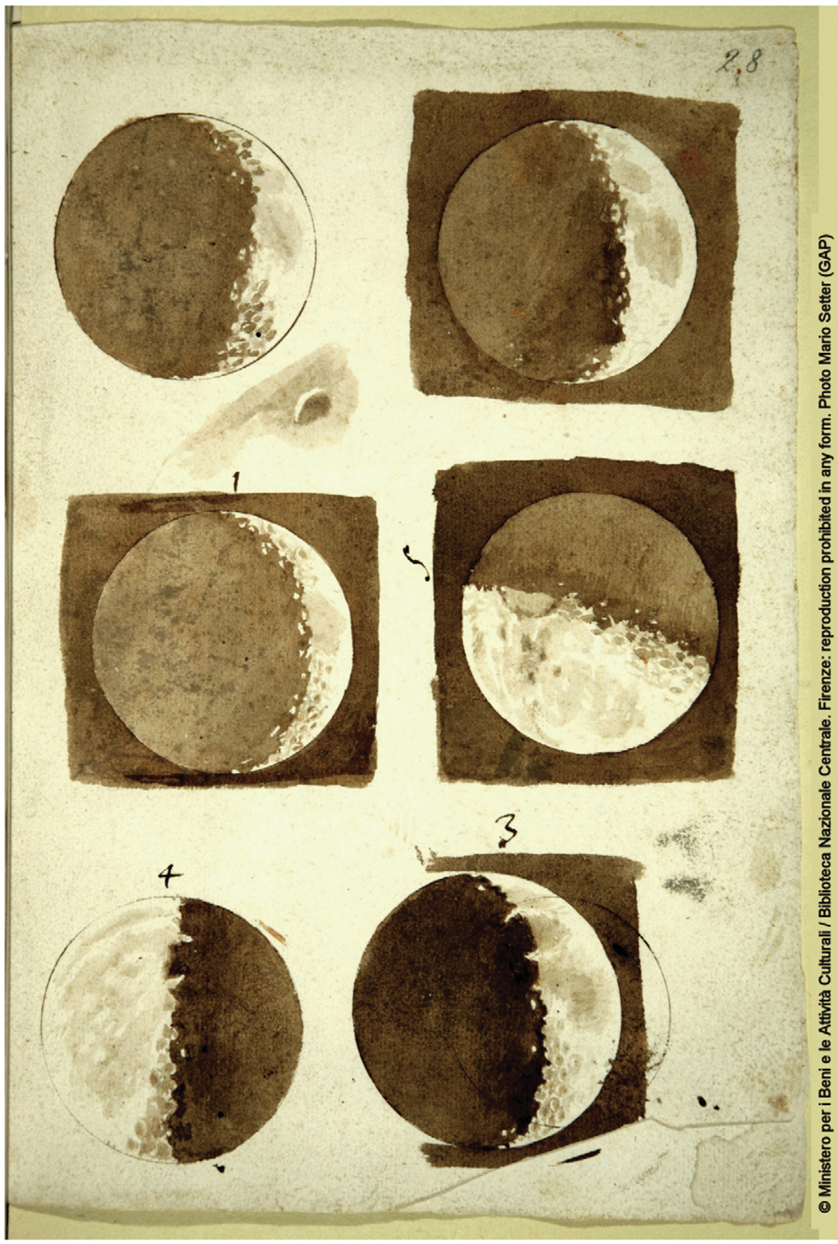

Figure 1. Watercolour images of the moon painted by Galileo to illustrate his first telescopic observations (© Biblioteca Nazionale, Florence). The visible non-homogeneities were interpreted by Galileo as evidence of mountains and craters on the moon. This conclusion was based on a series of observations, interpreted with reference to the laws of geometry, perspective and vision. This related particularly to knowledge of the variable aspects of light and shadow on irregular surfaces, which Galileo derived, in part, from his knowledge of the techniques of pictorial representation [8,9].

in Galileo's last published work*. Contrary to immediate appearances, he showed that the 'dark light' of the moon ('lunar candour') is actually much more intense than the light shone from the full moon onto earth. To realize comparable viewing conditions for the two luminosities (without transporting the observer to the moon), Galileo invoked twilight on earth as an intermediate state through which one could judge the physical intensity of two visual objects. Lunar candour can be noticed in the initial moments of sunset, whereas the illumination of earth by a full moon becomes appreciable only late after sunset. Minute details can, indeed, be seen on the surface of the earth in twilight that are invisible in the middle of the night even with a full moon. Moreover, the shadow of a terrestrial object produced by the full moon becomes appreciable only in late phases of twilight. Finally, long after sunset, distant and elevated buildings can be seen, which might be invisible in full moon light. Thus, Galileo concluded that illumination of the obscure part of the moon due to irradiation of sun light from the earth is more intense than the light reflected from the moon onto earth.

Galileo displayed a particular awareness of the global visual context (spatial contrast and background illumination) in the estimation of physical luminosity. Subjective estimations of brightness were open to error and so he made

* Galileo's text was written in 1640 in the form of a long letter addressed to Prince Leopold of Tuscany. It was published in 1642 inside the work of Fortunio Liceti *De Lunae subobscura,* Schiratti.